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The hydrology of an ephemerally flooded doline: Pwll-y-Felin, South Wales, UK

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Abstract: The first annual hydrograph from an ephemerally-flooded doline in the UK is described. Flood duration and volume were characterised by combining water-level data with a detailed topographic survey. Rapid surface runoff of Na–SO_4-type water is derived from a localized topographic catchment. The inflow stream produced a 'flashy' hydrograph with maximum flood depths reaching 7m when the doline can contain 7,383 m^3 of water. Flooding occurred over 161 of the 365 day study period, with an average flood depth of 2.4m. Stage dependent drainage properties suggested that water loss is greater when the flood depth is >3m, indicating that there may be additional drainage conduits at higher levels within the doline. A conservative estimate of 138 ML year is provided for net loss of water to the underlying aquifer. The vegetation shows some zonation potentially related to flood duration, with higher diversity in the marginal zone subject to the greatest fluctuation in water levels. The classification of Pwll-y-Felin and other small ephemeral karstic water bodies should be considered not only as geological landforms but as small karstic dependant wetlands. Under-recording of small, isolated temporary water bodies is of concern to international conservation bodies. The methodology presented can help to characterize the hydrology of ephemerally flooded dolines and could be used better to understand karst dependent habitats, recharge in karst aquifers, water budget calculations and to improve management and regulation in karst aquifers.

Keywords: karst hydrograph, wetland, temporary pool, stream sink, recharge

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Ephemerally flooded dolines in karst terrain act as pathways for recharge into underlying limestone aquifers. Characterization of their hydrology is required to help better understand the groundwater recharge and to improve water balances and conceptual models in karst aquifers. Interactions between the hydrology, flood depth and duration, water chemistry and vegetation also need to be better understood if these small, temporary pools are to be classified as wetlands. This paper sets out to show how the hydrology of an ephemerally flooded doline can be characterized and how this information can be used to quantify direct recharge to underlying aquifers. The case is also made for consideration of these small ephemeral water bodies as true wetlands.

The study site for this investigation is a doline known as ***Pwll-y-Felin***, which is located near the village of Ystradfellte, southern Wales, UK [NGR 294207 212085]. Like many stream sinks, Pwll-y-Felin receives a perennial surface water inflow but its distinctive feature is that it can retain water for long enough to become frequently flooded, creating a small temporary water body (Photos 1 and 2). The doline, which is approximately 60m in diameter and 10m deep, is situated in an area of interstratal karst, on the interfluve between two major river valleys, the Afon Mellte to the west and the Afon Hepste to the east (Fig.1a, b, c, d). The term ***interstratal karst*** is commonly applied to areas where karstic rocks are present beneath less soluble covering strata (Waltham *et al.,* 1997). In southern Wales the Twrch Sandstone Formation is a widely recognized example of a less-soluble lithology that locally hosts caprock dolines and stream sinks (Farrant and Cooper, 2008). Pwll-y-Felin is situated on the edge of this interstratal karst area within the ***feather-edge zone*** in an area where only a thin layer of sandstone overlies the limestone (Fig.1e).

Photo 1: *The Pwll-y-Felin doline in full flood (03 July 2007). (Photo: Alan Bowring.)*

Photo 2: *Pwll-y-Felin after recession (13 July 2013). The entrance to the draining conduit can be seen in the top left-hand corner of the image. (BGS© NERC.)*

