EU IVB FloodResilienCity Project

Final Report – Dublin

Volume Five

Pluvial Flood Alerting and Warning System Integration
EU IVB FloodResilienCity Project
Final Report – Dublin

Client: Dublin City Council
Project: EU IVB FloodResilienCity Project
Job No: 32102500
Document Title: Final Report Dublin
Volume Five: Pluvial Flood Alerting and Warning System Integration

Originator
NAME: Ronnie Falconer and others
DATE: October 2012
SIGNATURE:

Checked by
NAME: David Price & Iain Blackwell
SIGNATURE:

Reviewed by
NAME: David Price & Iain Blackwell
SIGNATURE:

Approved by
NAME: Kelly Kasperczyk
SIGNATURE:

Document Status: Issue to Dublin City Council

Copyright
Copyright Dublin City Council. All rights reserved.

No part of this report may be copied or reproduced by any means without prior written permission from Dublin City Council. If you have received this report in error, please destroy all copies in your possession or control and notify Dublin City Council.

Legal Disclaimer
This report has been prepared for the exclusive use of the commissioning party (Dublin City Council) and unless otherwise agreed in writing by Jacobs Engineering Ireland Limited, no other party may use, make use of or rely on the contents of this report. Neither this report nor the services provided by Jacobs Engineering Ireland Limited are intended for the express or implied benefit of any third party. The commissioning party shall indemnify and hold Jacobs Engineering Ireland Limited harmless from any third party claims arising out of any use or reliance on the contents of this report. No liability is accepted by Jacobs Engineering Ireland Limited for any use of this report, other than for the purposes for which it was originally prepared and provided.

Opinions and information provided in the report are on the basis of Jacobs Engineering Ireland Limited using due skill, care and diligence in the preparation of the same and no warranty is provided as to their accuracy. It should be noted and it is expressly stated that no independent verification of any of the documents or information supplied to Jacobs Engineering Ireland Limited has been made.
Volume Five: Pluvial Flood Alerting and Warning System Integration

PREFACE

GLOSSARY

ABBREVIATIONS

SECTION 1  NEW TECHNOLOGIES AND IMPLEMENTATION OF A PLUVIAL FLOOD FORECASTING AND WARNING SYSTEM
1.1 Introduction
1.2 Raingauge Network
1.3 Rainfall Sensors and Communication Systems
1.4 Calibration of Radar Rainfall Systems in near Real Time
1.5 Implementation and Integration of a Pluvial Flood Forecasting and Warning System

SECTION 2  INFORMATION MANAGEMENT AND DATA PROCESSING TECHNOLOGIES
2.1 Assessment of Current Situation and Available Information Technologies
2.2 Recommendations for Intelligent and Innovative Data Processing

Links to Software Providers

References
PREFACE

Dublin FloodResilienceCity (FRC) Technical Report Volume Structure

This technical report, ‘Volume Five: Pluvial Flood Alerting and Warning System Integration’ is one of five Volumes which accompany the Dublin FRC Project Non Technical Summary. The Non Technical Summary provides the background to the Dublin FRC Project and a summary of each of the technical report Volumes. These Volumes comprise:

Volume One Rainfall and Forecasting
Volume Two City-Wide Pluvial Flood Risk Assessment
Volume Three Pluvial Flood Risk Management
Volume Four Detailed Pluvial Flood Risk Assessment of Pilot Areas
Volume Five Pluvial Flood Alerting and Warning System Integration

Each Volume should be read in conjunction with the other Volumes as sections within each may be cross-referenced to other Volumes. Figure P1 illustrates both the one-way and two-way relationships between the report Volumes, with arrow size indicating relationship scale.

The extent of the Dublin FRC Project study area is shown in Figure P2 which also indicates the five administrative areas within Dublin City.
Volume Five Structure

**Section 1.** This Section describes New Technologies and Implementation of a Pluvial Flood Forecasting and Warning System for Dublin. It covers the basic rainfall data capture systems and infrastructure, including raingauges, rainfall sensors and the use of rainfall radar systems, and how this data might be used in a pluvial flood forecasting and warning system.

**Section 2.** This Section describes the Information Management and Data Processing Technologies including an assessment of the current situation, as well as making recommendations on the scope for introducing new technologies in hardware and information handling and processing. This includes the use of innovative approaches to data processing.

There is a strong link between this report Volume and Volume One Rainfall and Forecasting: The technologies available to implement the functional requirements for a pluvial forecasting and warning system discussed in Volume One are outlined in Volume Five.
### Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregated Micro-Storage</td>
<td>A corrective/mitigation measure used for storing surface water in hard standing areas in built up areas (car parks, roof areas, sports facilities). This measure has the potential to maximize benefit from many relatively small storage areas and optimize the control of this storage in real time.</td>
<td></td>
</tr>
<tr>
<td>Annual Exceedance Probability (AEP)</td>
<td>This is the technical term used to express the likelihood, or chance, of a particular event (e.g. flood or rainfall) being equaled or exceeded in any one year. It is usually expressed as a percentage or a ratio i.e. the 10% AEP event or 1 in 10 AEP. In technical terms the rarity of an event is sometimes also referred to as a return period i.e. the 10% AEP event is equivalent to an event having a 10-year return period, but the use of return periods can be confusing to the wider public.</td>
<td></td>
</tr>
<tr>
<td>Attenuate</td>
<td>Providing temporary storage or other measures designed to reduce the volume of surface runoff which could cause flooding. A particular focus of attenuation is on reducing peak flows through an area.</td>
<td></td>
</tr>
<tr>
<td>Blue Roof</td>
<td>A form of roof which is designed to capture water, most typically rainfall.</td>
<td></td>
</tr>
<tr>
<td>Breakline</td>
<td>Two dimensional geographical features (railway lines, rivers, roads and canals) which are represented in the modeling software as lines that may have a significant impact on the propagation of the rainfall runoff.</td>
<td></td>
</tr>
<tr>
<td>Catchment</td>
<td>A catchment area or drainage basin is an extent or an area of land where surface water or fluvial flow converges to a single point; usually the exit of the basin, where the waters join another water body, such as a river, lake, reservoir, estuary, wetland, sea, or open sea.</td>
<td></td>
</tr>
<tr>
<td>Climate Change</td>
<td>Long term variations in global temperature and weather patterns caused by natural and human actions.</td>
<td></td>
</tr>
<tr>
<td>Climate Fluctuation</td>
<td>Variations in global temperature and weather patterns.</td>
<td></td>
</tr>
<tr>
<td>Coastal Flooding</td>
<td>Coastal flooding that results from a combination of high tides and stormy conditions. If low atmospheric pressure coincides with a high tide, a tidal surge may happen which can cause serious flooding.</td>
<td></td>
</tr>
<tr>
<td>Contour Polygon Screening (CPS)</td>
<td>A GIS based technique for assessing topographical data and identifying hazardous depressions with regard to potential flooding.</td>
<td></td>
</tr>
<tr>
<td>Convective Available Potential Energy (CAPE)</td>
<td>A measure of the amount of energy available for convection (which can lead to intense rainfall).</td>
<td></td>
</tr>
<tr>
<td>Convective Rainfall</td>
<td>Convective rainfall originates from convective clouds and falls with rapidly changing intensity over a small area for a relatively short period of time.</td>
<td></td>
</tr>
<tr>
<td>Conveyance Flow</td>
<td>This is essentially the carrying capacity of a surface or culverted watercourse or a below-ground sewer or drainage system. It is significantly influenced by the roughness of the river or stream bed, or the piped system. Debris carried along in the flow and/or obstructions can reduce conveyance flow. In relation to sewer design capacity the conveyance capacity of urban drainage networks is usually such that they will flow full in a 1 in 5 AEP (20%) rainfall event. In a more extreme event they will usually surcharge up to road level and no more flow will enter through road gullies. In a 1 in 10 AEP (10%) rainfall event and events greater than this severe road flooding and property flooding may result.</td>
<td></td>
</tr>
<tr>
<td>Critical Infrastructure</td>
<td>Infrastructure (assets) essential for the functioning of society and the economy related to electrical generation, telecommunication and public health (i.e. hospitals, power stations, treatment works).</td>
<td></td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>------------</td>
<td></td>
</tr>
<tr>
<td>Culvert</td>
<td>A channel or pipe that carries a watercourse below the level of the ground.</td>
<td></td>
</tr>
<tr>
<td>Dam extreme operation / failure flooding</td>
<td>Some reservoirs hold large volumes of water above ground level. Although the safety record for reservoirs is excellent, it is not impossible that a dam could fail. This would result in a large volume of water being released very quickly.</td>
<td></td>
</tr>
<tr>
<td>Debris Factor</td>
<td>A variable used to quantify hazard which represents the fact that deep, fast flowing flood waters might mobilize loose objects and move them along flow paths thus increasing flood hazard.</td>
<td></td>
</tr>
<tr>
<td>Department for Environment, Food and Rural Affairs (DEFRA)</td>
<td>DEFRA is the UK government department responsible for policy and regulations on the environment, food and rural affairs.</td>
<td></td>
</tr>
<tr>
<td>Depth Duration Frequency (DDF)</td>
<td>Rainfall depth-duration-frequency (DDF) curves describe rainfall depth as a function of duration for given rainfall probabilities.</td>
<td></td>
</tr>
<tr>
<td>Depth Gauge</td>
<td>A gauge used to measure the depth of accumulated rainfall.</td>
<td></td>
</tr>
<tr>
<td>Digital Elevation Model (DEM)</td>
<td>A digital elevation model which shows topographic information including buildings and vegetation.</td>
<td></td>
</tr>
<tr>
<td>Digital Terrain Model (DTM)</td>
<td>A digital terrain model which show topographic information excluding buildings and vegetation.</td>
<td></td>
</tr>
<tr>
<td>Direct Rainfall approach</td>
<td>A hydraulic modeling approach which involves the application of rainfall hyetographs representative of storm events to active model cells within a two dimensional domain.</td>
<td></td>
</tr>
<tr>
<td>Drainage Infiltration and Exfiltration</td>
<td>In relation to sewer and drainage systems these terms are often used to describe seepage into or out of a drainage system through joints and cracks in the pipework. However for the purposes of this Pluvial Flood Study they are used to describe that portion of surface water flow that is carried into the below-ground system (infiltration) mainly via the roadside gullies, and the portion of flow which floods out from the below-ground system when capacity is exceeded (exfiltration).</td>
<td></td>
</tr>
<tr>
<td>Dry Mapping</td>
<td>Digital mapping of potential pluvial hotspots using the Rolling Ball and Contour Polygon Screening Techniques. This mapping is based on topography (LiDAR) and does not include any hydraulic or hydrological assessments. It is usually applied for preliminary assessments.</td>
<td></td>
</tr>
<tr>
<td>Exceedance Flow</td>
<td>This is normally used to describe the flow which exceeds the capacity of the below-ground sewerage or drainage system to carry stormwater flows. The Exceedance Flow is the portion that surcharges and floods at the ground surface and flows along the surface, often together with direct runoff from pluvial flooding.</td>
<td></td>
</tr>
<tr>
<td>External Resistance Measures</td>
<td>Measures designed to keep flood water out of properties and businesses (i.e. flood guards). Resistance measures can be fitted to prevent surface water entering buildings. Measures can be fitted to new properties or retrofitted to existing properties.</td>
<td></td>
</tr>
<tr>
<td>External Stakeholder</td>
<td>Stakeholders considered to be involved or affected but not as directly integrated into existing arrangements for flood risk management and risk identification.</td>
<td></td>
</tr>
<tr>
<td>Extreme Rainfall</td>
<td>Defined within this study as rainfall that leads to (or is likely to lead to) pluvial flooding. Whilst all rainfall is, by definition, pluvial, it is only intense rainfall events that give rise to pluvial flooding.</td>
<td></td>
</tr>
<tr>
<td>Federated Emergency Response Plan (FERP)</td>
<td>A FERP is designed to harmonize federal emergency response efforts with those of the provinces/territorial governments, non-governmental organizations, and the private sector.</td>
<td></td>
</tr>
<tr>
<td>Flood</td>
<td>The temporary covering by water of land not normally covered with water.</td>
<td></td>
</tr>
</tbody>
</table>
**Flood Alert**  
Dissemination to interested parties of an early indication that a flood event exceeding a critical threshold is possible and a warning may be given.

