08 - GROUNDWATER FLOOD MECHANISMS AND HAZARDS IN IRISH KARST TERRAINS

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Abstract

Flooding and flood risk management is seen as one of the major societal challenges facing communities across Ireland. The recent flood events of 2009 and 2015, unprecedented in many parts of the country, have reinforced the need to develop greater understanding of flood processes and improve our ability to quantify the location and likelihood of flood occurrence. Of particular relevance in Ireland is the phenomenon of groundwater flooding, which represents a significant flood hazard for many rural communities. Groundwater flooding is primarily associated with the extensive karstic limestone lowlands in the west of the country. The combination of low storage, high transmissivity and widespread groundwater-surface water interaction leaves these systems particularly susceptible to groundwater flooding. The heterogeneity characteristic of karstic groundwater flow also poses unique challenges in evaluating groundwater flood risk. Effective flood risk management requires an understanding of the recharge, storage and transport mechanisms during flood conditions, but is often hampered by a lack of adequate data. Using information gathered from the 2009 and 2015 events, the main hydrological and geomorphological factors which influence flooding in a complex karst system, the Gort Lowlands, are elucidated. A new three-year Geological Survey of Ireland (GSI) programme is also introduced which, in collaboration with Trinity College Dublin, will provide the necessary information to allow effective future management of groundwater flood risk in Ireland.

1. INTRODUCTION

Floods are natural phenomena which cannot be completely prevented; they have the potential to cause fatalities, damage property and infrastructure, and compromise economic development (Directive 2007/60/EC). The catastrophic flooding during the winters of 2009 and 2015 are two such examples, which caused widespread damage and disruption to communities across the country. Such extreme weather events highlight the pressing need to improve our understanding of the factors and mechanisms which cause flooding, in order to ensure efficient flood prevention and mitigation in future. This is addressed within the aims of the EU Directive on the assessment and management of flood risks (2007/60/EC), or the “Floods” Directive.

The EU Floods Directive (Directive 2007/60/EC) requires all Member States including Ireland to reduce and manage the risks that all forms of flooding pose through the mapping of probabilistic flood extents and the establishment of flood risk management plans. During the first implementation phase of the Floods Directive, the Preliminary Flood Risk Assessment (PFRA), groundwater flooding was identified as posing a significant flood hazard in the west or Ireland (Mott Mc Donald, 2010). Groundwater flood risk management poses its own set of technical, environmental and socio-economic problems that differentiate it from other flood forms (e.g. fluvial, coastal etc.). Groundwater flooding can occur in a discontinuous manner across the landscape, often with no indication of flood risk prior

to an extreme event, making effective land-use planning difficult. Groundwater flooding can manifest in a variety of ways, often in combination with fluvial, pluvial and coastal flooding. It is also typically driven by cumulative rainfall over a prolonged period, with the accumulation of excess recharge over a period of weeks or months determining flood severity and duration.

This paper will give an overview of some of the main features and mechanisms of groundwater flooding using the example of the Gort Lowlands, a complex karst system which experienced unprecedented flooding in recent years. A new three-year GSI programme is also introduced which, in collaboration with Trinity College Dublin, will provide the necessary information to allow effective future management of groundwater flood risk in Ireland.

Figure 1: *Groundwater flooding in the Gort Lowlands, Co. Galway. Image provided by the Office of Public Works (OPW).*

2. GROUNDWATER FLOODING IN IRELAND

Groundwater flooding is most closely associated with the karst limestone areas of the western lowlands, which extend from the River Fergus in Co. Clare in the south to the areas east of Lough Mask and Corrib in Co. Galway and southern Co. Mayo (Mott McDonald, 2010). The prevalence here is fundamentally linked to bedrock geology; the regional limestone lithology is susceptible to dissolution by water, in a process known as karstification. The passage of water through the bedrock dissolves and enlarges flow pathways, creating a complex system of water-carrying fractures and conduits beneath the ground surface. This process has occurred in limestones throughout Ireland, but it is in the pure, well-bedded Carboniferous limestones in the west where karst drainage dominates regional hydrology. The combination of low storage, high transmissivity and widespread groundwater-surface water interactions of these systems renders them particularly susceptible to groundwater flooding (Coxon and Drew, 1998; Naughton *et al*., 2012).

