Journal of Hydrology 548 (2017) 801–817

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

# Demonstrating the value of community-based ('citizen science') observations for catchment modelling and characterisation

Eleanor Starkey [a,*], Geoff Parkin [a], Stephen Birkinshaw [a], Andy Large [b], Paul Quinn [a], Ceri Gibson [c,1]

[a] School of Civil Engineering and Geosciences, Newcastle University, Newcastle upon Tyne NE1 7RU, UK
[b] School of Geography, Politics and Sociology, Newcastle University, Newcastle upon Tyne NE1 7RU, UK
[c] Tyne Rivers Trust, Unit 8, Shawwell Business Centre, Corbridge, Northumberland NE45 5PE, UK

ARTICLE INFO

*Article history:*
Received 13 August 2016
Received in revised form 30 November 2016
Accepted 10 March 2017
Available online 18 March 2017
This manuscript was handled by G. Syme, Editor-in-Chief, with the assistance of M Smith, Associate Editor

*Keywords:*
Community-based
Citizen science
Monitoring
Flash flood
Hydrological modelling
SHETRAN

ABSTRACT

Despite there being well-established meteorological and hydrometric monitoring networks in the UK, many smaller catchments remain ungauged. This leaves a challenge for characterisation, modelling, forecasting and management activities. Here we demonstrate the value of community-based ('citizen science') observations for modelling and understanding catchment response as a contribution to catchment science. The scheme implemented within the 42 $km^2$ Haltwhistle Burn catchment, a tributary of the River Tyne in northeast England, has harvested and used quantitative and qualitative observations from the public in a novel way to effectively capture spatial and temporal river response. Community-based rainfall, river level and flood observations have been successfully collected and quality-checked, and used to build and run a physically-based, spatially-distributed catchment model, SHETRAN. Model performance using different combinations of observations is tested against traditionally-derived hydrographs. Our results show how the local network of community-based observations alongside traditional sources of hydro-information supports characterisation of catchment response more accurately than using traditional observations alone over both spatial and temporal scales. We demonstrate that these community-derived datasets are most valuable during local flash flood events, particularly towards peak discharge. This information is often missed or poorly represented by ground-based gauges, or significantly underestimated by rainfall radar, as this study clearly demonstrates. While community-based observations are less valuable during prolonged and widespread floods, or over longer hydrological periods of interest, they can still ground-truth existing traditional sources of catchment data to increase confidence during characterisation and management activities. Involvement of the public in data collection activities also encourages wider community engagement, and provides important information for catchment management.



## 1. Introduction

Under future climate change scenarios, wetter winters and more intense summer storms are expected to exacerbate already complex catchment management issues throughout the UK and western Europe (Chan et al., 2015; Forzieri et al., 2016; Kendon et al., 2014). Empirical data is therefore required to characterise catchment behaviour over time, model floods, improve forecasts and subsequently enhance community resilience as part of the wider catchment management process. The importance of meaningful data is further emphasised when considering the performance of new flood management interventions such as 'natural flood management' (Nicholson et al., 2012; SEPA, 2015). The potential benefits of engaging, collaborating and actively involving local communities within affected catchments is also rapidly being

*Abbreviations:* AE, Actual Evaporation; AWS, Automatic Weather Station; BADC, British Atmospheric Data Centre; CB, Caw Burn; HB, Haltwhistle Burn; Ks, Saturated Hydraulic Conductivity; NSE, Nash-Sutcliffe Efficiency; PGB, Pont Gallon Burn; P, Precipitation; PBIAS, Percentage Bias; PBSD, Physically-based spatially-distributed; PE, Potential Evapotranspiration; Q, Discharge; Q*obs*, Observed Discharge; Q*sim*, Simulated Discharge; RLGB, River Level Gauge Board; RMSE, Root Mean Square Error; $R^2$, Coefficient of Determination; SD, Soil Depth; SOF, Strickler Overland Flow; TRT, Tyne Rivers Trust.

* Corresponding author.
*E-mail address:* eleanor.starkey@ncl.ac.uk (E. Starkey).
[1] Present address: The Freshwater Biological Association, The Ferry Landing, Far Sawrey, Ambleside, Cumbria LA22 OLP, UK.

http://dx.doi.org/10.1016/j.jhydrol.2017.03.019
0022-1694/© 2017 The Authors. Published by Elsevier B.V.

recognised as a vital component of an integrated catchment management toolkit (Bracken et al., 2014; Large et al., 2017).

Despite the UK having some of the world's most reliable and dense hydrometric and meteorological monitoring networks, data remains scarce for many rural catchments (Buytaert et al., 2016; Illingworth et al., 2014; UK Met Office, 2010). A variety of methods are used for observing and/or estimating spatial rainfall patterns (Bárdossy and Pegram, 2013; Durkee, 2010; Lanza et al., 2001; Shaw et al., 2011) but data availability and accuracy issues still persist on a local level. There are a number of issues; catchments are spatially and temporally complex, and flash floods, while of particular interest and importance to both hydrologists and communities, are hard to characterise given that they are rare, spatially localised, short lived and often occur in locations without formal monitoring (Archer and Fowler, 2015; Archer et al., 2016; Perks et al., 2016).