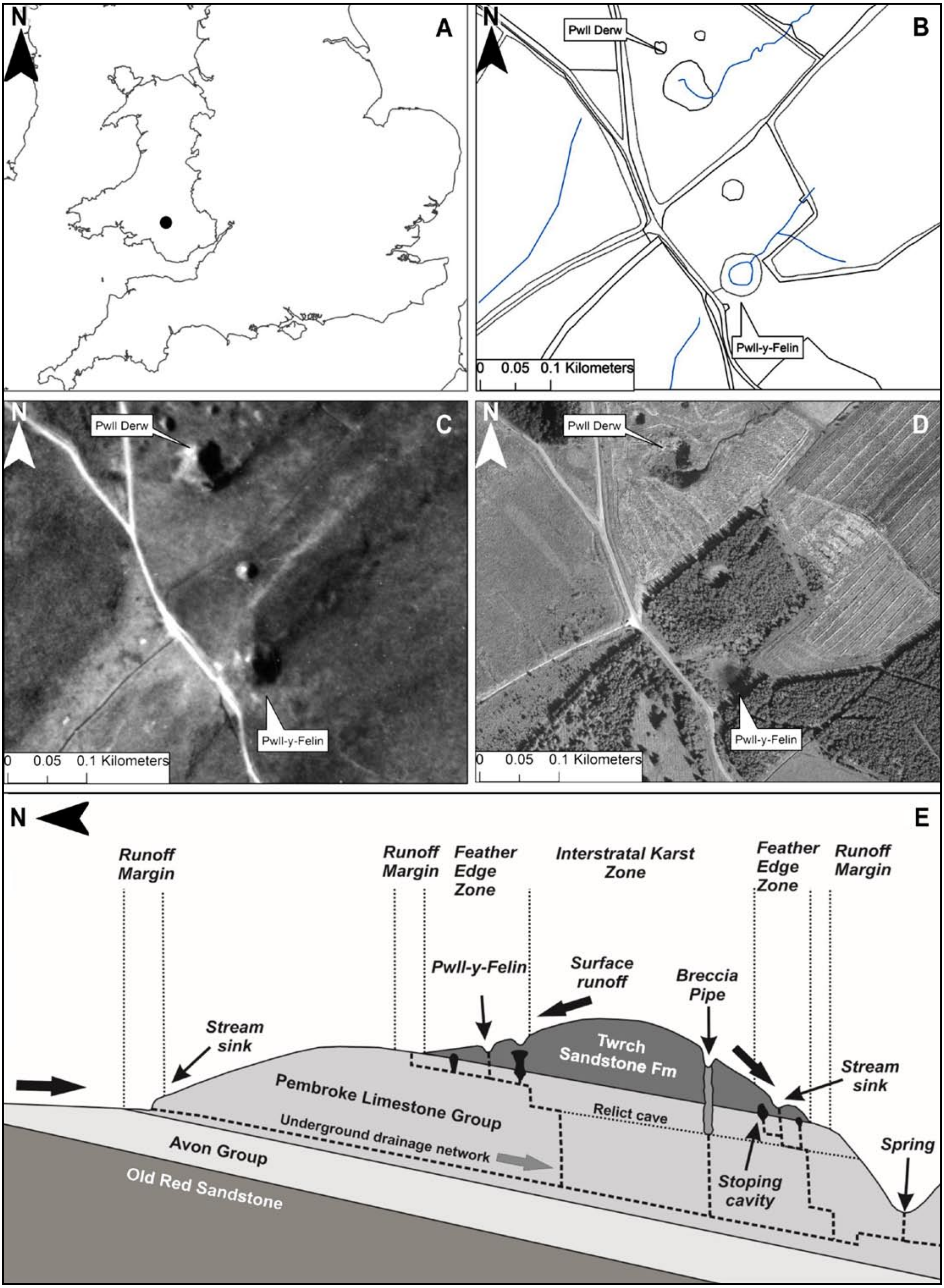

Figure 1: *Location maps and aerial photographs of Pwll-y-Felin displayed with a regional conceptual model showing the location of Pwll-y-Felin on the marginal feather edge zone of the interstratal karst.* ***A–B****: Ordnance Survey map © Crown Copyright and database rights 2015;* ***C****: Historic aerial image from Welsh Government's Aerial Photograph Unit;* ***D****: © UKP/Getmapping Licence No. UKP2006/01 and* ***E****: from Farrant and Cooper, 2008.*

The interstratal karst of southern Wales is described by Thomas (1974), who refers to Pwll-y-Felin and Pwll Derw as: "*text book examples of stream sinks lying on the Millstone Grit cover rocks"* (p.142). Many other streams sink in the area (Thomas, 1974), and Pwll Derw doline, approximately 250m north of Pwll-y-Felin (Fig.1b, c, d) is a fine example of a doline that receives a permanent stream inflow. Pwll Derw does not flood, possibly due to the absence of a substantial low permeability cover in the base of the doline or to better interconnected and developed drainage conduits. However, Pwll Derw has been dye traced successfully to the Hepste Resurgence some 2.5km to the south (Waltham and Everett, 1989). No tracer tests have been carried out from Pwll-y-Felin.

Pwll-y-Felin lies on the western edge of an upland moor area that is partially underlain by drift deposits of unknown thickness, including glacial till and peat. Bedrock geology comprises Early Carboniferous limestones of the ***north crop*** of the south Wales succession, with the lowermost Avon Group overlain by the Pembroke Limestone Group (Fig.1e). The Pembroke Limestone rocks are the main focus for cave and karst development in southern Wales and locally include the Dowlais Limestone Formation and overlying Oxwich Head Limestone Formation. North of Penderyn the Dowlais Limestone is estimated to reach 105m in thickness and is dominated by tabular-bedded dark grey bituminous, bioclastic packstone-wackstones (Barclay *et al.,* 1988; Waters *et al.,* 2009). This formation contains most of the local large cave systems including Dan yr Ogof and Ogof Ffynnon Ddu in the upper Swansea Valley. These systems currently exceed 16km and 50km in length respectively (UK Caves Database, 2016). The overlying Oxwich Head Limestone includes a lower oolitic unit and an upper unit of dark grey limestone with shelly and crinoidal grainstones; the total thickness of the formation varies laterally between 13 and 53m (Barclay *et al.,* 1988). The Pembroke Limestone Group succession is overlain by the Twrch Sandstone Formation, still commonly referred to as ***Millstone Grit***, which thins completely towards the north (Fig.1e) and forms the prominent caprock to the doline. In other dolines, such as the nearby Pwll Derw (Fig.1b, c, d), it is exposed at the surface (Thomas, 1974). The Twrch Sandstone Formation is dominated by quartzose sandstone, with common conglomeratic beds and thin mudstone-with-siltstone interbeds (Barclay *et al.,* 1988; Waters *et al.,* 2009).