**Flood Defence**  
Infrastructure used to protect an area against floods such as floodwalls and embankments; they are usually designed to a specific standard of protection (design standard).

**Flood Depth Estimation System (FDES)**  
The Flood Depth Estimation System (FDES) is a GIS based tool (which Jacobs has developed) which allows for the calculation of flood damages based on the depth outputs from the TUFLOW modeling software.

**Flood Forecast**  
The prediction of a flood event through the application of measured and/or modeled scenarios.

**Flood Hazard**  
The potential for a flood to cause damage or harm – usually shown as the extent of flooding for a flood with a specific probability or likelihood. A flood hazard does not necessarily lead to harm unless there is a ‘receptor’ such as people or property that could be harmed or damaged.

**Flood Information and Warning System (FLIWAS)**  
The Flood Information and Warning System is a web based GIS orientated application for the monitoring of forecasts and aiding the implementation of Emergency Plans and evacuation plans.

**Flood Risk**  
Flood Risk in flood risk management is defined as a product of the probability or likelihood of a flood occurring and the consequence of the flood, for example damage to property or harm to people.

**Flood Studies Report (FSR)**  
The Flood Studies Report, published in 1975, is used in relation to rainfall events in the United Kingdom. It has since been replaced by the Flood Estimation Handbook.

**Flood Warning**  
The resultant dissemination of a forecast to a body of interested parties in order that they may prepare for the flood event with the aim of reducing its impact. Usually given once a critical threshold has been reached and involves taking action.

**Flow Paths**  
Surface water flow paths with supporting gradient and accumulation information.

**Fluvial Flooding**  
Flooding resulting from water levels exceeding the bank level of a river. Also known as river flooding, this occurs when a watercourse cannot accommodate the volume of water draining into it from the surrounding land. It is generally infrequent, but flooding can occur rapidly or over a long duration depending on the nature of the upstream catchment. Watercourses are more likely to be overwhelmed when rainwater cannot be absorbed into the land onto which it falls. It might be very steep, water logged, or built over. Rapid melting of snow also leads to river flooding in some cases. Also, obstructions such as collapsed buildings/walls can exacerbate flooding. Flooding from small urban watercourses can be a particular problem in urban areas even though the catchment area may be small. Impermeable ‘sealed’ surfaces in built up areas can result in increased and more rapid runoff to these small watercourses such that flows in the watercourse can build up rapidly and result in flash flooding (an extreme form of fluvial flooding). Urban watercourses are often culverted over long sections and the entrances to these culverts can often be flooding ‘hotspots’. These watercourses are also often constricted in places resulting in bottlenecks which can make flooding worse. Debris, both natural and man-made also often accumulates in urban watercourses which not only constricts the watercourse but can accumulate at culvert screens and even block these screens in extreme cases.

**Food and Agriculture Organization of the United Nations (FAO)**  
The Food and Agriculture Organization of the United Nations (FAO) is a specialized agency of the United Nations that leads international efforts to defeat hunger, serving both developed and developing countries.

**GeoDirectory**  
A property database showing locations of properties in Ireland. Attribute information includes data such as property number, street name and coordinate information.

**Geographic Information Systems (GIS)**  
A geographic information system integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information.
<p>| <strong>Greater Dublin Strategic Drainage Study (GDSDS)</strong> | The GDSDS was a study commissioned in June 2001 to carry out a strategic analysis of the existing foul and surface water systems in the local authority areas of Dublin City, Fingal, South Dublin, Dun Laoghaire-Rathdown and the adjacent catchments in Counties Meath, Kildare and Wicklow. |
| <strong>Groundwater Flooding</strong> | Groundwater flooding occurs when water levels in the ground rise above the ground surface. It is most likely to occur in areas underlain by permeable rocks, or alluvial/coastal deposits. These can be extensive, regional aquifers, such as chalk or sandstone, or may be locally confined deposits such as sand or river gravels in valley bottoms underlain by less permeable rocks. |
| <strong>Gulley</strong> | An artificial hole, cavity or pit in a gutter which is covered with a grating and normally conveys surface water to a drainage system. |
| <strong>Gulley Monitor</strong> | A monitor used for measuring water levels within gullies. |
| <strong>Hydraulic Modelling</strong> | Computer software based method of modeling the flow of water in rivers and drainage systems. |
| <strong>Hydraulic Roughness</strong> | A means of accounting for the effect on the resistance to flow of surface materials, irregularities, obstructions and vegetation. |
| <strong>Hydro-meteorological Monitoring</strong> | A method for monitoring/forecasting conditions associated with flooding. |
| <strong>InfoWorks CS</strong> | InfoWorks CS is a modeling software package which is used to undertake hydrological modeling of the urban water cycle. Other applications include urban flooding and pollution prediction and the modeling of water quality and sediment transport throughout a network. |
| <strong>Internal Resilience Measures</strong> | Measures designed to reduce the impact of water that enters property and businesses. This can involve ensuring that the walls, floors, and fixtures are less damaged by water (or not at all), and also re-organising the house so that valuable and costly items (including service meters and the boiler) are above the level of the flood. |
| <strong>Internal Stakeholder</strong> | Stakeholders currently participating in the risk management and risk identification processes. |
| <strong>Interreg (IVB)</strong> | Community initiative that aims to stimulate interregional cooperation in the European Union. It is a financial instrument of the European Union's Cohesion Policy. It funds projects which support transnational cooperation. The aim is to find innovative ways to make the most of territorial assets and tackle shared problems of Member States, regions and other authorities. |
| <strong>Isohyets</strong> | A line joining points of equal precipitation on a map. |
| <strong>Light detection and Ranging (LiDAR)</strong> | A high Resolution digital terrain model showing elevation/topographic information. Can be supplied in either &quot;filtered&quot; (buildings and vegetation filtered out) or &quot;unfiltered&quot; (buildings and vegetation have not been stripped out). |
| <strong>Mass-balance Equation</strong> | In analysing stormwater events it is convenient to consider the 'mass balance relationship' which can be expressed in the form: Total Rain = Exceedance Flow (surface – as defined above) + Conveyance Flow (below-ground – as defined above) + Ground Infiltration (rainfall infiltration into sub-soils, gravels and bedrock) + Detained Infiltration (rainfall infiltration detained in storage systems) |
| <strong>Natural Infiltration</strong> | Precipitation that soaks into subsurface soil and strata naturally. |
| <strong>No Flow Condition</strong> | A parameter used in hydraulic models to stop flow from passing through an area or node. For example where flood defenses are present, a &quot;No Flow&quot; condition can be applied to a model. |</p>
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAH</td>
<td>An Interreg IIIB organization for research into the rapid transfer of data with respect to flood prevention. The NOAH partnership aims to strengthen the transfer of information between relevant EU funded projects, experts and public institutions, improve the knowledge base and transfer between water management authorities in order to strengthen transnational cooperation on these issues.</td>
</tr>
<tr>
<td>Numerical Weather Prediction</td>
<td>A form of weather prediction which utilises mathematical models of the ocean and atmosphere.</td>
</tr>
<tr>
<td>Office of Public Works (OPW)</td>
<td>The OPW is a service organization. Its clients include Government, other Departments, Offices and Agencies and the public. Core services provided by the OPW are property maintenance, property management, architectural and engineering services, heritage services, project management and procurement services, and flood risk management.</td>
</tr>
<tr>
<td>Ordnance Survey Ireland (OSI)</td>
<td>Ordnance Survey Ireland is the national mapping agency of the Republic of Ireland. It provides digital/hardcopy products and mapping services. It provides a range of urban, rural, tourist and leisure maps at a variety of scales. They also provide other products such as aerial photography and digital terrain models.</td>
</tr>
<tr>
<td>Pluvial flooding</td>
<td>Pluvial flooding is defined as flooding which results from rainfall-generated overland flow and ponding before runoff enters a watercourse or sewer or when it cannot enter because the drainage system is already full to capacity. It is also known as surface water flooding. The capacity of local drainage (both natural and man-made) is overwhelmed and surface ponding occurs sometimes to a significant depth. Such ponding, often in low spots in the ground surface topography can occur rapidly and be a particular risk to basements other below-ground facilities. Where slopes are steep, resulting high flood velocities along roads and streets can also be a hazard to pedestrians and traffic.</td>
</tr>
<tr>
<td>Ponding</td>
<td>An area where runoff collects in a depression and cannot drain.</td>
</tr>
<tr>
<td>Preliminary Flood Risk Assessment (PFRA)</td>
<td>The Preliminary Flood Risk Assessment (PFRA) is a requirement of the EU ‘Flooding’ Directive. The objective of the PFRA is to identify areas where the risks associated with flooding might be significant. These areas (referred to as Areas for Further Assessment or ‘AFAs’) are where more detailed assessment is required to more accurately assess the extent and degree of flood risk. The more detailed assessment that will focus on the AFAs are being undertaken through Catchment-based Flood Risk Assessment and Management (CFRAM) Studies.</td>
</tr>
<tr>
<td>Principal Stakeholder</td>
<td>Person, group, or organization that has direct (key) stake in an organisation (or project) because it can affect or be affected by the organisation’s projects, actions, objectives, and policies.</td>
</tr>
<tr>
<td>Radio Detection and Ranging (RADAR)</td>
<td>Radio Detection and Ranging (RADAR) is an object-detection system which uses radio waves to determine the range, altitude, direction, or speed of objects.</td>
</tr>
<tr>
<td>Raingauge</td>
<td>A gauge used to measure the depth of accumulated rainfall.</td>
</tr>
<tr>
<td>Rainfall Duration</td>
<td>The length of time a rainfall event lasts.</td>
</tr>
<tr>
<td>Rainfall Hyetographs</td>
<td>A graphical representation of rainfall distribution over time.</td>
</tr>
<tr>
<td>Rainfall infiltration</td>
<td>Precipitation that enters drainage systems or below-ground strata.</td>
</tr>
<tr>
<td>Rainfall Intensity</td>
<td>A measure of the amount of precipitation over time.</td>
</tr>
<tr>
<td>Rainfall Pattern</td>
<td>Variations in precipitation frequency, duration and intensity averaged over time for particular areas.</td>
</tr>
<tr>
<td>Rapid Flood Spreading Model (RFSM)</td>
<td>The Rapid Flood Spreading Model (RFSM) is a modeling approach which is used in pluvial studies and surface water management plans to represent overland flow at a high level (large scale). It is topography based and provides an indication of ponding areas and the potential depths of flooding within these areas. It is usually applicable for national or regional studies.</td>
</tr>
</tbody>
</table>
Volume Five – Pluvial Flood Alerting & Warning System Integration

