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TECHNICAL NOTE

GROUNDWATER FLOOD OR GROUNDWATER INDUCED FLOOD?

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Abstract: A number of 'groundwater flood' events have been recorded over the Chalk aquifer in southern England since the 1993 occurrence at Chichester, Sussex. Reporting of this event and subsequent groundwater floods indicates that there are two types of groundwater flood event. Type one is the true groundwater flood in which the water table elevation rises above the ground elevation, and Type 2 occurs when intense groundwater discharge via bourne springs and highly permeable shallow horizons discharges to surface waters and causes overbank flooding. It is recommended that a Type 1 event be referred to as a true 'groundwater flood' and Type 2 simply as a 'groundwater induced flood'. Such differentiation will provide a clearer picture for the environmental regulator, the planner and the insurance industry to apply to their own work.

The term 'groundwater flood' was introduced in a report on a flood event at Chichester, Sussex that occurred in 1993 (Posford Duvivier 1994). The term has since been adopted for a wide range of flood event types, only some of which relate to true groundwater flooding. In the British Isles groundwater flooding occurs over specific parts of the Chalk aquifer (Figure 1), but is not commonly recorded over other unconfined aquifer systems such as the widespread Permo-Triassic sandstone aquifers or minor aquifers. Exceptions are local flooding of gravel lowlands caused when the water table intersects the ground surface, but this is controlled essentially by local river stage (e.g. MacDonald *et al*. 2008), or the seasonal flooding of turloghs on Carboniferous Limestone, for example, in the low lying Burren area of Co. Clare in the Republic of Ireland (Drew 2008).

A groundwater flood event is one caused when the water table rises above the ground elevation resulting in ponding of groundwater on the surface. Environment Agency (2006) defines groundwater flooding as:

> The type of flooding that can be caused by the emergence of water originating from sub-surface permeable strata. The groundwater may emerge from either point or diffuse locations.

Groundwater flooding depends on the wetting up of the soil, given no soil moisture deficit, for a sustained period accompanied by a prolonged period of rainfall recharge at a rate which exceeds the drainage potential from the aquifer at a local or catchment scale. Groundwater flooding may be associated with episodic spring discharges, although not universally, whereas water once discharged from a spring to a bourne stream is essentially surface water derived from a groundwater source (c.f. Hughes *et al*. accepted paper).

This technical note examines the occurrence and causative processes of groundwater flooding over the Chalk aquifer in Britain with the objective of constraining the term 'groundwater flood' to events caused only by exceptionally high water table conditions. This will provide hydrogeologists with a clearer message to give to the user community, e.g. within regulatory authorities, planning services and the insurance industry.

KEY RECENT GROUNDWATER FLOOD EVENTS RECORDED OVER THE UK CHALK AQUIFER

Chichester 1993/94

One of the first major flood events to attract attention from hydrogeologists was the Chichester flood, when the River Lavant overtopped its banks, that occurred in the winter of 1993/94 causing £6 million damage (Taylor 1995; Midgely & Taylor 1995; Posford Duvivier 1994). Groundwater levels rose in response to higher than normal autumn rainfall and then in December and the first half of January the area received an additional 350 mm rainfall. The long term observation well at nearby Chilgrove House [NGR SU83561440] became artesian in early January and remained artesian for 18 days, the longest period this has occurred since records began in 1836 and coincident with the highest recorded water levels in the aquifer. The elevated water table caused numerous episodic springs and seepages to appear, adjacent to the River Lavant, causing an increase in flow in the river from 0.3 $m^3 s^{-1}$ in mid-December to 8.1 $m^3 s^{-1}$ in mid-January; the long term average flow in the river is 0.26 $m^3 s^{-1}$. At the same time the river response turned flashy. Posford Duvivier (1994) identified a critical water level at Chilgrove House above which the catchment becomes responsive to rainfall and the water level in the aquifer can thereafter only increase marginally. The likely cause of this is that the water table rises above this critical level into a highly conductive zone in the aquifer through which rainwater ingress rapidly discharges via springs to supplement the river flow. The Chichester flood was described at the time as a groundwater flood.