The absence of whole-catchment data can complicate the catchment modelling process (Seibert and McDonnell, 2015), especially when attempting to replicate or predict extreme events in unique locations. While workers like Zhu et al. (2013, 2014) describe how rainfall radar observations are becoming more readily available, providing improved spatial and temporal coverage in hydrological models, errors relating to timing and magnitude can propagate through the modelling process (Harrison et al., 2000). Good quality and detailed ground-based observations are therefore required to create robust models (Beven, 2009; Beven and Westerberg, 2011; Vidon, 2015). Through incorporation of such observations, the improved predictive power of the model will then play a significant role in influencing choices made by stakeholders in the catchment characterisation and management process.

The co-production of 'indigenous' knowledge and the activity of community-based monitoring (and related activities described in the literature using a range of terminology including citizen science, volunteered geographical information (VGI), crowd-sourcing, citizen observatory and participatory monitoring) is rapidly expanding (Follett and Strezov, 2015; Pocock et al., 2014; Wentworth, 2014). The term used depends on the degree of 'volunteer' involvement and the specific techniques adopted, but in general they all refer to the participation of the public (i.e. non-professionals) in the generation of new knowledge about the natural environment (Buytaert et al., 2014; Pocock et al., 2014; Starkey and Parkin, 2015). Regardless of which term is used, encouraging general engagement, participation and empowerment on a local level means that the public have the potential to offer timely and low-cost solutions to the data collection phase in catchment science. Social benefits to the community are also valuable, supporting policies and management frameworks which increasingly request an integrated and bottom-up approach to catchment management. A relevant example includes the emerging 'Catchment Based Approach' (CaBA, 2016) which has surfaced from the EU Water Framework Directive and is managed in the UK by Defra, the Department of Environment, Food and Rural Affairs.

The growth in more readily available and low-cost technologies, such as smartphones, social media and the internet itself, is allowing community-based initiatives to grow rapidly. Areas include biodiversity (Sutherland et al., 2015), weather and climate (Burakowski et al., 2013; Muller et al., 2015) and disaster management (Aulov and Halem, 2012). Across North America the public are collecting regular rain, hail and snow observations and sharing them with the national CoCoRaHS network (http://www.cocorahs.org/), and a similar scheme is also active primarily across Europe, North America and Australia through the UK Met Office 'Weather Observations Website' (http://wow.metoffice.gov.uk/).

It is only recently that this type of data collection activity has started to flourish in hydrology and hydrogeology, for example, in Ethiopia (Walker et al., 2016). Only a few examples exist in the UK which specifically collect river and flood observations with some form of public involvement, for instance the Wesenseit (http://wesenseit.eu/) and Oxford Flood Network (http://flood.network/). Even fewer studies have explored the potential value of this data to support real hydrological applications, including catchment modelling, primarily due to data quality concerns or general lack of recognition (Buytaert et al., 2014, 2016; Muller et al., 2015). Only a small number of studies have made use of crowd-sourced data to validate their models, but they frequently discarded multiple observations as location, date and time stamps were absent (Fohringer et al., 2015; Kutija et al., 2014; Mazzoleni et al., 2015; Smith et al., 2015). In addition, these studies either involved 'reactive' data collection methodologies following large floods or used synthetic data to imitate citizen science, thus did not actually involve or even engage with the public. Full engagement is essential if ongoing community-based monitoring schemes are to be relied upon by professionals and regularly harnessed as an additional source of catchment information. Nevertheless, scientists and engineers are still generally reluctant to integrate this type of data into their work, which Barthel et al. (2016) attributes to professionals not being experienced enough to actually carry out the full range of participatory activities required. This includes engagement, facilitation, training and dissemination activities which are all prerequisites of successful community-based monitoring schemes.

This paper presents results from a catchment study which demonstrates the value of community-based observations for understanding and modelling spatial and temporal catchment response, including the ability to capture the shape, timing and magnitude of flood peaks for a sequence of flash flood events. Data quality issues are a particular concern with 'citizen science' studies and we take this into account by applying appropriate data quality checks before allowing further use of the data in the modelling process. The modelling results presented also infer additional information about the quality of the observations used. Walker et al. (2016) concluded that data quality from community-based observations can be of high quality if they are properly managed. Our study takes this approach a step further as it is one of the first assessments which embeds real community-based observations into a detailed catchment modelling study. To achieve this, work has been carried out on the Haltwhistle Burn catchment, a tributary of the River Tyne in northeast England, where a physically-based, spatially-distributed hydrological catchment model, SHE-TRAN (Ewen et al., 2000), has been used. The findings will be of interest to catchment managers, hydrologists, as well as community and environmental groups who have a common interest in holistic catchment management and who wish to expand their management toolkits.

## 2. Study area & focus community

Known for being located in the 'Centre of Britain', the 42 $km^2$ steep and low stream order Haltwhistle Burn catchment responds rapidly to heavy rainfall. This predominantly rural catchment suffers from multiple pressures (Fig. 1) and in recent years it has experienced a number of floods, including 2007, 2012, 2014 and winter 2015/2016. Flood risk is exacerbated as the main impact zone (the town of Haltwhistle) is located at a 'pinch-point' close to the outlet, and just downstream of an incised gorge section. The elongated shape of the catchment and resulting river network have also been influenced by the igneous Whin Sill outcrop which intersects this area.

Rivers Trusts exist across the UK and aim to enhance their local river basin with the help of volunteers and communities through their charitable objectives. Tyne Rivers Trust (TRT) led an