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Receptor</strong></td>
<td>Different sensitive receptors, that could possibly be affected by flood events (i.e. human health, critical infrastructure, environmental and cultural heritage and economy).</td>
</tr>
<tr>
<td><strong>Return Period</strong></td>
<td>A return period, also known as a recurrence interval, is an estimate of the interval of time between flood events or river discharge flow of a certain intensity or size. It is a statistical measurement denoting the average recurrence interval over an extended period of time, and is often used for risk analysis (i.e. whether a project should be allowed to go forward in a zone of a certain risk) and also to dimension structures so that they are capable of withstanding a flood event of a certain return period.</td>
</tr>
<tr>
<td><strong>Risk</strong></td>
<td>In flood risk management, risk is defined as a product of the probability or likelihood of a flood occurring, and the consequence of the flood.</td>
</tr>
<tr>
<td><strong>Rolling Ball Technique</strong></td>
<td>A GIS based form of analysis used to predict pathways of preferential flow direction based on terrain slope.</td>
</tr>
<tr>
<td><strong>Sewer flooding</strong></td>
<td>Flooding caused by a blockage or overflowing due to heavy rainfall in a sewer or urban drainage system. Sewer flooding can occur when ‘combined’ sewers (which carry both foul sewage and stormwater) are overwhelmed by heavy rainfall or when they become blocked, or can be attributed to infrastructure failure (e.g., pumping station failure). The likelihood of flooding depends on the capacity of the local sewerage system. Land and property can be flooded with water contaminated with raw sewage as a result. Rivers can also become polluted by sewer overflows. In urban areas, pluvial flooding and sewer flooding often combine, polluting the floodwater. It should be noted that in some newer developments foul sewage and stormwater is conveyed in ‘separate’ systems. In such cases flooding due to heavy rainfall is usually associated with the stormwater system.</td>
</tr>
<tr>
<td><strong>Stakeholder</strong></td>
<td>A person or organization affected by the problem or solution, or interested in the problem or solution. They can be individuals or organisations, and include the public and communities.</td>
</tr>
<tr>
<td><strong>Street as Streams/Roads as Rivers (SaS/RaR)</strong></td>
<td>This specific type of measure is used to manage surface and overland flow. It involves the identification of designated surface and overland flow pathways along streets and roads through the urban environment most likely to designated storage areas.</td>
</tr>
<tr>
<td><strong>Surface Water</strong></td>
<td>Rainwater (including snow and other precipitation) which is on the surface of the ground (whether or not it is moving), and has not entered is not being conveyed by a watercourse, drainage system or public sewer. Surface Water Flooding is the term often used to describe the combined surface flooding from multiple sources and can include pluvial flooding, sewer flooding, groundwater flooding at the surface and flooding from small urban watercourses.</td>
</tr>
<tr>
<td><strong>Sustainability</strong></td>
<td>Sustainability is the long-term maintenance of responsibility, which has environmental, economic, and social dimensions. It is a term used to define an approach (relating to the implementation of measures or a plan) which does not compromise the interconnected needs of the economy, society and environment in the future.</td>
</tr>
<tr>
<td><strong>Sustainable Urban Drainage System (SuDs)</strong></td>
<td>Methods of management practices and control structures that are designed to drain surface water in a more sustainable manner than some conventional techniques.</td>
</tr>
<tr>
<td><strong>Tidal Flooding</strong></td>
<td>Flooding resulting from sea levels exceeding high tide levels, or coastal flood defences. This type of flooding occurs in coastal areas and places where tidal influence may affect water levels (i.e. estuaries, coastal inlets)</td>
</tr>
<tr>
<td><strong>Tipping Bucket Raingauge</strong></td>
<td>A tipping bucket raingauge is a meteorological device that can measure rainfall intensity as well as the total amount of precipitation that has fallen.</td>
</tr>
<tr>
<td><strong>TUFOLOW</strong></td>
<td>Modeling software that simulates pluvial flooding for a range of rainfall events of various severities (in duration and intensity)</td>
</tr>
<tr>
<td><strong>Wet Mapping</strong></td>
<td>Pluvial flood maps which have been produced as an outputs from the TUFOLOW model, which demonstrate the possible flood depth, velocities and hazard.</td>
</tr>
</tbody>
</table>
### ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1D/2D</td>
<td>One dimensional/Two dimensional</td>
</tr>
<tr>
<td>AEP</td>
<td>Annual Exceedance Probability</td>
</tr>
<tr>
<td>ARF</td>
<td>Areal reduction factor</td>
</tr>
<tr>
<td>CAPE</td>
<td>Convective Available Potential Energy</td>
</tr>
<tr>
<td>CFRAM</td>
<td>Catchment Flood Risk Assessment and Management Study</td>
</tr>
<tr>
<td>CoP</td>
<td>Code of Practice</td>
</tr>
<tr>
<td>CPS</td>
<td>Contour Polygon Screening</td>
</tr>
<tr>
<td>DCC</td>
<td>Dublin City Council</td>
</tr>
<tr>
<td>DDF</td>
<td>Depth-duration frequency</td>
</tr>
<tr>
<td>DEFRA</td>
<td>Department for Environment, Food and Rural Affairs, UK</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
</tr>
<tr>
<td>DTM</td>
<td>Digital Terrain Model</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>EWA</td>
<td>European Water Association</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization</td>
</tr>
<tr>
<td>FDES</td>
<td>Flood Depth Estimation System (software developed by Jacobs)</td>
</tr>
<tr>
<td>FEH</td>
<td>Flood Estimation Handbook (UK)</td>
</tr>
<tr>
<td>FERP</td>
<td>Federated Emergency Response Plan</td>
</tr>
<tr>
<td>FLIWAS</td>
<td>Flood Information and Warning System</td>
</tr>
<tr>
<td>FRC</td>
<td>FloodResilienCity</td>
</tr>
<tr>
<td>FRM</td>
<td>Flood Risk Management</td>
</tr>
<tr>
<td>FSR</td>
<td>Flood Studies Report</td>
</tr>
<tr>
<td>FSU</td>
<td>Flood Studies Update (Ireland)</td>
</tr>
<tr>
<td>GDSDS</td>
<td>Greater Dublin Strategic Drainage Study</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
</tr>
<tr>
<td>GPRS</td>
<td>General Packet Radio Service</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communications</td>
</tr>
<tr>
<td>IZ</td>
<td>Impact Zones</td>
</tr>
<tr>
<td>LiDAR</td>
<td>Light Detecting and Ranging</td>
</tr>
<tr>
<td>MEM</td>
<td>Major Emergency Management</td>
</tr>
<tr>
<td>NOAH</td>
<td>An Interreg IIIB organization for research into the rapid transfer of data with respect to flood prevention.</td>
</tr>
<tr>
<td>NRA</td>
<td>National Roads Authority</td>
</tr>
<tr>
<td>OPW</td>
<td>Office of Public Works</td>
</tr>
<tr>
<td>OSI</td>
<td>Ordnance Survey Ireland</td>
</tr>
<tr>
<td>PFRA</td>
<td>Preliminary Flood Risk Review</td>
</tr>
<tr>
<td>PRA</td>
<td>Principal Response Agency</td>
</tr>
<tr>
<td>PSTN</td>
<td>Public Switched Telephone Network</td>
</tr>
<tr>
<td>Radar</td>
<td>Radio Detection and Ranging</td>
</tr>
<tr>
<td>RBD</td>
<td>River Basin District</td>
</tr>
<tr>
<td>RDBMS</td>
<td>Relational Database Management Systems</td>
</tr>
<tr>
<td>RFSM</td>
<td>Rapid Flood Spreading Model</td>
</tr>
<tr>
<td>SAFER</td>
<td>Strategies and Actions for Flood Emergency Risk management</td>
</tr>
<tr>
<td>SaS/RaR</td>
<td>Street as Streams/Roads as Rivers</td>
</tr>
<tr>
<td>SuDs</td>
<td>Sustainable Urban Drainage</td>
</tr>
<tr>
<td>TBR</td>
<td>Tipping Bucket Raingauge</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
</tr>
<tr>
<td>WPG</td>
<td>Weighing Principle Gauge</td>
</tr>
</tbody>
</table>
SECTION 1 NEW TECHNOLOGIES AND IMPLEMENTATION OF A PLUVIAL FLOOD FORECASTING AND WARNING SYSTEM

1.1 Introduction

“Of all the components of the hydrological cycle, the elements of precipitation… are the most commonly measured…… However, climatologists and water engineers appreciate that making an acceptable precipitation measurement is not as easy as it may first appear” (Ref 1).

In Volume One Rainfall and Forecasting, functional requirements for a pluvial flood forecasting and warning system were developed based on analysis of heavy rainfall events across Dublin, review of existing warning systems and assessment of each individual forecasting and warning element based on a tiered warning approach. This Volume Five reviews new and emerging technologies and approaches in both hardware and information systems and how these can best be applied in implementation of a pluvial flood alerting and warning system fully integrated with the wider forecasting warning systems for other types of flood risk including coastal, river and sewer flooding.

In both Volume One and Volume Five the term flood ‘alerting’ is used to signify early indication that a pluvial flood event is possible and that this might develop to a ‘warning’. Throughout the remainder of this volume the term ‘warning system’ is used to cover all stages from early flood alerting through to flood warning and ultimately a return to ‘all clear’.

The following aspects are addressed in this section:

- Review of existing networks of raingauges and telemetry system.
- Review of alternative sensor/logger combinations based upon emerging technology and recommendations for an expanded network of raingauges.
- The appropriateness of calibration of radar rainfall systems in near real-time to input to a pluvial forecasting system.
- Programme for phased development, integration and implementation of a pluvial flood alerting and warning system.

In Section 4.7 of Volume One various functional elements and technologies which could contribute to a suitable information management system for flood warning in Dublin were reviewed.

This section also addresses such questions as:

- The accuracy and availability of both radar and raingauge data.
- Good practice in site selection, installation and on-going maintenance of raingauges (including training).
- The outcomes of recent trials around the world on new technology for rainfall measurement.
- Current research on the potential improvement of radar rainfall measurement via calibration techniques.
The approach adopted involved the following:

- Meetings with Dublin City Council and Met Éireann to investigate existing hardware and data availability.
- Review of new field equipment and telemetry options.
- Review inventory of existing equipment.
- Review potential for radar calibration.
- Prepare programme for phased development.

1.2 Raingauge Network

1.2.1 Review of Existing Raingauge Networks

Prior to the FloodResilienCity project, Dublin City Council relied on a number of manually serviced rain gauges (nine in all) to provide historic rainfall data for post-event analysis.

Since 2010, a collaboration between the Drainage Division and the FloodResilienCity project team has resulted in a number of new fall loggers added to the greater Dublin water network telemetry system. Together with a number gauges owned by Fingal County Council these provide several rain gauge networks available to the City Council Flood Forecasting and Monitoring Team in an event.

There are nine gauges within the city itself:
1. Grange Tank
2. Ballymun Pumping Station
3. Donnycarney Tank
4. Chapelizod
5. Civic Offices
6. Ringsend Main Lift Pumping Station
7. Terenure Library
8. Rathmines Library
9. UCD Horticultural College

The Drainage Division/ FRC initiative will be completed in 2013 with gauges at:
10. Mellows Road
11. Bunratty Road
12. Botanic Avenue
13. South Inner City
14. Ballyfermot

Recently Met Eireann have given Dublin City Council real time access to their rain gauge in Phoenix Park while the NRA have recently commissioned Tipping Bucket Rain Gauges at their Dublin weather stations and are arranging for Dublin to have real time access to these additional points. These two collaborations will increase the number of data points at:
1. Phoenix Park
2. M1/M50 Airport
3. M50 Blanchardstown
4. M50 Sandyford Exit
5. Port Tunnel City Entrance
6. Bray By Pass
The layout of these is shown in Figures 1.3 and 1.4 which shows a well balanced rain gauge network across and around the city.

In addition to these “city gauges” there are a number of gauges in the vicinity, or near vicinity of the city which are of considerable use in an event to confirm prevailing rain patterns:

1. Roundwood
2. Sallygap
3. Turlough Hill
4. Ballymore Eusace
5. Bohernabreena
6. Ballycoolen
7. Garristown
8. Colecotte
9. Dungriffen
10. Swords
11. Malahide

Generally these all record 1min, 5min and 24hr totals but poll at different sub-daily frequencies depending on their hardware links to the telemetry network.