Patcham 2000/01

Groundwater emergence at Patcham, in the northern suburbs of Brighton, when the groundwater table rose above the ground elevation, is recorded in the Borough archives for 1877, 1913, 1915, 1916 and 1925, the period 1913 to 1916 representing a potentially cyclic return period of intense wet weather. Floods also occurred in the winter of 2000/01 and this event attracted attention from hydrogeologists (Binnie, Black & Veatch 2001). This event was more damaging than the earlier floods because surcharging of sewers and flushing of storm drains exacerbated surface flooding.

The severity and extent of the flooding reflected both the meteorological conditions and high antecedent groundwater levels. Local groundwater hydrographs offer little autocorrelation, typically only over a few months, and tend to be flashy at higher groundwater levels with limited variation in annual groundwater minima. This is a consequence of the well-developed and connected secondary fracture porosity in small Chalk catchments and the proximity of the coastal discharge zone. The aquifer response to recharge and discharge is rapid, and groundwater levels generally recede normally regardless of the amount of recharge.

In the period from September 2000 to April 2001 there were eight successive months of exceptional rainfall. As a result, the southern region of the UK received 201% of its long-term average (1961–1990) rainfall during September–December 2000 and there was no precedent for the intense recharge the aquifer received that winter. The likely mechanism of the surface flooding at Patcham was simply the saturation of the Chalk matrix, starting initially above poorly permeable marl and hard bands and working upwards until the entire matrix was saturated between the normal water table elevation and the ground surface (Adams *et al*. 2010). The result was surface ponding with the flood waters characteristically blue/grey in colour, standing up to a metre deep at one location. The blue grey colour typical of Chalk water discharges contrasts with the turbid brown coloured waters that are characteristic of overland flow.

Pang/Lambourn 2000/01 and 2002/03

A third groundwater flood scenario, related to bourne-type spring discharge, this one recorded on the Pang and Lambourn sub-catchments to the Thames in Berkshire, has also been reported (Robinson *et al*. 2001, Finch *et al*. 2004). There is a history of flooding in these catchments, with recorded incidents dating back to the 1930s. Two significant groundwater flooding events have occurred recently; the first during the winter of 2000/1, at the same time as the Patcham flood, and a smaller event which occurred in the winter of 2002/03. Both coincided with unexceptional and brief rainfall events, not normally associated with surface flooding, but following prolonged and intensive wet weather (Defra 2001).

Investigation of the Pang/Lambourn flood events indicates that when the aquifer receives about 100 mm of effective rainfall per month, for three consecutive winter months, it attains a potential to flood parts of the catchments. Additional rain dictates the length and severity of the flooding. Hence in 2000/1 the prolonged high effective rainfall continued after the initiation of flooding, and high water levels and associated flooding persisted for about eight months, whereas in 2002/3, the water levels receded about two months after the monthly rainfall dropped below average in February.

The two catchments act as typical Chalk bournes whereby stream flow, in the otherwise dry valleys, starts at a spring source that reflects the elevation of the water table. Thus the stream will generally flow from a higher elevation in a bourne catchment in winter than in summer. The higher elevation springs flow in wet winters, typically between February and March or February to May, but in 2000/1 and 2002/3 the higher springs started to flow early in December.

As with Chichester and Patcham the flooding events in the Pang and Lambourn are again collectively described as groundwater flood events, albeit associated with bourne type spring discharge.

THE PROCESSES – A REVIEW

Hughes *et al*. (accepted paper) suggest that there are four key types of groundwater flood event:

- Natural water table rises caused by extreme high intensity and/or long duration rainfall, resulting in surface water ponding, intermittent stream flow or the anomalous activation of springs.
- Groundwater flow in alluvial deposits by-passing river channel flood defences.
- Groundwater level rise due to cessation of groundwater abstraction.
- Underground structures creating barriers to groundwater flow which result in water tables rising to cause flooding.

Whilst all of these mechanisms can result in significant flooding, it is the first mechanism that commonly describes 'groundwater flooding' in Chalk catchments.