Equipment and methods

A Leica Smart Rover survey tool was used to record 100 elevations from the base and sides of Pwll-y-Felin, to create a 3D surface model using Surfer10®. The model (not shown) was used to calculate Stage (m AOD) – volume (m^3) relationships defined at 5cm intervals, allowing a relationship between flood depth (stage) and volume to be formed. A Mini-Diver™ water-level logger with a 10m range, accuracy of ±0.5 cmH_2O and resolution of 0.2 cmH_2O was installed in the base of the doline to record changes in flood water levels. The Mini-Diver™ also recorded water temperature to an accuracy of ±0.1°C and resolution of 0.01°C. However, because of the open nature of the site, the logger was installed 30cm below ground level in a shallow 50mm-diameter dipwell backfilled with gravel. A Baro-Diver™ barometric pressure transducer was installed at the base of a fence post within 30m of the doline, the barometric pressure data are used to correct the data collected from the submerged Mini-Diver. The Baro-Diver™ has an accuracy of ± 0.5 cmH_2O and resolution of 0.1 cmH_2O. Both the Mini-Diver™ and the Baro-Diver™ were set to record at 30-minute intervals, collecting data from 13 July 2013 to 13 July 2014. Hourly rainfall and atmospheric temperature data were obtained from the Ogof Ffynnon Ddu climate monitoring station (Easting 285600, Northing 215200) operated by Natural Resources Wales and located about 9km to the northwest of Pwll-y-Felin. Two water chemistry samples were collected (in October and May) directly from the area of flowing water before the principal drainage conduit, with analysis performed using standard procedures described in APHA *et al.* (2005). The pH was measured using an Extech EC600 pH meter calibrated for 4.7 and 10.01. Dissolved Oxygen (DO) was measured using a Lutron PDO519 field dissolved oxygen meter. The redox potential (Eh) was measured using an Extech Exstick ORP meter. The Eh values are representative numbers of electron activities in the water sample, and show the oxidizing and reducing ability of the water sample. Electrical conductivity (EC) was measured using a portable Extech EC600 electrical conductivity meter. Alkalinity measurement was performed using a Hanna Instruments field titration kit. The bicarbonate ion (HCO_3^-) concentrations were calculated using the relationships provided in APHA *et al.* (2005). The water samples were filtered through a 0.22 µm filter and acidified with HNO_3 for cation analysis. Solids deposited on the filter medium were dissolved by 1:1 HCl to estimate the suspended iron and manganese. The acidified samples were analysed for cations using an Optima 2000-Perkin Elmer ICP-OES (Inductively coupled plasma optical emission spectroscope). The water samples filtered through 0.22µm were examined for anions (fluoride, chloride, sulphate and nitrate) using a Dionex ion chromatograph configured with hydroxyl-based anion retention column. The samples were preserved at 5ºC in the laboratory prior to analysis. Although no formal vegetation survey of Pwll-y-Felin was undertaken, selected plant identification was undertaken on species collected from known elevations and flood depths within the doline.

Photo 3: *Section through the infill sediments in Pwll y Felin. (BGS© NERC.)*

The total volume of direct recharge or drainage was estimated by measuring and combining data relating to 38 flood events that occurred over a combined duration of 161 days of the year. During the remaining 204-day period, when there was no flooding but water continued to drain into the doline, a baseline of 2 l/s was assigned. This low-flow figure was calculated from ***bucket and stopwatch*** measurements undertaken after a period of limited precipitation on 03 September 2015. This summer-low-flow value is likely to underestimate the total volume of water that drained into the sink during the 204-day period when no flooding was recorded, because it was not possible to record the upper limit of flow that could occur without flooding taking place.

Photo 4*: Water drains from Pwll-y-Felin via a discrete conduit in the base of the doline. The low-permeability glacial till deposits that line the doline can also be observed to a thickness of at least 1.5m. (BGS© NERC.)*