This network is not intended to provide data of absolute scientific accuracy for research purposes but does provide accurate and reliable information in an event. The multiplicity of locations increases the confidence of the results as any temporary fault at a single location soon becomes apparent.

During the project it has been recommended that these be switched to much higher interval data provision during rainfall in order to provide more definitive and timely data for the Flood Warning System (refer to Volume One Section 4). Later in this section alternative communications methods are examined.

Although most of these are now available in real time the Telemetry System cannot transmit the data automatically to an external site and access is restricted to personnel with dedicated access rights. This situation will change in early 2013 when improvements to the Telemetry System software are due to be implemented.

The actual placement of raingauges should be determined by the purpose for which they are intended. There have been many approaches to systematise the design of raingauge networks, but these have been largely for research or modelling purposes and the main determining factor has often been even distribution across catchments. Often these have been in open countryside where only the natural terrain limits matching the conceptual distribution of gauges on the ground, but even so an exact match to a systematised design is challenging.

The following example (Figure 1.1) shows the conceptual model for the HYREX\(^1\) network, with distances in fractions of a kilometre (Ref 8). This can be used to assist in the optimal design of raingauge networks. HYREX was a NERC\(^2\) special topic running from May 1993 to April 1997. Field experiments with an emphasis on radar, plus related interpretation and modelling, were carried out to investigate the short term forecasting and hydrological implications of precipitation. A special purpose-built dense raingauge network was established in Somerset as part of the project.

---

\(^1\) HYREX – HYdrological Radar EXperiment
\(^2\) NERC – The UK Natural Environment Research Council
It should be noted that the objective of that project (HYREX) focussed upon estimation of areal precipitation across a largely rural catchment, which is not the focus of the Dublin project.

In urban settings factors such as safety, permission of access, availability of suitable power and communications, and other issues such as overhead obstructions in the built environment increase the complexity. This in turn increases the difficulty of locating raingauges at exact locations such as the centre of radar grid squares, as has been highlighted most recently in the on-going work on the City RainNet project in the UK (Ref 4). In that project the raingauge locations are determined according to 1km squares, but not every grid square is populated, and it has been impossible to place many at the exact radar grid square centre. Figure 1.2 below shows the impact of urban installation issues on actual installation locations, and the inappropriateness of developing a strict conceptual network model in many urban settings.

![Figure 1.1: Synthesised model for catchment sub-network from HYREX (0.55 and 0.69km distances)](image1)

![Figure 1.2: Synthesised model and actual City RainNet network](image2)
Typically 36 telemetry raingauges are used for each of the urban areas in the City RainNet study, determined by a balance between distribution and the volume of data required for the exercise, while the urban areas themselves are made up of hundreds of such grid squares (a typical area of study is 420km$^2$, which is comparable with Dublin). Again, this is a product of the purpose of the network as the aim of the exercise is to develop dynamic calibrations for an urban area by comparing a significant number of gauges with the radar grid squares in which they are located, and extrapolating the resulting calibrations.

In summary, in urban environments a precise conceptual design of raingauge locations is less important than meeting the core criteria of the individual project. With the emphasis of the Dublin FloodResilienCity project on flooding caused by urban pluvial events, and in particular on warning, the networks should be placed for well distributed general coverage, and the urban environment demands a pragmatic view of the best installation sites, rather than a systematised approach to exact locations. “A broad general understanding of the meteorological and topographical factors influencing the volume, variability, spatial and temporal distribution of precipitation has been developed over the past century. However, this has not yet developed far enough to allow accurate prediction of precipitation or to make possible a purely theoretical design of a sampling network for any area. Network design is still therefore an essentially empirical process” (Ref 9).

1.2.2 Recommendations for Future Raingauge Networks

Carrying through the approach set out in Volume One Section 4, the multi-tiered approach to networks providing rainfall data can be outlined as follows:

1. A widely distributed network of existing gauges across Ireland from which data can be obtained quickly (e.g. National Roads Authority and other councils) to act as the first stage of ground measured early warnings, with added weight given to those located nearest to Dublin. Generally speaking, these gauges are not under control of Dublin City Council and the data from them should be used for warning purposes rather than detailed post-event analysis of the characteristics of rainfall and its relationship to urban flooding, although post event comparisons of accuracy may be useful.

2. An evenly distributed network of well located and maintained Dublin City Council gauges throughout Dublin City to help detect the very sudden, short and intense cells of (sometimes convective) rainfall commented upon in Volume One.

3. Strategically placed gauges determined by the Flood Mapping exercise to focus on areas of particular vulnerability to flooding within Dublin city. These gauges, and those above within the city, will be under direct control of Dublin City Council, and there is an opportunity to establish a high-quality resource of data suitable for confident post-event analysis and feedback to improve the warning system. This network will require that good quality instruments are used, located and maintained according to current good practice.

4. Data from other high-quality gauges within the urban area which may provide near-real-time data for warning purposes, and also long-term analysis of depth-duration-frequency of events. Such data has been purchased from Met Éireann for analysis purposes. Data sharing is the subject of an on-going dialogue, and should not be underestimated (regarding raingauges or radar data), as the project team is aware of security and technical access problems and delays on similar ventures elsewhere.
Dublin City Council would have responsibility and control of those raingauges in the city which fall into the second and third groups shown above, and these form the core of proposals on gauge locations.

Based on the above, a network of raingauges extending to a total of around 25-30 gauges providing high frequency data (particularly during high intensity rainfall events) would provide excellent coverage of the Dublin area. This would include all well maintained gauges with a suitable accuracy for flood warning and radar calibration purposes, capable of delivering data in the required timeframe for alerting and warning.

All gauges providing time interval readings should be set to the same interval as the Dublin radar (15-minute clock-time), or a shorter interval, or based upon tip events which can be integrated to different intervals (see below). This will allow direct comparative analysis of the data, and may contribute to a future exercise in evaluating the radar estimates. Should the radar be upgraded to a shorter interval, the gauge intervals would also need to be reviewed.

The specific locations of additional gauges to be introduced for this purpose should add to the distribution of the existing gauges, but it is not necessary to plan precise locations on a conceptual basis, providing that the general requirement for an evenly distributed network is met. Indeed, the standards and guides tend to place the main emphasis in an inner city environment upon whether the urban area is “sufficiently represented in terms of the original objectives”, providing that there are “[no] significant gaps between gauges” (Ref 9).

For a network based entirely upon precipitation measurement gauges in western Europe, a guideline of no more than about 1km gaps between gauges has been suggested for flood design purposes (Ref 1), but this does not allow for the potential in-filling with radar data. Where suitable radar data is available, the costs of capital investment and maintenance associated with a physical raingauge network covering every 1km can potentially be saved, as discussed later.

There is also a spread of telemetry gauges already in place or planned for the city, as shown in Figure 1.3 which shows the location of raingauges under control of various agencies as at 2010 together with initial proposals for additional rain gauges. Therefore it is recommended to apply a phased approach, with areas of poor radar cover, i.e. in north Dublin City and high vulnerability to pluvial-related flooding being covered in the first phase; and a further phase which would include a smaller or larger number of gauges, dependent upon the potential to use the improved local radar data with a calibration system. If the radar and calibration approach can be used effectively at that later time (i.e. the latter phase), the number of gauges to add to the network may be relatively small. If it cannot, then any problems remaining with the radar data could be balanced by a larger spread of gauges, which will themselves add value, both to the emergency response, and to post-event analysis.

The main determining factor in planning specific rain gauge locations for Dublin, is the early highlighting of possible flooding impact in areas which could be susceptible to flooding (whether caused by surface flooding, sewer surcharge, blocking of culverts and other such infrastructure, or raised river and stream levels). Flood mapping can assist in identifying such areas.

Areas of particular vulnerability to pluvial related flooding have been identified (see Volume One, Section 3 and Volume 2), and it is recommended that the network is

---

3 In due course other gauging such as depth monitoring at critical culvert locations can be linked in to the telemetry network.
supported with gauges at the high risk locations, combined with the expert local knowledge of Dublin City Council staff. In this way the warning system can be enhanced by warning of the very localised impacts of high intensity convective rainfall, a little before the actual flooding is brought to the attention of the authorities by emergency call centres.

Another consideration is the “cone of silence” surrounding Dublin Airport radar and other Met Éireann concerns about the general accuracy of radar data covering the Dublin area, as discussed in Volume One, meaning that radar readings either cannot be obtained or are uncertain. These issues have now been progressed but it should be ensured that any remaining parts of the Dublin City Council urban area still impacted by this following the radar upgrades are covered by a reasonable spread of gauges. A possible alternative solution might be a small or mobile radar system to be installed and run by Dublin City Council to cover this area, but this would add to the complexity and staff costs necessary to manage such equipment and data, and the capital costs are very high, so this is not recommended. A raingauge solution could also make use of any existing gauges and weather stations in the area, such as those operated by Met Éireann, providing that the data provision can be put in place. Three or four gauges providing data to the Information Management System and spread across the area affected in the north of the city could be of very considerable benefit.

In summary, the following is recommended:

- A sub-network of Dublin City Council gauges across the urban area within any remaining radar cone of silence areas;
- Placement of further individual gauges determined by locations of particular risk from intense rainfall; and
- Infill any major gaps of coverage within the City.

Based on all the above considerations, the proposed expanded network of raingauges within Dublin City (as at February 2012) is shown in Figure 1.4. This shows:

- Existing Dublin City Council raingauges already on the telemetry system.
- Existing Dublin City Council raingauges to be transferred on to the telemetry system.
- Proposed locations for new Dublin City Council telemetry raingauges.

Also shown are:

- Met Éireann raingauges.
- National Roads Authority raingauges.
Figure 1.3: City-wide monitoring network shown with the Dublin FRC Hydraulic Model Boundaries
Figure 1.4: Proposed expanded raingauge network (as at February 2012) shown within the Dublin FRC Hydraulic Model Boundaries
Another major area of importance here which was highlighted in Volume One Section 4 is the timely and automated combination of data from multiple sources for use by the warning system. Dublin City Council raingauge data is currently handled within the telemetry system, but uncertainty remains as to whether the existing gauges and telemetry system can be programmed to provide data at higher frequency, i.e., sub-hourly. Sub-hourly NRA data is accessed on request via a web login and manual download. These issues can be progressed and refined further during evaluation and implementation of the warning system.

A balance has to be achieved between the quality of this data for analysis purposes, and the types of device used as well as the installation and maintenance standards followed. More information on both of these aspects is provided in subsequent sections. For example, the following section discusses technology used by the NRA, and the discussion on good practice in Rainfall Measurement raises issues which would apply equally to any network under the control of any operator.

1.3 Rainfall Sensors and Communication Systems

There is a long history of rainfall measurement in Europe, based upon manual gauges of various designs, but all using the principle of storing the volume of rain that has fallen over a known period, measuring and recording it, to compile a record which can be analysed year-on-year to reveal information such as long-term averages.

1.3.1 Carrying Storage Gauges

The principles of these Storage Gauges (refer to Figure 1.5) are very well established and enshrined in some countries as written standards, as well as incorporated into guidelines by the World Meteorological Organisation (WMO) (Ref 9 & 16). The daily manual inspection of such gauges is still enshrined in some countries in the concept of a climatological and water day, which ends at 9:00am when a daily manual reading has always been taken historically, and is also used for all climate measures including temperature and wind. There are several examples of such gauges in the Dublin area, many maintained by Met Éireann, and historic records of flooding events show the value of these, and other similar manual devices operated by individual persons, in helping to understand the intensity and distribution of rainfall.

Figure 1.5: Typical Storage Gauge in-situ
1.3.2 Tipping Bucket Rain gauges

During the later 20th century Tipping Bucket Rain gauges (TBRs), which automatically empty small containers of a known capacity and record these electronically as “tip” events, came to be a standard device, as they do not require manual measurement every day or every hour, but can hold their record for a relatively long period and be “downloaded” during occasional visits. The actual rainfall total over various periods of time is calculated by multiplying the number of tip events in that timeframe by the known bucket size. Sometimes this conversion to totals or intensities is done automatically on the device itself before the measurements are made available for downloading, and sometimes it is done in post-processing. Figure 1.6 illustrates examples of such raingauges.