The hydraulic properties of the Chalk are complex and result from a combination of matrix and fracture properties (see, for example, Price *et al*. 2000). Groundwater flow in the saturated zone is primarily through fractures and as a consequence can be rapid. Groundwater storage occurs within macro and micro fractures and also within the Chalk matrix. Recharge through the unsaturated zone can occur very rapidly through fractures or slowly within the matrix (Ireson & Butler 2011).

The mechanisms and processes that lead to a groundwater flood events over the Chalk aquifer are summarised in Table 1, although there is some uncertainty over the exact nature of the controlling or dominant processes during each specific event. Common to any groundwater induced flood event is the wetting up of the Chalk matrix in the unsaturated zone, the dominant cause of the Patcham event and clearly a significant contributor to flooding at Chichester and in the Pang/Lambourn. Common to both Chichester and Pang/Lambourn is groundwater discharge to surface waters leading to overbank flooding, and in both cases localised ponding was also caused directly by the water table elevation exceeding the ground level elevation. An essential prerequisite is unusually large accumulations of rainfall over a period approaching 90 days assisted by wet antecedent conditions.

But is this a simplistic interpretation of the recorded flood events or might there be some other processes at work? There are obvious fears that climate change may increase the return period of likely flood events although increased occurrence of storm events alone will not be a major contributory factor. The Patcham event suggests that the built environment may exacerbate flooding and the progress of urbanisation may create new 'hot spots'. There remain some uncertainties over the exact nature of the wetting up processes yet to be teased out as process simulation modelling work advances, e.g. Ireson *et al*. (2009); Ireson & Butler (2011). In the meantime the basic understanding of the groundwater flood event is becoming clearer and areas liable to flooding are being included in national flood risk delineation programmes devised for the planner and insurer alike.

GROUNDWATER FLOOD OR CONVENTIONAL SURFACE FLOOD?

Table 1 shows two clear types of flood event, albeit types that can be areally juxtaposed:

1. *The Patcham and partly the Pang/Lambourn type*. The simple elevation of the water table above the ground level. In Patcham, this is caused by a local depression of the land within a synclinal trough of the Chalk and in the Pang/Lambourn by high catchment land at which the slope of the land is not consistent with the otherwise dry valley so allowing localised ponding.
2. *The Chichester and part Pang/Lambourn type*. Discharge from bourne springs and/or shallow high permeability layers in the Chalk enhance flow to surface waters and cause overbank flooding.

Both types of flood event are correctly termed groundwater floods in that groundwater is the source of the flood water (Environment Agency 2006). However, it is misleading to label the Type 2 flood event simply as a groundwater flood and a better description of this type is ‘groundwater induced flood’.

CONCLUSIONS

Recent and significant so called ‘groundwater flood’ events over the Chalk aquifer in southern England have attracted the attention of the hydrogeological community. Although the exact nature of the processes that cause these events remains uncertain, the overall causes of these events are understood. Evidence from flood events at Chichester and Patcham in the South Downs aquifer and from the Pang/Lambourn catchments in the Berkshire Downs indicate that there are two types of groundwater flood event. Type one is the true groundwater flood in which the water table elevation rises above the ground elevation, and Type 2 occurs when intense groundwater discharge via bourne springs and/or highly permeable shallow horizons discharges to surface waters and causes overbank flooding. It is recommended that a Type 1 event (Patcham and part Pang/Lambourn) be referred to as a groundwater flood and Type 2 (Chichester and part Pang/Lambourn) as a groundwater induced flood event. Adoption of these labels will allow a clearer picture to be transmitted to end users of the analyses of these events.

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Table 1 Processes and mechanisms controlling flood events on the English Chalk aquifer

Process/mechanism	Chichester	Pang/Lambourn	Patcham
Saturation and transport to surface via normally unsaturated shallow high permeability horizons	Major		
Bourne type spring discharges causing local flooding		Major	
Wetting up of deep unsaturated zones above marl and hard bands until water table rises above ground level	Contributory	Contributory	Major
Proposed terminology	Groundwater Induced Flood		Groundwater flood

LIST OF FIGURES

1. Outline of the Chalk outcrop in England and locations of flood events