During periods of intense rainfall, the rate of recharge exceeds the storage and drainage capacity of the underlying karstic groundwater flow system, causing surface flooding to occur in low-lying areas

(Naughton *et al*., 2015). Where flooding occurs on an annual basis, characteristic wetland vegetation communities develop in topographic depressions known as turloughs. Turloughs play a key role in lowland karst hydrology; they act as temporary storage for local and regional excess recharge, analogous to attenuation ponds in storm drainage systems. During extreme and/or prolonged rainfall, floodwaters within the basins can reach extreme levels and cause widespread damage and disruption to surrounding properties, infrastructure and agricultural land. Transient overland and shallow groundwater flow routes can also activate in response to the exceptional groundwater levels, causing unpredictable flooding of locales and communities that are often unprepared for such events.

3. THE GORT LOWLANDS

Historically the worst groundwater flooding to have occurred in the Rep. of Ireland has been centred on the Gort Lowlands, Co. Galway. The Gort Lowland catchment covers an area of approximately 500km^2 in south Galway, bounded by the Dunkellin, Slieve Aughty Mountains and the Burren plateau to the north, east and south respectively. Bedrock geology is divided between the relatively impermeable sandstones of the Slieve Aughty Mountains in the east and the Carboniferous limestone of the lowlands in the west. Allogenic recharge (originating outside the limestone catchment) drains from the sandstone uplands into the groundwater flow system of the lowlands below, which comprises a well-developed network of conduits, turloughs and epikarst. The combination of large quantities of allogenic recharge, extensive catchment area, a high capacity conduit system and relatively deep surface depressions results in significant groundwater flooding throughout the Gort Lowlands.

Numerous notable flood events have been recorded throughout the 20th and 21st century. A series of flood events during the mid-1990s prompted the Gort Flood Study, a major investigation of flooding in the catchment carried out by a consortium led by Southern Water Global (Southern Water Global, 1998). A range of engineering solutions that could potentially provide flood mitigation to serious flooding were considered. These solutions all involved very large capital costs relative to the level of benefit achieved, and were ultimately deemed economically unjustifiable. Instead, a number of local measures were implemented and houses deemed indefensible in the long-term were demolished and the residents voluntarily relocated.

Public interest and concerns about flooding in this South Galway catchment have been reignited in recent years due to the unprecedented flooding the winters of 2009 and 2015, which exceeded 1990s levels considerably in many areas. The Gort catchment experienced exceptional rainfall during both winters (Walsh, 2012). Monthly rainfall at the Met Éireann Gort (Derrybrien) station for November 2009 was 428 mm, or 310% the long-term monthly average (1981–2010), while totals of 268mm and 384mm were recorded in November and December 2015, representing 194% and 263% of the long-term monthly averages respectively. For a detailed description of the meteorological conditions, river discharges and groundwater flooding in 2009 and 2015 see McCormack and Naughton (2016) and Naughton et al. (2015). This paper will focus principally on the mechanisms of flooding, that is the way in which groundwater floods manifest, within the catchment.

Under such extreme conditions the vast quantities of recharge entering the catchment cannot be accommodated by the storage and discharge capacity of the system and widespread flooding can occur (figure 2). This led to complex and often unpredictable patterns of surface flooding and ephemeral overland flow developing, posing a flood risk to surrounding buildings, agricultural land and infrastructure (Naughton *et al*., 2015). The extent and complexity of the flooding in the catchment

highlighted the importance of improving understanding of the interactions between recharge, storage and transport mechanisms during flood conditions.