Such TBRs can be stand-alone, or connected to a Scada (Supervisory Control And Data Acquisition) or Telemetry system for delivery of data. Some such systems are hard-wired, particularly if the network of devices is relatively close together. Where the devices are spread over a wider area there has been a movement away from entirely manual downloads to remote Telemetry. At first this made use of PSTN (Public Switched Telephone Network) telephone landlines and relatively slow and expensive modems. In the late 20th century the norm became GSM (Global System for Mobile Communications i.e. mobile phone) technology with special arrangements made by the service provider to enable SIM cards for data exchange, but in the 21st century much cheaper GPRS (General Packet Radio Service) communications (akin to text or picture messaging on mobile phones) is replacing both PSTN and GSM. Further discussion of communications options is presented in later sections.

A recognised weakness of TBRs is their small funnel-shaped rain receiver which is easily blocked by leaves, grass cuttings and other wind blown rubbish, or by the activities of insects such as spiders. This restricts the full benefit of the device on Scada or Telemetry as it must be visited regularly, simply to ensure that there are no physical problems with the mechanism. Monthly or even weekly visits are commonplace in order to maintain data quality, and this can sometimes be particularly expensive in terms of labour and transport. CCTV monitoring may be possible though this is not often applied.

Figure 1.6: Typical TBR mechanisms
1.3.3 Weighing Principle Gauge

The Weighing Principle Gauge (WPG) is a different design from the TBR, and in some ways is a descendent of the Storage Gauge in that rainwater is captured and maintained within the device for a longer or shorter period depending upon design. They have few or no moving parts and a relatively wide aperture with no funnel arrangement, and so are not prone to clogging. The rainwater is weighed and this is converted to a volume which is recorded. Early WPGs were introduced many years ago but some have had problems, particularly with aspects such as siphons used for removal of excess water, which can sometimes block. 21st century WPGs are of better design and construction and can have a larger capacity which makes a siphon redundant and require only one or two visits a year for emptying and general maintenance. Some of these have sophisticated on-board software for corrections such as temperature / density of the stored water, and also elimination of anomalies such as birds entering the gauge reservoir (refer to Figure 1.7 below).

Figure 1.7: Weighing Principle Gauge in an urban environment

1.3.4 Impact Sensors

A more recent innovation is Impact Sensors. These have no moving parts and therefore no possibility of clogging. Their novel applications range from simple domestic warnings of rainfall with no actual measurement, through vehicle windscreen wiper automation, to sophisticated weather stations measuring multiple parameters. The volume of rain has to be calculated based upon the number of impacts and assumed droplet size, and double impacts from splashing can be an issue. Also the droplet size of the rainfall can vary from place to place and time to time so the calculation is open to inaccuracy, particularly at the high and low extremes of rainfall. Manufacturers and researchers have carried out investigations into the development of appropriate calibrations for given locations, and some of these are still under way. However at this stage of development these devices would only be of limited benefit to DCC given their present level of accuracy.
1.3.5 Comparison of Technologies and Recommendations

Some aspects of installation and maintenance costs naturally vary according to the demands of the technology used.

In terms of site location, calibration and surveys there is little significant difference between old and new technologies. For example, survey to aid with optimum alignment and avoidance of landscape features which can interfere with rain measurement is recommended for Weighing Principle and Impact Sensor devices just as much as for Tipping Bucket Raingauges (TBRs).

The main differences between old and new technology in respect of TBRs are:

- **TBR ‘Tip Recording’**: Some older tipping bucket raingauges only provided data as ‘tip’ event record. The device collects a measured amount of rainfall and makes a physical tip of the small bucket receptacle to reset itself, with the amount tipped and the date and time of the tips making up an irregular pattern in the records. These have generally been superseded by the newer tipping bucket devices that provide regular sequence records at a given interval, or which can provide event records and/or regular sequence. Data from these newer tipping bucket devices are not usually presented as tip events, but rather time interval (e.g. the amount of rain which has fallen within a configurable period such as every 5 minutes). Some can be configured to mimic event data if this is preferred, but normally event data has to be converted to time period in order to be of use in analysis and warning systems, so is of limited value in an application such as this one.

- **TBR Comparative Costs**: Purchase price of these newer tipping bucket devices is usually higher than traditional tipping bucket raingauges and can be significantly higher, although bulk discounts can reduce these costs.

- **TBR Maintenance Costs**: The maintenance costs of the newer tipping bucket devices in terms of visits to inspect and remove debris are extremely low by comparison, and over a 2-year period or more they are calculated to be significantly cheaper on total cost of ownership. Practical experience in this has been gained on projects with a number of UK water companies.

- **TBR Accuracy and Reliability**: The potential for better accuracy and dependability of data from the newer technology is felt to be much higher as the potential for undetected blocking is negligible by comparison with older TBRs. Where a TBR is found to have been blocked upon a maintenance visit, the whole period of record since the last visit is suspect. In the UK, some Environment Agency regions have recently started compensating for these problems by installing dual TBRs at each location and evaluating the data from both to select the likely best dataset where one is wholly or partly blocked or suffering from some other failure. This can improve data for long term analysis, but is only of benefit with significant human intervention in the review, and does not really solve the problems for a near-real time application such as a warning system. One also has to ask the question, if I have two different non-zero measurements from the same location, which one is right? This aspect is considered later in this section.

Considering accuracy and cost of other new technology devices, some are not yet fully proven. Further advances are on the horizon, but field evaluations carried out in the western UK by the Environment Agency (Ref 7), and a comprehensive report focussing on both laboratory and field evaluations in Italy by the WMO (Ref 6) suggest...
that Impact Technology (Impact Sensors) is not yet ready for use “out of the box” in hydrometric applications requiring high accuracy readings: “the variation in performance between different events of similar intensities meant that it was not possible to calculate a correction factor so that (impact sensor) data could be adjusted” (Ref 7).

In the same WMO study, the newer approaches in TBR technology via additional software correction, and the alternative of low maintenance Weighing Principle Gauge (WPG) Technology, are both shown to be significantly more accurate and reliable than traditional older type TBRs. The software corrected TBRs which scored highly in the study are not very readily available on the market at present, whereas the WPG device which performed best is relatively expensive but relatively available.

Our **overall recommendation** for the Dublin area is that well sited and maintained Tipping Bucket Rain gauges (with older existing TBRs being replaced in due course by the newer type TBRs) provide a reliable source of data by comparison with Impact Sensors and should continue to be utilised under a suitable maintenance regime (discussed in later sections).

We also recommend that the Weighing Principle Gauges which performed highly in the WMO study should also be seriously considered – particularly for locations where post-processing of highly accurate intensity readings will be important, and if reductions in on-going maintenance costs are taken in balance against the initial capital costs. Use of a small number of WPGs (say 1 per model catchment area or associated polygon group – see Figure 1.4) to run in parallel with TBRs could prove to be a useful exercise to compare performance and to monitor costs. Both of these factors would then inform future investment decisions with regard to the raingauge network.

Impact Sensor technology is of value in providing warnings of high intensity rainfall, and offers an excellent combination of capital cost and low maintenance for alerting purposes, but these are not sufficiently accurate at the present time as a primary component of the warning system or for post event analysis. Therefore it is not **recommended** that they should be used for the **primary network** within the city area itself although they might be used for alerting and to augment the primary network via access to the NRA network.

The following summaries are taken from the WMO study (Ref 6) and illustrate some of the **typical performance** scores for the classes of device which have been reviewed. As such they augment and are broadly in line with the experience of the authors. Please note that the newer software corrected TBRs are currently difficult to source. The choice of gauge type, location and network density depends on a wide range of factors, and therefore, the final design of the network should be based on a thorough site assessment and evaluation.
Table 1.1: Summary of Raingauge Performance

<table>
<thead>
<tr>
<th>Type</th>
<th>Performance in laboratory (constant flow)</th>
<th>Performance of 1 minute Rainfall Intensity* (RI) measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBR (traditional)</td>
<td>**</td>
<td>***</td>
</tr>
<tr>
<td>TBR with software correction</td>
<td>******</td>
<td>******</td>
</tr>
<tr>
<td>WPG</td>
<td>******</td>
<td>******</td>
</tr>
<tr>
<td>Impact Disdrometer</td>
<td>**</td>
<td></td>
</tr>
</tbody>
</table>

1.3.6 Communication

Consideration should also be given to the possibility of a cost-effective communications method such as GPRS (General Packet Radio Service). As already observed, rainfall data which will be essential to the warning system is only automatically retrieved on a 1, 3 or 6 hourly basis for many of the existing gauges (some more frequently), with a manual dial-up access required in order to obtain current readings. This was required by the need to minimise telephone call charges, and it has been suggested that one alternative is a regime supported by some modern field equipment to enter a higher frequency call-in schedule when readings of rainfall begin or intensity exceeds a specified threshold.

PSTN (Public Switched Telephone Network) landline communications are characterised by installation costs associated with line connection and traditional telephone rental charges. The on-going charges may or may not be very significant, depending upon the contract arrangement with the phone company. Choice of location may also be limited by phone line access. GSM (Global System for Mobile Communications) mobile phone technology, and more recently GPRS, overcome these issues, particularly in an urban environment where signal strength should not be an issue at most sites, and can simplify the physical installation.

Availability of data via GPRS is simpler than GSM or PSTN. GPRS data can typically be obtained via an Internet Protocol (IP) address rather than a dial up modem. The IP address can be accessed in the same way as if the field device was any piece of computer equipment. In some cases this can be provided via FTP (File Transfer Protocol) file transfer direct to the receiving system.

Figure 1.8 helps to show the place of GPRS in bridging between critical field data collection, data provision on the web, database management systems, and the various uses of this data by specialists and managers. In this case the illustration is for culvert monitoring, but there are other water sector applications in use such as water quality sampling.

---

* Rainfall intensity over a given standard period, which is a standard measurement for rainfall data, and 1 minute rainfall intensity was used as the measurement type and measurement interval in the WMO trial and report from which this table was derived. The WMO have concluded that 1 minute Rainfall Intensity is the best measurement for comparative trials.
In parts of the world, GSM has taken over from PSTN during the past decade for field data transfers, and GPRS is fast becoming the new standard, both for the technical reasons given above, and also because of a general perception of savings in costs.

Jacobs’ sub-consultants were given unique access to cost data regarding remote Telemetry of environmental applications across Scotland and Wales, where topographical and weather conditions are similar to Ireland. This team sought to evaluate such cost savings to test the assumptions commonly claimed in the industry, and carried out an analysis on GSM and GPRS invoices for various similar telemetry applications: “The overall picture on these projects in Scotland and Wales shows GSM being typically 2 to 3.5 times more expensive than GPRS. Hourly call in via GPRS typically cost only 30% more than daily call in on GPRS, so is still significantly cheaper than daily call in on GSM, and sub-daily GSM is very expensive. This should open the door to cost effective GPRS sub-daily data provision on more installations.” (Ref 15).

SIM cards to enable GSM and GPRS communications can be purchased or rented from providers of telecommunications or telemetry services.

It is understood that Dublin City Council has up to 80 or 90 traffic masts (giving coverage of the all important city area and immediate suburbs) which are linked back to Civic Offices by fibre optics. Their use for raingauge telemetry can therefore be considered.
1.3.7 Compatibility

At the start of the project no field devices on the Dublin City Council telemetry system were utilising GPRS communications and it was not known whether this was possible. A trial has since been initiated on a small number of field devices which is yielding good results so far, particularly for field devices on mains power which effectively can be seen as “always on” the network, which is a major improvement. Battery operated devices require more careful configuration in order to balance the benefits of more frequently available data against battery consumption. The current version of the telemetry system allows for a relatively small number of GPRS devices on trial, but a later upgrade would provide for extensive use of this technology if the trial is successful. The way in which data is downloaded from devices may also need further consideration with regard to how the data is transferred to a public information system.