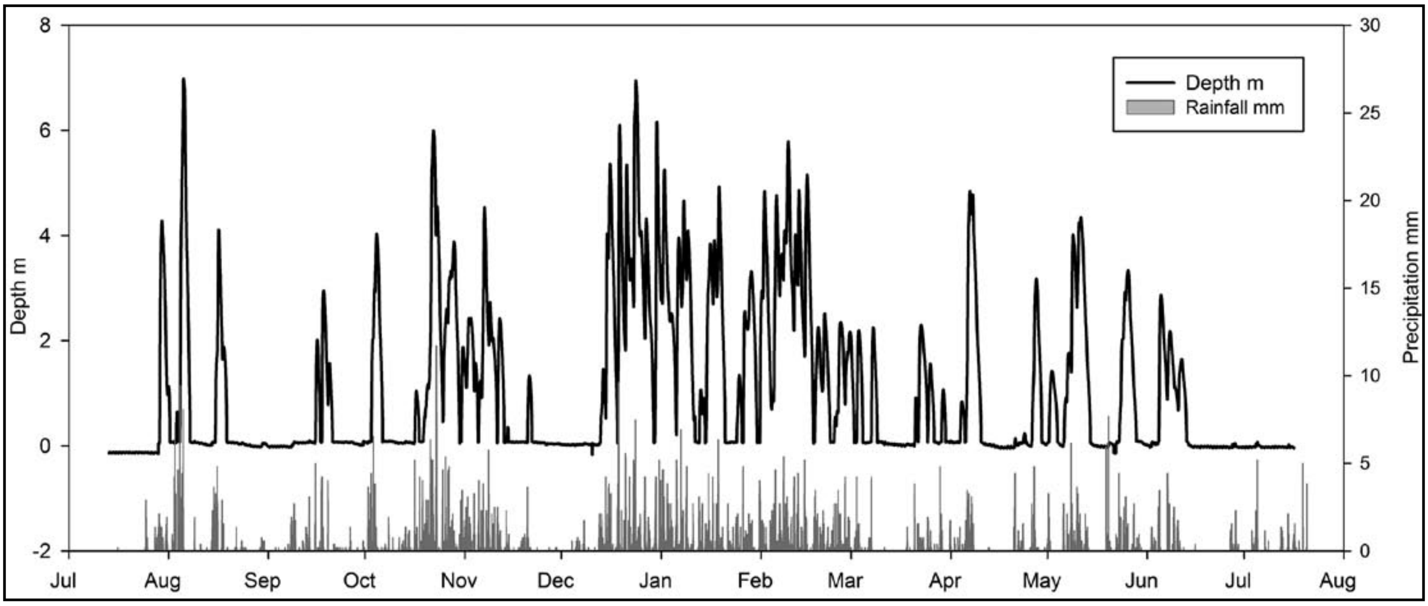

Figure 2: *Flood hydrograph and rainfall, 13 July 2013 – 13 July 2014.*

Hydrology

Pwll-y-Felin receives a permanent but variable stream inflow from the east, in addition to direct precipitation and small surface water channels around its flanks contributing to the cumulative inflow. A single stream sink in the base of the doline is the principal visible pathway controlling water loss to the underlying aquifer, with the doline filling with water only when the input is greater than the capacity of the available drainage conduit.

The surface water catchment characterized by low-intensity land-use dominated by conifer plantations is most likely constrained by the local topography, and is estimated to cover at least 2.5km^2, primarily to the east of the doline (Fig.1c, d). Local rainfall within the surface water catchment is 1683mm/year and annual effective rainfall (AER) is 1164mm/year (1961–1990 yearly average MORECS square 154).

Low permeability deposits including peat, glacial till and the Twrch Sandstone Formation ***caprock*** within the surface water catchment may enhance rapid surface-water runoff towards the doline**.** An infill of low permeability clay and a clay-rich till deposit helps to retain water within the doline. The flood hydrograph (Fig.2) recorded a maximum flood depth of 6.98m and a calculated volume of 7383m^3 that was achieved just twice during the monitoring period, during late summer (August) and winter (December) 2013. When flooded, the average depth is 2.3m, with the doline containing ~1000m^3 of water. Water levels within the doline responded rapidly to precipitation events, commonly within 24 hours. The most rapid responses occurred during winter months, when the soil-moisture deficit was low, enhancing surface runoff across the low permeability catchment and thus recharge into Pwll-y-Felin. Drainage of floodwaters within Pwll-y-Felin occurred rapidly after the cessation of rainfall. The rate of recession suggests that due to its elevation (330m AOD at its base) the doline is likely to be situated within the unsaturated zone above the local piezometric water table. There are no boreholes in the immediate area from which data can be collected to support this hypothesis but, if this is the case, then flooding would be a result of excess point recharge rather than elevated groundwater levels.

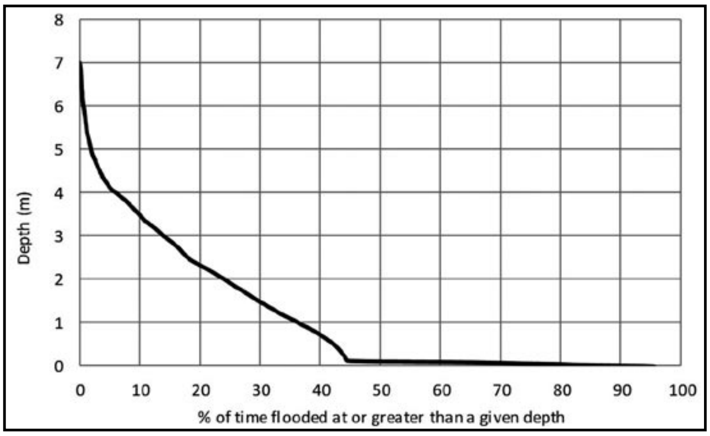

Figure 3: *Flood duration curve showing the percentage of the monitoring period (1 year) that flood levels were equal to or exceeded a given depth.*

The longest consecutive flooding events both occurred in winter: December (27 days) and January – February (18 days). The longest consecutive dry periods occurred during the summer, during August and September (27days) and June – July (30 days). The flood duration hydrograph (Fig.3) illustrates the percentage of the monitoring period (one year) that various flood depths were equalled or exceeded. Pwll-y-Felin remains dry for 56% of the year (~204 days), with flood events of various depths occurring during the remaining 44% (~161 days). The flood-duration graph shows that for 15% (~54 days) of the year Pwll-y-Felin is flooded to a depth of 3m or greater, covering the bare ground and also the marginal area where the greatest plant diversity is observed.