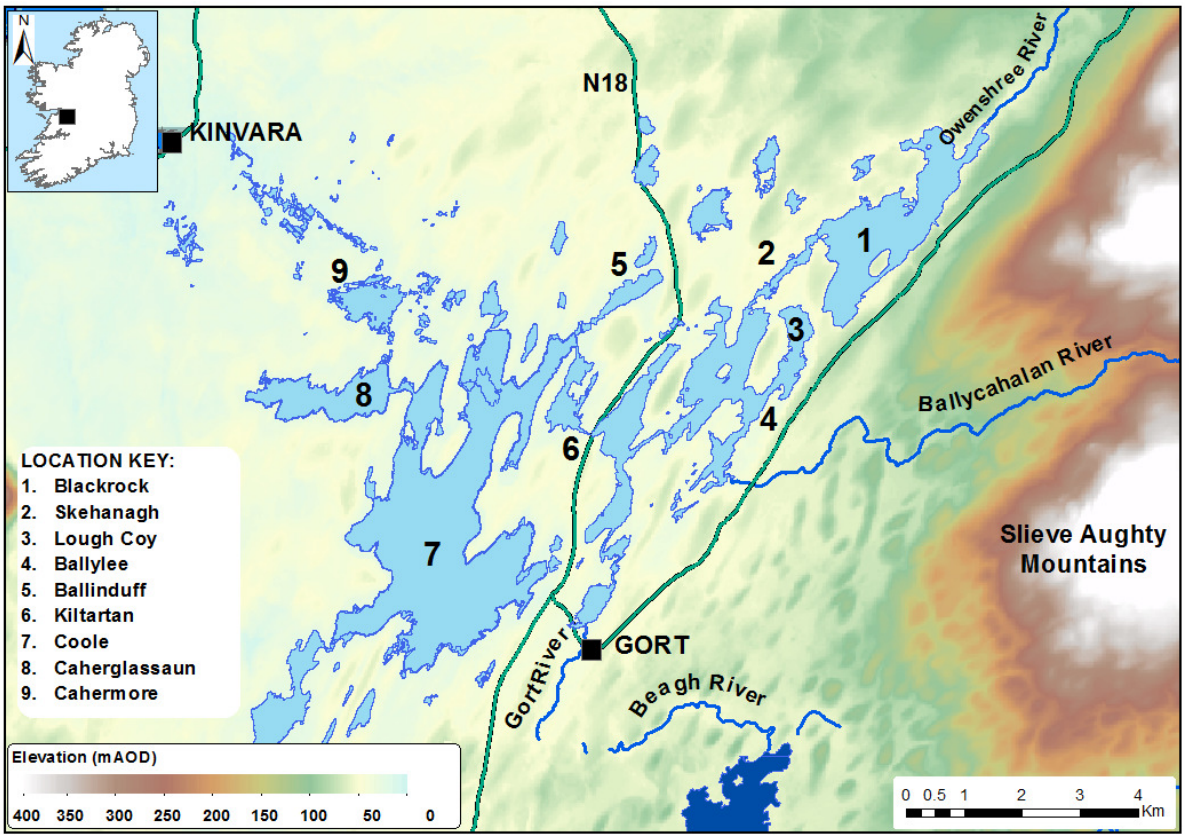

Figure 2: *Groundwater flood extent map for the Gort Lowlands, winter 2015-2016 (McCormack and Naughton, 2016)*

4. GROUNDWATER FLOOD MECHANISMS

Groundwater flooding in karst areas manifests itself in a variety of ways, often in combination with fluvial, pluvial and coastal flooding. Observed flood mechanisms included high water levels in turlough basins, backwater flooding of sinks, flooding caused by excess spring discharge, overland flow due to overtopping of sink depressions, and surface ponding in local epikarst watersheds. The main mechanisms identified in the Gort Lowlands are given and described in Table 1. These represent the type examples of how groundwater flooding can manifest in a lowland catchment. For example, the flooding at Caherglassaun Turlough (location 8, figure 2), can be classified as turlough flooding (type 1, table 1), and covered an area of approximately 2.8km^2. As water levels rose in Caherglassaun, overtopping of the topographic basin occurred with consequent overland flow effectively bypassing the groundwater flow system and causing rapid transfer of floodwaters from Caherglassaun to Cahermore.

Evidence has demonstrated that groundwater flooding events are frequently a result of multiple mechanisms acting in combination. For example, the flooding in and upstream of Blackrock Turlough could be considered a combination of turlough flooding (type 1) and backwater flooding (type 2). The turlough exceeded its normal bounds due to excess recharge (type 1); this was caused by insufficient capacity in the underlying conduit system to accommodate the allogenic flow from the Owenshree River (type 2).