In essence, there are two main options for incorporating data via this method into the telemetry system:

- Interface the telemetry system directly to GPRS via an IP address.
- Use one of a number of third party web-based applications to receive the GPRS data and immediately transfer it (typically via secure FTP) as files for the telemetry system to import upon arrival.

A third option would be to operate GPRS raingauge data directly through such a third party system (which normally provide a user interface) and incorporate the data with any required from the telemetry system in the type of central warehousing system for flood alerting and warning already discussed in Volume One Section 4.

To give some cost indications for comparison, we have obtained typical prices for annual GPRS card rental (incorporating call charges up to a 2Mb monthly limit), or for combined GPRS cards, calls and web service. These have been compared with annual cost figures for the existing PSTN outstations supplied by Dublin City Council staff. As can be seen in Table 1.2, the potential savings are significant, even when a much more frequent data exchange is used, and this could enable the more frequent provision of rainfall data required for an effective warning system.

### Table 1.2: Typical prices for annual GPRS card rental

<table>
<thead>
<tr>
<th>Cost Elements</th>
<th>Current PSTN</th>
<th>PSTN</th>
<th>GPRS</th>
<th>GPRS and Web Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Call Frequency</td>
<td>daily or 12 hourly</td>
<td>hourly</td>
<td>hourly</td>
<td>hourly</td>
</tr>
<tr>
<td>Line Rental</td>
<td>€251.52</td>
<td>€251.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Call Charge</td>
<td>€10.95</td>
<td>€131.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Rental including calls (up to 2Mb/month)</td>
<td>€262.47</td>
<td>€382.92</td>
<td>€67.00</td>
<td>€149.00</td>
</tr>
<tr>
<td>Annual Total</td>
<td>€262.47</td>
<td>€382.92</td>
<td>€67.00</td>
<td>€149.00</td>
</tr>
</tbody>
</table>

*Note: This cost data is based on available information for hourly downloads. More frequent downloads, perhaps every 15mins, are likely to be required.*

Should the existing outstations be unsuitable for GPRS, single channel outstations compatible with any of the raingauge technologies discussed in this report, and using long-life lithium batteries for low maintenance can be obtained.
1.3.8 Interfacing with other systems

Another aspect of potential interest to Dublin City Council in relation to field equipment is that some data loggers or outstations are capable of interfacing with local warning systems and flood management systems which can be activated locally upon reaching a threshold (refer to Figure 1.9 below). In terms of active flood management, such systems may for example be capable of controlling the filling and draining of small areas of flood storage in a coordinated way such that, collectively, a significant amount of storage is provided during an event at the anticipated optimum time and location based on forecast information (Aggregated Micro-storage). The potential is available within the functional specification of requirements for the Information Management System for flood warning (see Volume One Section 4.7) for activation of flood warning and flood management equipment in the field in response to automated analysis and centralised human control. However, as an absolute fallback in an emergency, the ability of the field equipment itself to activate such a device is of considerable merit, and we recommend that this should be considered as an option by Dublin City Council.

![Figure 1.9: Warning Beacons, Sirens and Signs can provide for independent local flood management](image)

In Volume One Section 4 the benefits of CCTV and still camera technology were outlined. This could help confirm pluvial events and possible flood risks, as a supplement to the warning system, and an illustration was provided of the strength of combining rainfall or other environmental data presentation with images of the actual situation on the ground, such as a blocked trash screen on a watercourse which might result in flooding.

Typical communications methods for CCTV include point-to-point and mesh link. Originally images from CCTV cameras were only available via bespoke applications provided by the camera manufacturers, or by direct viewing of physical screens in a control room environment. Therefore access to the images can be limited. However, live feeds via the internet are becoming increasingly common, and it has been reported that a number of police forces around the world are considering placing CCTV footage live onto the web as part of community policing, or to share amongst different agencies. The city of Chicago in the US, for example, combines CCTV video from multiple agencies and the private sector and makes it available to staff at emergency call centres. Internet Protocol (IP) and Integrated System cameras make this much easier than the older technologies.
We recommend that the Dublin City Council Flood Management Team should work closely with other departments and organisations covering Dublin City to explore access to these live feeds where possible, perhaps with the management team being located in the traffic control room for example.

Still cameras, activated by local monitoring of trigger levels, or remotely by centralised alerting systems and ad-hoc commands have recently been used in a number of small-scale trials and live systems for flood warning applications. These are relatively low cost and can be combined into applications alongside environmental data from the same location. A range of such cameras are available, many of which are ‘ruggedised’ or have rugged housings, and these can make use of IP communications, email and/or direct File Transfer Protocol (FTP) to client systems. They are of particular value in monitoring of potential risk areas including culverts and gullies which are prone to blockage, (or even for monitoring of TBRs), and can enable action to be taken to prevent flooding, or to provide local warnings to the public. Note that many still cameras operate over a defined focal length, and can sometimes be supplied set to an appropriate focal length for the applications, which is calculated during site survey using a simple formula.

Figures 1.10 and 1.11 below show example views from such cameras. In Volume One Section 4 an example was given of how this can be seen in a web application. It is recommended that this technology should be considered by Dublin City Council for trials at flood risk hot spots.

Figure 1.10: Bridge debris and surface water flooding risk locations are suitable for remote cameras

Figure 1.11: Camera installation planning and typical installation
1.4 Calibration of Radar Rainfall Systems in near Real Time

Use of raingauges in calibrating radar data requires availability of full sets of radar data (e.g. 1km grid square values); inputs from high quality raingauges; and application of the calibration which have been developed. This is not recommended at present until Met Éireann radar upgrades are in place, and findings of the City RainNet research and a UK Environment Agency study into radar-raingauge adjustment procedures are available from 2012 (Ref 4 & 14).

However the installation of well maintained gauges capable of delivering data at the same interval as the local radar may be of great value in building up an historic calibration for use in such a system, and background on some of the work that has been done in this area is given below in order to illustrate the requirements and potential.

In terms of general hydrological analysis, there has always been hope that detailed monitoring of sub-daily data by gauges can be reduced by use of dependable readings at the 1km or 2km grid scale from radar, and that for urban applications in particular radar can provide infill data between locally dense sub-daily networks. However, it is also recognised that it is important to consider radar data accuracy in terms of the impact of local topographical conditions, weather patterns and issues such as distance from the radar device, as already highlighted in Volume One. Therefore the general approach is usually to put in gauges where radar is weakest, as recommended earlier.

Other factors impacting upon the accuracy of radar estimates of rainfall are not fixed, but are related to the specific meteorological conditions at the time, and so cannot easily be addressed in this way. A good example is attenuation, caused by loss of radar energy as it passes through a storm, through scattering and absorption, which can block valid readings further from the radar (Ref 3). Another is the bright band or melting layer in the atmosphere which tends to produce over-estimated figures due to the high reflectivity, and which has a general seasonal profile, but varies considerably, and is also known to affect the Dublin radar (Ref 5). Potentially these factors can impact anywhere, and they are variable and not a static phenomenon. Their influence on the accuracy of forecasts has to be considered and quantified where possible.

Meteorological offices around the world recognise that there is continuing uncertainty with the current accuracy of radar estimates of precipitation, and also in the removal of spurious data and other techniques for improvement of these estimates, which have thus become increasingly refined over the years. Some of these techniques apply gauge adjustments, based on comparisons of historic radar and raingauge figures. This is usually a generalised adjustment for a large area, using a single adjustment factor, which is not calculated continuously but following reviews of raingauge records versus radar, such as once a week or longer (Ref 10).

In Nancy, France during the 1990s a system was developed which aimed to utilise radar data to improve the management of urban sewers with the aim of protecting against flooding and reducing the pollution caused by overflows. The system design included alarms and it was one of those examined as part of the background to the work reviewed in Volume One. It was built around a visual review to allow operators to

---

5 The calibrations can be run by the radar provider (but only if they have access to the gauge data) or by a third party as a service, or run on Dublin City Council platforms after numeric radar values have been received for combination with the gauge data. It is data availability which is critical together with who can reliably process and provide the calibrated data.
evaluate the likely true nature of a rainfall event, and utilised radar confidence intervals. The system architecture overview was similar to any system seeking to process and display both radar and raingauge data (Ref 11) and the Information Management System for Dublin will need to operate in a similar environment for any future direct use of radar readings (refer to Figure 1.12). A simpler alternative more likely today would be to receive calibrated data or images from an external, possible web-based system, thus minimising the complexity of in-house systems.

![Figure 1.12: Nancy Radar System architecture 1999 utilising radar data to improve the management of urban sewers (Ref 11)](image)

In the late 1990s papers were published which approached different methods of utilising raingauge data to correct radar readings (e.g. Ref 12). One of these was the Probability Matching Method (PMM) and a further paper in 2003 illustrated the benefits of large sample sizes and other modifications to further increase the accuracy of this method, such as taking into account the variability in radar rainfall estimates caused by distance from the radar station (Ref 13).

It is this method, incorporating data from a dense network of urban gauges, which City RainNet seeks to implement in near real time (Ref 4). The project continues until late 2012, focussing on three UK urban areas. Progress to date has been limited to system design and planning, but there has been time for a desk checking exercise which has shown the relationship between radar data and ground measurements in one of the urban areas. The relationship is then used to correct radar rainfall figures automatically across a wide range of values, rather than using a single adjustment factor or requiring operator review (refer to Figure 1.13 below which illustrates an example of this from the UK, from the City RainNet project).

The first picture shows an example of the difference between measurements taken on the ground during a particular event, compared with the estimates given by the radar for the 2km and 5km grid square size respectively. 2 km grids are used in the UK for radar data which is outside the best accuracy area, and 5 km grids for the poorest accuracy (furthest from the radar device). In places where both grid sizes are available a comparison of this sort is possible, and both radar values can be considerably out of step with events on the ground.

The second picture illustrates the way in which a calibration profile is built up from pairs of gauge and radar readings. The rainfall values in this case have been reduced to a
common unit (decibels) which is a normal convention when working with radar data. The vertical axis shows the Probability Density Function which indicates the likelihood of the rainfall value. This relationship can therefore be turned into a multi-dimensional calibration which, by constant feeding with new pairs of raingauge and radar data, can be improved over time, and even respond to changes in the quality of the radar values.

Although the radar versus gauge graph is taken from a source which does not show the scale and dates clearly, the actual peak and pattern of difference between them can be seen in the illustration.

![Radar versus gauge discrepancies and calibration development](image)

Figure 1.13: Radar versus gauge discrepancies and calibration development
The output of City RainNet should be a set of tools which will easily integrate with a range of databases and applications to provide improved rainfall radar data. The potential to use radar data to better understand current rainfall across every grid of a city is very considerable, but while the PMM method has been well proven in off-line studies, its success as a real-time method to deliver results for flood risk management, sewer management and other purposes can only be proven in the later stages of the project.

In order to keep informed of progress and success of this technical development, arrangements have been made for Dublin City Council to be provided with regular updates on the City RainNet project during the whole project life cycle.

A vital element of such calibration exercises is the reliability and accuracy of the ground measurements with which the radar is compared. The advantages and disadvantages of various types of raingauge technology have been discussed above - an overview of good practice for installation and maintenance of such equipment is provided in Section 1.5.