The stage-dependent drainage properties of the Pwll-y-Felin are illustrated by the relationship between net drainage (l/s) and flood depth (m) (Fig.4). Importantly, the net drainage (l/s) is inferred from negative net changes in the volume of water retained in Pwll-y-Felin and not from gauging of flow into or out of the doline. It is due to this approach, converting volumetric changes into net drainage, that there appears to be such a large range of net drainage values at any given depth. For instance at 3m depth the net drainage appears to change from 0 l/s to 35 l/s. It is unlikely that the lower net drainage values are accurate as these ultimately represent minimal or no changes in volume rather than an actual reduction of the outflow, which occurs continually as long as there is inflow to Pwll-y-Felin. The data allow a characteristic stage-discharge curve to be inferred by the maximum outflow values across the flooding range, a similar approach to that undertaken for several Irish turloughs (Naughton *et al.,* 2012). One notable feature is that the stage-discharge curve appears to increase rapidly once above 4m depth (333.5m AOD). Whereas the specific mechanisms for this rapid increase in net drainage are not fully understood, two possible hypotheses are:

1) rising flood levels cause the partial and then full activation of additional conduits within the underlying bedrock, allowing a greater drainage capacity during extreme flooding events;
2) as water levels rise they are able to engage with other hidden conduits around the margin of the doline situated above the level of the low-permeability clay infill.

An initial conceptual model (Fig.5) illustrates the principal inflow and the proposed pathways for drainage as described above. During visits to Pwll-y-Felin (between 2012 and 2015) it was noted that there has been localized enlargement of the area around the main drainage conduit, with associated collapse and erosion of the low-permeability infill material. To date this loss of material has not resulted in the blockages of any conduits or inhibited Pwll-y-Felin from draining. However, should the erosion and loss of the low-permeability infill continue and new drainage conduits become exposed in the underlying bedrock, then it is possible that net outflow could become greater than net inflow and the ephemeral flooding regime of the doline could cease to occur. Pwll-y-Felin might then enter an erosional phase, with the loss of its infill material, or conversely become permanently flooded if the drainage conduits become infilled.

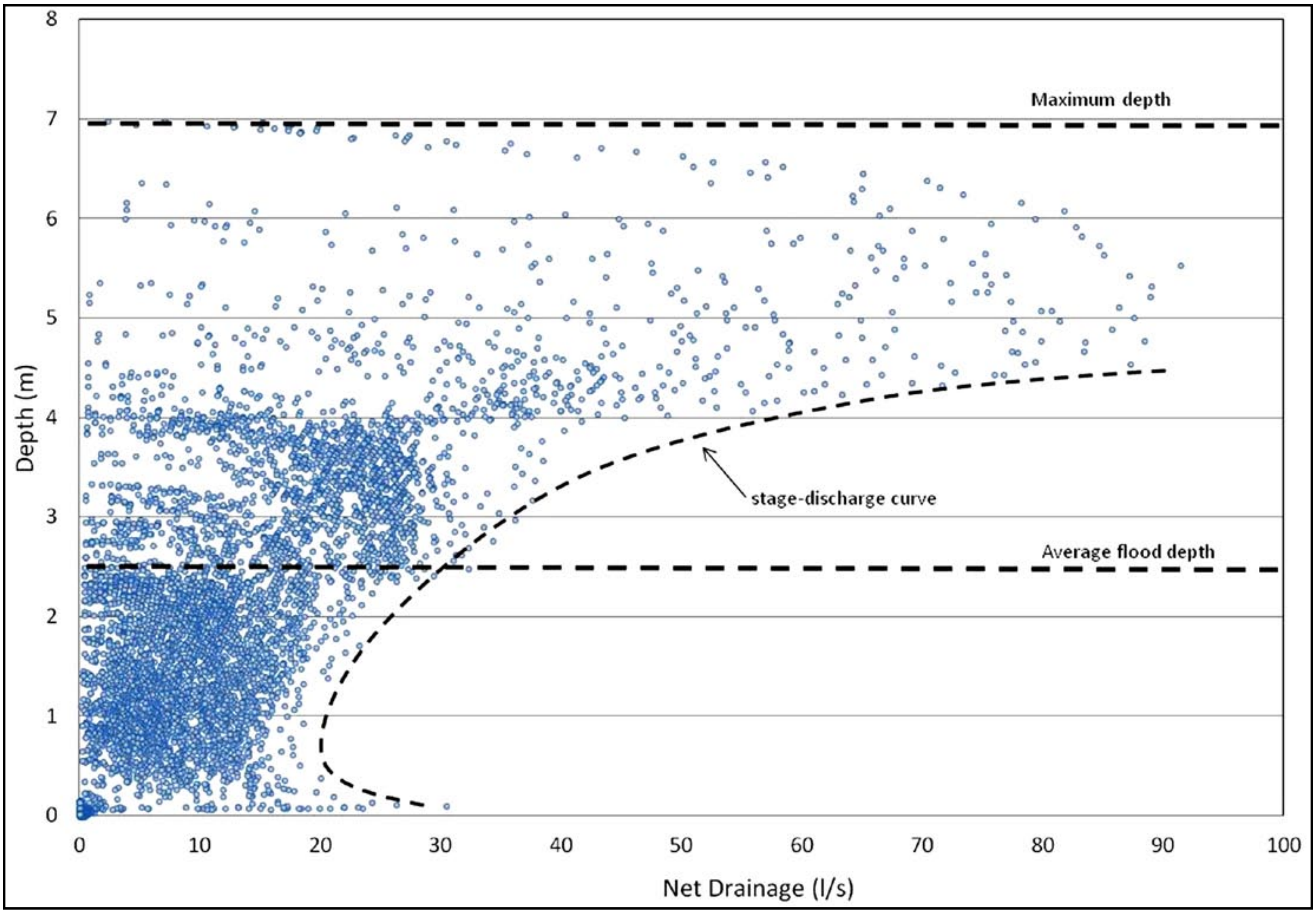

Figure 4*: Drainage capacity of Pwll-y-Felin showing increased drainage when water levels submerge the drainage conduit in the base of the doline.*