Table 1: *Groundwater flooding mechanisms*

ID	TYPE	DESCRIPTION
1	**Turlough flooding**	Turlough floodwaters rise to extreme levels and pose a flood risk to the surrounding area. Recharge can be derived from local or distal autogenic karst and/or allogenic non-karst catchments.
2	**Backwater flooding**	Point recharge (sinking streams/rivers) exceeds the drainage capacity of the underlying groundwater system, causing inundation of the sink itself and backwater flooding upstream.
3	**Overtopping of sinks/basins**	Where overland flow occurs due to overtopping of flooded topographic depressions (e.g. turloughs, sinkholes), effectively bypassing the groundwater system.
4	**Discharge-related flooding from springs and resurgences**	Groundwater springs and risings can exceed normal discharge levels and cause localised flooding around and downstream of the resurgence (groundwater-induced flooding).
5	**Shallow inter-basin transfer**	Shallow groundwater flow paths within the epikarst are activated by high groundwater levels, causing transfer of floodwaters to adjacent topographic depressions and consequent flooding

5. GWFLOOD: NEW GSI GROUNDWATER FLOODING PROGRAMME

In response to the serious flooding of winter 2015 specifically related to turloughs, the Programme for a Partnership Government (2016), under the area of Climate Change and Flooding, contains the following objective: *"Turlough Systems: We will provide resources to the OPW to commission studies into individual problematic (prone to flooding) Turlough systems, if requested by a local authority or another relevant State agency"*. The GSI, a division of the Department of Communications, Climate Action and Environment (DCCAE), were in a position to help deliver on this commitment through the existing groundwater and karst expertise and by the development of a new three-year project on groundwater and turlough monitoring and modelling. A detailed project plan was developed over summer 2016 and approved by DCCAE as an additional project of the GSI Groundwater Programme and funding was allocated in Budget 2017.

The GSI's Groundwater Programme has been studying karst systems and features, including turloughs, as part of the Groundwater Protection Schemes due to the critical role they play as potential pathways for aquifer pollution. Work to date has included desk studies, field mapping, aerial LiDAR surveys and targeted research resulting in the development of the National Karst Database (figure 3). This same approach and expertise will be enhanced, with additional resources and key collaborations with the University of Dublin Trinity College, to develop a new monitoring and modelling programme specifically in relation to groundwater flooding. This new programme will provide the fundamental technical knowledge to enable the OPW and local authorities to develop appropriate flood mitigation measures, and allow for informed flood assessments to be made in future.

Figure 3: *Installing temporary water level logging equipment in Lough Funshinagh, Co. Roscommon*

Hydrometric data is a crucial component to understanding the dynamics of hydrogeological systems. However, consistent long-term hydrometric data do not exist for groundwater flooding applications, limiting the scope and conclusions drawn in existing studies (Daly, 1995; Jennings O'Donovan & Partners, 2011; Southern Water Global, 1998). The GWFlood programme aims to provide the requisite data to address this knowledge gap by establishing a permanent monitoring network, as well as developing analytical tools to help address issues surrounding groundwater flood mapping, frequency estimation and likely climate change impacts. This new programme will provide flooding and hydrogeological information that will enable key stakeholders to make informed decisions with regards to groundwater flood mitigation measures. The collaboration between the GSI and Trinity College Dublin will also strengthen existing partnerships between the institutions and open new applied geoscience research opportunities in the fields of groundwater flooding, geohazards, groundwater-surface water interactions and remote sensing. Primary objectives of the proposed study are to:

- Establish a permanent monitoring network to provide long-term quantitative groundwater flooding data.
- Develop methodologies for improving groundwater flood hazard maps and real-time monitoring of groundwater flooding.
- Develop modelling/analysis methodologies for estimating groundwater flood frequency and the assessment of potential flood mitigation strategies for designated areas.
- Analyse the potential impact of climate change on turlough hydrological functioning and groundwater flooding.
- Investigate the influence of geostructural controls on turlough hydrogeology using 3D geological modelling and visualisation techniques.

The increased frequency, damage and disruption caused by groundwater flood events in recent years highlights the clear need for further research into the issue of groundwater flood prediction and risk assessment in karst regions. Due to the inherent complexity of karst groundwater systems and the lack of quantitative hydrological data generally available, this collaborative GSI/Trinity College Dublin project presents a unique opportunity to use a knowledge base gained by the project participants over the last decade to contribute to flood risk management practices in Ireland. The project will provide the necessary high-quality data, mapping and analysis techniques required to inform future planning decisions, and so help to ensure the sustainability of vulnerable rural communities affected by groundwater flooding as well as the turlough habitats themselves. The project will influence policy and governance by giving decision makers more information on the drivers and mechanisms of groundwater flooding in Irish karst systems, and allow them to make scientifically-informed decisions for better outcomes within the Floods, Water Framework and Habitats Directives.

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