### 1.5 Implementation and Integration of a Pluvial Flood Forecasting and Warning System

#### 1.5.1 Summary overview

There have been limited attempts to systematise urban raingauge networks for flood warning purposes, with the main emphasis being on the design of raingauge networks (e.g. Ref 8) for hydrological research or modelling purposes, as well as for calibration of trial instrumentation (Ref 7) or comparisons with data from other sources (Ref 4). In many cases, ideal network layouts have been designed, but the vagaries of factors such as terrain, tree canopy and power supply have often led to these being adapted during installation. Land ownership and access issues also figure prominently in decisions on instrument siting. In the case of urban environments, the challenges of matching the ideal of a symmetrical layout are even greater.

In foregoing sections suggestions are made for a suitable network layout of raingauges for the pluvial forecasting and alerting system, adopting an approach which is not driven by the traditional concerns of catchment boundaries or conceptual layout, but is strongly focused on the core subject of flood risk management, and reflects the information available on the specific nature of storms and pluvial flooding across Dublin City. This draws on experience in localised flood warning systems, the needs of the warning system covered in Volume One Section 4, and the specific results of the other studies across the city as part of this project.

A unified approach has been followed to realise the potential of as much existing data as possible, no matter what the source, while acknowledging the possible limitations of that data and the appropriate use to which it can therefore be put, together with recognition of the challenges posed by the urban environment.

This has led to a special approach to raingauge placement for Dublin together with recommendations on appropriate technology and measures in field equipment installation and management which address the issue of appropriate data quality for forecasting, warning and historic data analysis. While the variables such as exact locations of areas of extreme risk from pluvial-related flooding would be different, it is
considered that the general approach could be used with benefit in other urban areas also.

The proposals, recommendations and suggestions which have been made, based on review of new and emerging technology and approaches, should be read in conjunction with the proposed functional specification for an Information Management System for Pluvial Flood Warning purposes set out in Volume One Section 4. In summary:

Raingauge network
- The proposed raingauge network is as shown in Figure 1.4 and comprises:
  - Existing Dublin City Council raingauges already on or to be transferred on to the telemetry system.
  - Proposed locations for new Dublin City Council raingauges linked to the telemetry system.
  - Met Éireann raingauges to be included in the telemetry system.
  - National Roads Authority raingauges to be included in the telemetry system.

Raingauge sensors
- Tipping Bucket Raingauges provide a reliable source of data by comparison with impact sensors and should continue to be utilised under a suitable maintenance regime.
- Weighing Principle Gauges should also be seriously considered – these can provide highly accurate intensity readings – although initial capital costs are higher this is balanced by reductions in on-going maintenance costs.
- Impact Sensor Raingauges offer low capital and low maintenance cost and can be of value in providing warnings of high intensity rainfall, but these are not sufficiently accurate at the present time as a primary component of the warning system or for post event analysis.

Communications and interfacing
- Consideration should be given to the possibility of introducing a communications system based on GPRS (General Packet Radio Service) which has been shown to offer considerable cost savings over other communication systems.
- To check compatibility with existing systems a trial has been initiated on a small number of field devices which is yielding good results so far, particularly for field devices on mains power. Battery operated devices require more careful configuration in order to balance the benefits of more frequently available data against battery consumption. The current version of the telemetry system allows for a relatively small number of GPRS devices on trial, but a later upgrade would enable extensive use of this technology if the trial is successful.
- Two main options for incorporating data via GPRS into the telemetry system can be considered which can offer significant cost savings and more frequent data exchange over existing systems:
  - Interface the telemetry system directly to GPRS via an IP address.
  - Use one of a number of third party web-based applications to receive the GPRS data and immediately transfer it as files for the telemetry system to
import upon arrival or operate GPRS raingauge data directly through such a third party system.

- The potential is available within the functional specification of the Information Management System (Volume One Section 4) for flood warning, for activation of flood warning signage and ‘active’ flood management equipment in the field (for example Aggregated Micro-storage - see Volume Three) in response to automated analysis and centralised human control. As a fallback, the ability of the field equipment to activate itself once a trigger level is reached should also be considered as an option by Dublin City Council.

- The benefits of linking in CCTV and still camera technology should be considered to assist in confirmation of flood risks at specific hotspot locations by providing images of the actual situation on the ground. There could be scope for interdepartmental collaboration within Dublin City Council on access to live CCTV feeds and this should be investigated. Still cameras, activated by local monitoring of trigger levels, or remotely by a centralised warning system are relatively low cost and can be of particular value in monitoring of potential risk areas including culverts and gullies which are prone to blockage. Such technology should be considered by Dublin City Council for trials at flood risk hot spots.

**Calibration of rainfall radar**

- It is anticipated that the proposed network of raingauges could be used to calibrate the Met Éireann radar data in near real-time once the radar has been upgraded by Met Éireann. For urban applications in particular calibrated radar data can provide infill rainfall data between locally dense sub-daily raingauge networks. The City RainNet and other research projects are currently ongoing but it is expected that outcomes can be used to inform the provision of such a facility whereby the relationship between radar data and ground measurements is used to correct radar rainfall figures automatically across a wide range of values.

- Arrangements have been made for Dublin City Council to be provided with regular updates on the City RainNet project outcomes.

### 1.5.2 Good practice in rainfall measurement

During various discussions and site visits related to this project, the commitment of staff throughout Dublin City Council to good practice and high quality data became very clear. However, there was also an awareness of the limited documentation or written requirements for standards to be followed in installing and maintaining field equipment used for long term monitoring (Ref 5).

#### (i) Training

An appropriate training course in installation and maintenance of tipping buckets, weighing principle gauges and (if appropriate), impact sensors for staff that Dublin City Council employed in these roles is strongly recommended, as well as the development of a specific written set of standards for such work around Dublin, together with a maintenance schedule. In addition to providing high quality data for the Information Management System and post-processing analysis of rainfall events, this material would also form a very useful focus of dialogue with other providers of data outside Dublin City Council itself, and allow the quality of data from these sources to be better assessed.
(ii) Summary of guidelines

The following is a summary of useful guidelines for raingauges and other monitoring systems drawn from standards, guidelines and other sources regarding installation and maintenance, together with experience built up over many years of field installation work and data processing:

- The drainage of the monitoring site should be considered. If a site that is itself prone to flooding cannot be avoided, then drainage will need to be installed and a provision made for the gauge or sensor stopping or having a “flagging” message indicating unreliable results under high intensities or rising water levels.

- Particularly windy sites should be avoided or appropriate wind-breaks used (inappropriate wind breaks can cause turbulence with unpredictable effects on the gauge – see Ref 16).

- For a high intensity focussed application such as for Dublin a tipping bucket size of 0.2mm would be recommended for short interval analysis.

- All types of raingauge or sensor should be levelled at installation.

- The exact raingauge installation location should be checked with survey equipment to ensure that there are no obstructions which can shield rainfall or cause splashing that can impact on the readings: “Sites where the distance between the raingauge and the surrounding objects is less than twice the height of the object above the rim of the raingauge are considered to be over sheltered. If the angle of elevation of the object exceeds 26½° the raingauge is considered to be over sheltered, and generally the raingauge catch will be reduced by an amount dependent on the wind speed.” (Ref 9).

- The height of a raingauge above the ground has been considered very significant in the past, but since the 1960s the WMO and others have recognised that this is less of an issue providing that the site provides protection from high speed winds and avoids the possibility of splashing from surrounding objects. This clearly has benefits in urban environments where the choice of secure sites at ground level may be restricted. (Ref 2 & 16).

- Manufacturers instructions should always be followed as closely as possible in terms of site selection and installation and maintenance procedures.

- Any device with moving parts should be checked at installation and again at regular intervals so that it operates freely. This can be done simply by pouring a measured volume of water into the device, but care should be taken not to generate false readings that are incorporated into the Information Management System.

- Those devices which can be tested physically with a known volume of water should be calibrated upon installation and at least annually, using repeated tests, and must return readings equivalent to an accuracy of at least 2%.

- Regular checking of tipping bucket raingauges and removal of debris is important. Site specific considerations might include grass cutting and the presence of trees in the area for autumn leaf fall. A typical regime for TBRs

---

6 This may be a particular issue for or Impact Sensor installations - manufactures guidance should be followed. Many aspects of good practice would be similar to TBRs, but if the Impact Sensor devices are similar to the Vaisala WXT520 then a clear area of 150m in all directions is required. This is often achieved using masts on top of buildings which are not overshadowed.

7 It is anticipated that Dublin City Council will arrange for “as constructed” records of existing installations to be prepared.
would involve at least monthly maintenance visits, with weekly or fortnightly visits at certain times of the year.

- Occasional inspections of Weighing Principle Gauges and Impact Sensors for stability etc., including at least 6 monthly checking and cleaning of Impact Sensor heads.
- Annual emptying of any non-siphon storage devices and topping up with oil, anti-freeze, anti-organic treatments and any other maintenance, following specific manufacturer’s instructions.

1.5.3 Programme for Phased Development of System

As has been demonstrated in this project, urban flooding resulting from rainfall can take place in almost any season, either through prolonged periods of precipitation possibly with embedded higher intensity cells or periods, typically caused by winter frontal rainfall, or sudden very intense and unpredictable events, often caused in summer or autumn by convective conditions and thunderstorms.

A phased introduction in a timely manner of additional technology to assist in the detection of actual intense rainfall over a range of integration periods is considered appropriate and a phased implementation programme as set out in Table 1.3 is recommended for consideration by Dublin City Council. Such a programme prepares staff and resources, prioritises the areas of most risk, allows for a measured evaluation of other technologies, and then completes the development of the network to meet the requirements of the proposed Information Management System for Pluvial Flood Warning.

Table 1.3: Proposed programme for phased development

<table>
<thead>
<tr>
<th>Task No.</th>
<th>Task Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Detailed examination of TBR/WPG cost benefits to Dublin City Council</td>
</tr>
<tr>
<td>2</td>
<td>Training as described above</td>
</tr>
<tr>
<td>3</td>
<td>Consideration of distributed TBRs and/or WPGs in the cone of silence.</td>
</tr>
<tr>
<td>4</td>
<td>Installation of TBRs and/or WPGs at locations of high risk from intense rainfall.</td>
</tr>
<tr>
<td>5</td>
<td>Field trials of beacon/sign/camera/active flood management technology combined with raingauges</td>
</tr>
<tr>
<td>6</td>
<td>Detailed appraisal of radar following upgrades</td>
</tr>
<tr>
<td>7</td>
<td>Detailed appraisal of radar calibration outcomes and suitability for Dublin</td>
</tr>
</tbody>
</table>
| 8        | Final gauge installation phase:  
            (a) to complete even distribution of raingauges across the city, as necessary  
            (b) to meet requirements of radar calibration. |
Key learning outcomes from Section 1 with regard to the New Technologies and Implementation of a Pluvial Flood Forecasting and Warning System are as follows:

- Following a review of existing rain gauge networks, the following recommendations for future raingauge networks are made, and the proposed expanded network of raingauges within Dublin City is mapped:
  - A sub-network of Dublin City Council gauges across the urban area within any remaining radar cone of silence areas;
  - Placement of further individual gauges determined by locations of particular risk from intense rainfall; and
  - Infill any major gaps of coverage within the City.

- Tipping Bucket Raingauges are proposed as a reliable source of sub-hourly data.

- Weighing Principle Gauges are proposed for locations where post-processing of highly accurate intensity readings will be important.

- Impact sensors are not considered to be sufficiently accurate at the present time as a primary component of the warning system or for post event analysis.

- Communication by GPRS offers considerable advantages in terms of cost and efficiency for the overall Information Management System for Pluvial Flood Warning.

- The potential is also available for active flood warning signage and operation of flood management equipment in the field linked to the forecasting and warning system as well as ‘live feed’ access to CCTV and still imagery at specific flood hotspots.

- A phased introduction in a timely manner of additional technology to assist in the detection of actual intense rainfall over a range of integration periods is considered appropriate.