A conservative estimate of the total volume of direct recharge to the underlying aquifer can be calculated from the addition of the maximum volumes of 38 separate flood events recorded during 161 days of the survey, suggesting that at least 103 ML of water was lost to the aquifer. The remaining 204 days where no flooding occurred, but when the inflow to the sink continued, were assigned a conservative summer low-flow value of 2 l/s or 35 ML/year. The amount of water lost to ground during the one-year study period is estimated at a minimum of 138 ML/year or an annual average of 4 l/s, the volume of which could vary greatly during flood conditions as indicated by the stage discharge graph (Fig.4). If outflow is assumed to occur at the rate defined by the maximum outflow values across the flooding range, as given by the stage-discharge curve, the water lost to the aquifer during flooded periods equates to approximately 453 ML/year, rising to 489 ML/year assuming a low-flow value of 2 l/s.

Water chemistry

Temperature was recorded by the same logger used for collecting water level data. The logger was installed 30cm below the surface of the doline floor and so, as a result of this, the open-water temperature was not measured. However, this near-surface temperature in the base of the doline displayed a seasonal trend varying between 17.4°C (July) and 3.5°C (November) with an average of 8.9°C close to that of the local average annual air temperature of 8.5°C. It was not possible to measure the water temperature above the doline floor surface continually because of the open nature of the site. Field observations (12 December 2012 and 14 December 2012) have shown that the surface layer of water in Pwll-y-Felin can freeze, forming a sheet of ice that then collapses as water levels recede.

Water quality samples (Table 1) were collected from the main inflow stream into Pwll-y-Felin (Photo 2). The water is of Na–SO_4 type, unevolved and low in dissolved ions, and representative of water derived from recent rainfall within the immediate surface-water catchment. The water samples exhibit an acidic pH range that can be derived either from organic acids in the peat or/and by high $CO_{2(g)}$ dissolution. The atmospheric $CO_{2(g)}$ is likely to be dissolved more in cold water than in hot water, and under low pH conditions $CO_{2(g)}$ becomes carbonic acid rather than dissociated to bicarbonate. Thus the solubility of $CaCO_3$ in natural

Date	15 October 2013	21 May 2014
Temperature °C	10.0	11.7
pH	6.7	5.13
Eh V	0.23	0.228
Electrical conductivity (uS/cm)	37.9	34.5
TDS (mg/l)	24.6	22
$O_{2(aq)}$ (mg/l)	10	8.9
Carbonate alkalinity (mg/l as $CaCO_3$)	<10	15
HCO_3^- (mg/l)	0	18
Ca^{2+} (mg/l)	1	1
Na^+ (mg/l)	3.5	4.9
K^+ (mg/l)	0.33	0.14
Mg^{2+} (mg/l)	0.51	0.41
Mn^{2+} (mg/l)	0.072	0.016
Fe^{2+} (mg/l)	2.05	0.95
Fe^{3+} (mg/l)	0.013	0.38
Al^{3+} (mg/l)	0.02	0.19
Zn^{2+} (mg/l)	0.002	0.2
F^- (mg/l)	0.35	0.04
Cl^- (mg/l)	5.1	7.97
SO_4^{2-} (mg/l)	8.5	11.18
Water type	Na–SO_4	Na–SO_4
Saturation Index		
Calcite	−3.81	−6.16
Aragonite	−3.98	−6.32

Table 1: *Water quality analysis of autumn (15 October 2013) and summer (21 May 2014) inflow to Pwll-y-Felin.*