- This phased introduction will prepare staff and resources, prioritise the areas of most risk, allow for a measured evaluation of other technologies, and then complete the development of the network to meet the requirements of the proposed Information Management System for Pluvial Flood Warning.
SECTION 2 INFORMATION MANAGEMENT AND DATA PROCESSING TECHNOLOGIES

2.1 Assessment of Current Situation and Available Information Technologies

Dublin City Council has indicated that while the organisation has conventional file servers and I.T. infrastructure sufficient to run their existing system, any recommendations from this report should be considered a new development. This is how this area has been approached, however it will still be possible to connect legacy systems in the future if the information they provide is of use to a wider audience.

2.1.1 Required Dataset formats

Table 2.1 summarises the types of datasets held by Dublin City Council which are relevant to Flood Risk Management. There are large number of data formats, some relating to mainstream office software, others relating to very specific graphics and modelling software. The size of the data totals around 30GB. Some of the files are static documents, others are spatial datasets which can be treated as “live” data. It is important that all these files are managed properly going forward. Data management enforces rules and procedures which will reduce future costs and allow the maximum value to be extracted from each dataset. Future costs can be reduced through data management by removing the need to repeat tasks, replace lost files and time spent searching.

Table 2.1: Project data formats

<table>
<thead>
<tr>
<th>Data Category</th>
<th>Data Formats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecasting</td>
<td>gif, xls, rrb, doc, pdf</td>
</tr>
<tr>
<td>Post Event Analysis</td>
<td>xls, ppt, pdf, doc, + various photo / video</td>
</tr>
<tr>
<td>Rainfall</td>
<td>xls, raster, pdf, txt</td>
</tr>
<tr>
<td>Emergency Planning and Response</td>
<td>vob, mpg, doc, ppt, pdf</td>
</tr>
<tr>
<td>General Information</td>
<td>pdf, xls, dvd, ppt, pdf</td>
</tr>
<tr>
<td>GDSDS</td>
<td>tab, iwt, pdf, tif, map, doc, iwc, jpeg, infoworks</td>
</tr>
<tr>
<td>Background Mapping</td>
<td>shp, dxf, xyz, tab, dbase, map, xls, ppt, tif, ntf, dgn</td>
</tr>
<tr>
<td>Drainage</td>
<td>pdf</td>
</tr>
<tr>
<td>Raingauge</td>
<td>xls, pdf, dgn, msg, docx, xlsx, dwg, doc</td>
</tr>
<tr>
<td>Flooding Events</td>
<td>txt, mdb, dbase</td>
</tr>
<tr>
<td>Media</td>
<td>jpg, pdf</td>
</tr>
<tr>
<td>Soil Data</td>
<td>red</td>
</tr>
<tr>
<td>Coastal Flooding</td>
<td>red, tab, shp, pdf</td>
</tr>
<tr>
<td>Dam Flooding</td>
<td>shp, tab</td>
</tr>
<tr>
<td>Fluvial Flooding</td>
<td>shp, map, tab, pdf</td>
</tr>
<tr>
<td>Population</td>
<td>xls</td>
</tr>
<tr>
<td>Asset Database</td>
<td>mdb (soon to be discontinued)</td>
</tr>
<tr>
<td>Website</td>
<td>dvd</td>
</tr>
<tr>
<td>Pluvial Flood Risk Mapping</td>
<td>tab, pdf</td>
</tr>
</tbody>
</table>
2.1.2 Management of Non-Spatial Datasets

Storage of documents on a filing system has limitations even if there is a well defined folder structure. The most efficient approach to organising large numbers of disparate file types is the use of a document management system. These systems consist of a user-friendly interface software and database back end. The software provides an intuitive way of organising files which provides a central repository for all users where files can be searched and user access levels specified to control editing. It is possible to see who is currently editing a particular document in addition to the document history and version dates. It is also possible to view previous versions of a document and highlight changes. The software can be configured to store data to ISO document management standards.

There are several examples of document management systems on the market. One of the most popular is Microsoft SharePoint but there are others such as EpiWare which is an open source software if this is a particular preference. Both these options are web-based solutions and this environment brings many advantages including the ease of maintenance and the fact that the software can be administered centrally.

In addition to basic document management functionality there are additional features which could prove very useful:

- **Communication** – The software can be configured to provide an introductory news page which provides any news or headlines which are relevant to the content. This is often used to remind staff of important dates and deadlines but it could in the case of Dublin City Council give details of recent or imminent flood policy changes with links directly to useful resources.

- **Dynamic Graphing** – Using spreadsheets within the repository it is possible to develop dynamic graphs from multiple sources and then share the output with other users.

- **External use** - Areas can be setup within the repository (subject to I.T. and security restrictions) which allows external parties access to designated files. This would mean that when a document is ready for review it can be shared with an external user group by simply uploading to this area.

- **Customisation** - The user-interface can be easily customised and allows data feeds from a variety of sources. An example would be Met Éireann forecasts and radar GIS which could be connected and provide a display side by side with historic data from the repository.

- **Integration with external data sources** – These web-based document management systems are based on RDBMS so other external databases and systems from around the organisation could be potentially linked. This is a very powerful feature as often databases can find themselves offline and of limited use. With a connection to the document management system, multiple users can extract the information they need.

- **Integration with external software** – In the case of Sharepoint there are many add-on tools which have been added including the ability to interface with ESRI ArcServer or MapInfo. In the case of EpiWare any add-ons which do not already exist can be easily developed using the open source architecture.

- **Integration with corporate intranet** - Because these systems are web-based they can easily be linked to or integrated with existing corporate intranets. Some organisations also use these management systems to administer their intranet/internet content.
2.1.3 Management of Spatial Datasets

A large amount of the spatial data held by Dublin City Council is stored in MapInfo format. As a result the following refers mainly to MapInfo based software but the same approach can equally be applied to ESRI or other GIS software products.

MapInfo can now connect directly with SQL server and store data using SQL spatial data types. With the addition of MapInfo “SpatialWare” software the data can be managed efficiently providing access to multiple users from a central hub, providing a structured index to datasets and the ability to set access rights and control how data is used and updated.

An advantage of this software is the ability to translate data from other systems and formats. As new datasets or updates arrive they can be imported using predefined procedures and queries. The spatial management software offers many of the features of the document management software and again relies on an RDBMS. The use of these enterprise database platforms makes it possible to employ spatial indexing for improved performance when requesting spatial data from the server. Full multi-user editing is possible and this is a major advantage over file-based datasets.

Each dataset must conform to quality standards to be loaded into the database. It is also possible to configure the database so that spatial rules are enforced and spatial relationships and models can be developed.

One of the main strengths of the system comes from the ability to obtain a particular version of a spatial dataset and display a history of edits and metadata using the INSPIRE directive or other international standard. This is extremely valuable in order to gain confidence in GIS data and be able to provide information as to the source and licensing restrictions, which is very useful when supplying data to external parties or providing information for an audit.

2.1.4 Relational Database Management Systems (RDBMS)

The use of a RDBMS such as SQL Server or Oracle would bring a number of advantages to Dublin City Council. These systems provide a platform for serving data which once established provides maximum flexibility and extensibility.

File-based data bases provide a familiar user interface to many computer users but they do have limitations in file size / record size and the number of users who can simultaneously interact with the data. Use of these file-based data sources is not recommended for anything above the size of a small team.

The RDBMS can be expanded as more datasets become available. The size of the database is only really limited by the hardware available. The RDBMS provides a stable platform for intensive data access and querying improved performance over file based sources, integrity is improved through the enforcement of rules and relationships and the data is made more secure with the use of standard database backup procedures.
2.2 **Recommendations for Intelligent and Innovative Data Processing**

The document management and spatial data management systems described above are designed to store the various data formats in the optimal way and are recommended. Non-spatial data can be imported directly into the management system with previous versions providing historical information. A sensible naming convention is essential. Datasets can be updated on an ad hoc basis or if available on a regular basis, reminders can be set for the update task, helping the system to remain current and reliable.

For spatial data, the data sources arrive in a huge variety of formats and standards. Depending on the chosen software platform the required procedures may differ but the basic approach should be applicable in all cases. Scripts or customisations can be set up which can automate the process for a particular dataset. These scripts or customisations may well require little or no programming depending on the software but importantly they provide a consistent process for import and conversion. These procedures would cover tasks including the following:

- Conversion of x,y point features from grid coordinates (text and spreadsheet files)
- Conversion between geographic coordinate formats
- Conversion of geographic coordinates (Latitude and Longitude) to grid coordinates (Eastings and Northings)
- Conversion between grid coordinate systems (in the case of Dublin City Council, conversion between Irish National Grid and Irish Transverse Mercator would be the important one)
- Conversion of ascii grid data to raster surfaces

These examples are just some of the common tasks which are encountered when receiving spatial dataset for uploading to the database. Once these have been created and tested they can then be used repeatedly on datasets as they arrive. This provides consistency and repeatability and as more data is received and changes need to be made, the scripts and procedures can be added to, forming a library for the future. Guidance on this process can be developed which should be circulated to the relevant staff and enable the processes to be continued in the event of staff absence. The scripts and processes should be developed in such a way that they can be operated by non-specialist staff. This is very much possible with the use of modern software.

Importantly, these scripts or procedures can be configured to store the original files in the database in the state that they were received in addition to subsequent revisions in other formats. This means that Dublin City Council can always revert to the original received file as a reference and to ensure not data is lost or altered unintentionally.
Figure 2.1 provides an illustration of how we recommend an overall data management system would link together, integrating the various systems and providing intelligent and innovative data processing.

Aspects of this system would be integrated with the Information Management System for Flood Warning discussed in Volume One Section 4. It should be possible to link in data directly from Met Éireann. Once this is achieved the data could then be used within the spatial management system but also integrated with the web-based interface. Discussions should be progressed between Dublin City Council and Met Éireann in order to enable this system but it is very much possible for a web-based interface to be developed which provides a view port to various data sources including dynamic reports from internal databases, historical flood information and documents referenced to locations, all within a single system. In addition there is data such as the NRA raingauge and forecasting information to be integrated.

Such a system will require a range of user levels including administrators, who can make updates, and end users with a read only view. Such a system could also be configured to share certain datasets with the public. This could be high level warning information provided on the Dublin City Council website or shared more widely via a Rich Site Summary (RSS) feed which the public could use to keep up to date on flood information.
Key learning outcomes from Section 2 with regard to the Information Management and Data Processing Technologies are as follows:

- Proposals for information management and data processing systems are made.

- Proposals cover both non-spatial documentation management and spatial datasets as well as relational database management systems (RDBMS) which, once established, provide maximum flexibility and extensibility.

- The way in which an overall data management system would link together, integrating the various systems and providing intelligent and innovative data processing is proposed. Such a system would integrate with the Information Management System for Pluvial Flood Warning described.

- It is anticipated that a web-based interface can be developed which provides a view port to various data sources including dynamic reports from internal databases, historical flood information and documents referenced to locations, all within a single system.

- Such a system will require a range of user levels including administrators, who can make updates, and end users with a read only view. Such a system could also be configured to share certain datasets with the public. This could be high level warning information provided on the Dublin City Council website or shared more widely via an RSS feed which the public could use to keep up to date on flood information.
Links to Software Providers

**Document Management Systems**


EPIWare - [http://www.epiware.com/](http://www.epiware.com/)

**Spatial Data Management Systems**


References

1. Hydrology in Practice, Elizabeth M Shaw, Stanley Thornes, 1994
5. Meeting Notes: Met Éireann, Jacobs, Dublin City Council 08/09/2010, 19/10/2010 & 20/10/2010
9. BS 7843 1.1 – 2.3 Standards for Meteorological Precipitation Data (please note that these standards are currently under review for republishing)
15. GPRS verses GSM Cost Analysis for Scotland and Wales, Hydro-Logic Ltd internal report, March 2011