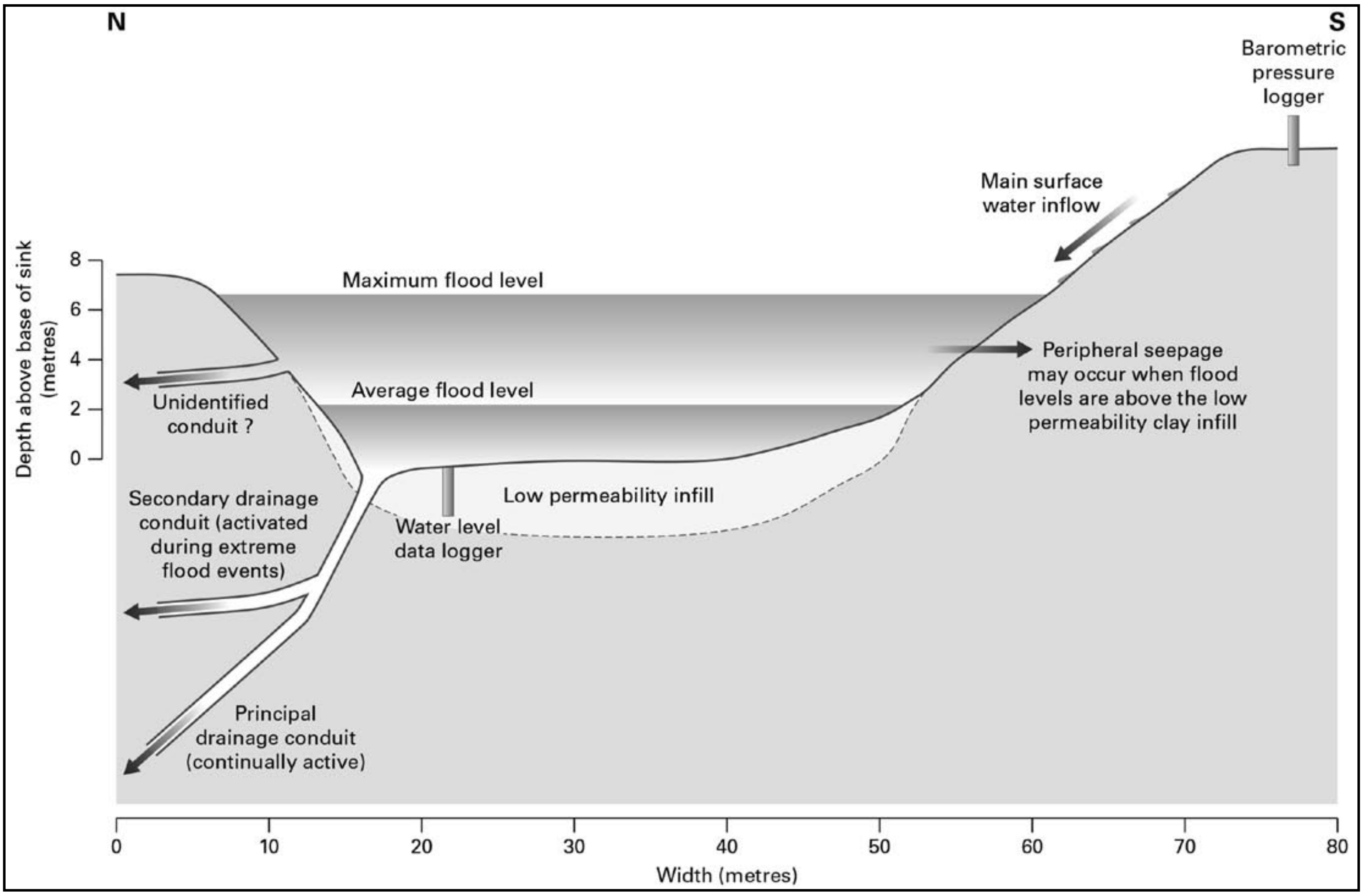

***Figure 5:** Initial hydrological conceptual model.*

water increases under lower temperature conditions. The limestone dissolution can be described by the reaction (Krauskopf and Bird, 1995) $CaCO_3 + H_2CO_3 \Leftrightarrow Ca^{2+} + 2HCO_3^-$. Under most natural conditions dissolution of calcium carbonate is more likely to be induced by weak acids such as carbonic acids (from atmospheric $CO_{2(g)}$ dissolution) rather than strong acids. The saturation indices of the water samples (Table 1) show that the water samples are under-saturated in terms of calcium minerals and would be aggressive within the underlying limestone aquifer. The water quality analysis also complements interpretation of the hydrograph: supporting the theory of a rapid response to precipitation events from locally sourced surface runoff.

Vegetation

Plant species from the base, margins and sides of the doline were collected and identified. The base of Pwll-y-Felin is dominated by partially bare ground comprising glacial till. The presence of bare ground suggests that periods of submergence might be long enough to prevent establishment of a full coverage of plant species, but not persistent enough to allow aquatic plant communities to form. The margins of the doline lying above the bare ground but below the average flood depth are more diverse and are characterised by the occurrence of species that can withstand permanent or frequent periodic flooding. Bryophytes, including *Sphagnum denticulatum* and *Warnstorfia fluitans,* are classic acid bog-edge species and can withstand partial or total submergence (Jonathan Graham, *pers. comm.*). One liverwort species, *Gymnocolea inflata,* was recorded from the edge of the bare ground, along with *Persicaria hydropiper* (water pepper). *Juncus bufonius* (toad rush) is also abundant in the basal part of the doline. *Carex rostrata* (bottle sedge) is abundant locally in the base of the doline and more so along the margins of the bare ground. Also colonizing the margins of the doline from the surrounding grassland at higher elevation are *Carex nigra* (common sedge) and *Agrostis stolonifera* (creeping bent). *Molinia caerulea* (purple moor grass) dominates the edges of the doline.

Vegetation in large ephemeral karst-dependant water bodies such as turloughs has been well documented, commonly showing zonation related to flood depth and water chemistry within the turlough basin (e.g. Blackstock *et al*., 1993). The vegetation found in Pwll-y-Felin is less diverse than that described in turloughs, and only limited vegetation ***zonation*** related to flood depth and frequency was observed within the doline. Use of the flood depth cumulative frequency curve allows description of the flood duration that can be tolerated by selected species within the doline (Table 2), suggesting that flood depth and duration may influence the presence or absence of certain species. Whereas water depth provides one possible control on the occurrence of plant species within Pwll-y-Felin, other factors such as soil, slope, aspect and localized water seepages might also be limiting factors.

	Species	Setting	Occurrence above base of doline (m)	Maximum Flood Depth (m)	Flood Duration (% of year)
Bryophytes	*Sphagnum denticulatum*	Marginal	1 – 2	4 – 6	20 – 40
	Warnstorfia fluitans	Marginal	1 – 2	4 – 6	20 – 40
	Mnium hornum	Marginal	1 – 2	4 – 6	20 – 40
Sedges and lower plants	*Persicaria hydropiper*	Marginal	1 – 2	4 – 6	20 – 40
	Juncus bufonius	Base of doline	<1	7	40
	Carex rostrata	Marginal	1 – 2	4 – 6	20 – 40
	Carex nigra	Marginal, edges and surrounding grassland	0 – 7+	0 – 6	0 – 40
	Agrostis stolonifera	Marginal	1 – 2	4 – 6	20 – 40
	Molinia caerulea	Very common on edges of doline	0 – 7+	0 – 6	0 – 40
Liverwort	*Gymnocolea inflata*	Marginal	1 – 2	4 – 6	20 – 40

***Table 2:** Setting, occurrence and flood duration for selected plant species.*

Classification of ephemerally flooded dolines as wetlands

It is useful to consider the classification of Pwll-y-Felin within both karst and wetland terminology. The latter is important in order to raise the profile of these sites in terms of their habitat potential, and hopefully to afford more protection to the important sites. Firstly, by applying karst terminology Pwll-y-Felin can be described as a caprock doline with a sinking stream that results in ephemeral flooding. However, long periods of flooding require that Pwll-y-Felin must also be considered as a wetland. Article 1.1 of the ***Ramsar Convention on Wetlands*** (Ramsar, Iran, 1971) defines wetlands as: *"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt"*. The Ramsar classification system provides a category for ***seasonal pools,*** into which Pwll-y-Felin and many other small temporary karst pools in the UK could be incorporated. To date, only the larger seasonal pools or ephemeral karst-dependent wetlands, such as turloughs and meres, have received substantial investigation. Ramsar guidelines indicate that small, temporary, pools should be designated as wetlands and that their ephemeral nature, and commonly small size, lead to under representation (Ramsar, 2002), a concern that is shared by the European Environment Agency (2009).

Conclusions

This study has provided the first annual hydrograph from an ephemerally flooded doline in the UK. The method described provides a simple approach to quantify direct recharge from ephemerally flooded dolines, and can be used to gain a better understanding of recharge processes in karst aquifers. This method will also help to improve understanding of water balances in karst aquifers by providing better information on direct recharge via dolines.

In Pwll-y-Felin the flooding regime is strongly related to periods of localized precipitation, with the time lags between rainfall and the increase in flood depth commonly less than 24 hours. During flood periods the average water depth in Pwll-y-Felin is 2.3m and the doline contains about 1,080 m^3 of water. However, more intense precipitation events can result in water depths reaching nearly 7m, at which times the doline contains 7,383m^3 of water. Recession of water levels occurs rapidly during periods of reduced precipitation; although the inflow stream continues to flow, it sinks and flooding is not caused until the next rainfall event. This responsiveness results in a very 'flashy' flood hydrograph. The maximum period of continual flooding was 27 days, and the most prolonged dry period was 30 days. Flood depths >3.5m were associated with more rapid drainage of 40–90 l/s. Flood depths <3.5m are associated with lower drainage rates <40 l/s with the average drainage during the year being 7 l/s. During the year of the study it was estimated that at least 138 ML of water was lost to the underlying aquifer.

The acidic $Na–SO_4$-type waters are low in dissolved ions, also supporting the conceptual understanding of recharge via localized surface runoff. The base of the doline is dominated by bare ground, primarily clay and sandy clay and a marginal zone related to the most frequent flood depths (0 – 2.3m) is characterized by plant species that can withstand permanent or frequently repeated flooding. Pwll-y-Felin can be described using karst terminology as a caprock doline with a stream sink, and using wetland terminology as a temporary or ephemeral freshwater karst pool. In the UK little is known concerning the ecological significance of ephemerally flooded dolines, and their classification as true wetlands has not fully been realized.

Future research should focus on hydrological monitoring of similar ephemeral karst features to improve the understanding of recharge in limestone aquifers. This could be especially useful in quantifying the volume of recharge in areas where groundwater is used for human consumption, including karst groundwater Source Protection Zones and Safeguard Zones delineated around public water supplies. To help protect these ephemeral and commonly under recorded sites more effectively, research is needed to record temporary and permanent karst water bodies in the UK and to characterize their hydrology. Ecological surveys should identify plant species that are adapted to, dependent upon, or exclusive to, ephemeral hydrological regimes, to improve understanding of zonation within dolines and the tolerance of different species to flood depth and duration. Invertebrate and vertebrate surveys could identify animal species that specialize to the fluctuating hydrological regime. Water chemistry baseline surveys would provide information to characterize these habitats more clearly, while also improving knowledge of the chemistry of water that flows into cave systems and recharges aquifers.

Many of these small ephemeral karst pools are nameless and understudied in terms of their hydrological and ecological functioning and classification. A survey of dolines on Mynydd Llangynidr (Gunn, 2012) includes initial observations on dolines that either retain water or act as stream sinks. Examples of more well-known sites that could warrant further hydrological and ecological classification include; the Cascade Sink (Easting 317682 Northing 215283) and Llyn y Garn Fawr, Mynydd Llangynidr, South Wales (Easting 312659 Northing 214925).

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