Article:

Sefton, C., Sharp, L. orcid.org/0000-0002-1611-9239, Quinn, R. et al. (2 more authors) (2022) The feasibility of domestic raintanks contributing to community-oriented urban flood resilience. Climate Risk Management, 35. 100390. ISSN 2212-0963

https://doi.org/10.1016/j.crm.2021.100390

Climate Risk Management 35 (2022) 100390

Contents lists available at ScienceDirect

Climate Risk Management

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

The feasibility of domestic raintanks contributing to community-oriented urban flood resilience

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ARTICLE INFO

Keywords:
Raintank
Urban Flood Resilience
Community
Action research
Stormwater
Engagement

ABSTRACT

This interdisciplinary study investigates the technical and social feasibility of developing a domestic raintank programme to increase urban flood resilience. Hydrological modelling of different types of tank was used to determine the advantages and disadvantages of different models in controlling runoff. Qualitative socio-cultural interviews with local people revealed that raintanks were broadly acceptable to the local community. However, interviews with representatives from flood authorities suggest that resource constraints and technocratic industry norms focused on physical flood risk mitigate against consideration of a raintank programme. Our research suggests that there are transformative advantages to a more community-oriented approach to flood resilience, particularly the potential to change the relationship between the public and flood authorities away from a traditional model that pictures the former as passive, towards a process of mutual learning and two-way communication. Our research illustrates that this is not merely a matter of 'good practice', but a shift that can produce new practical solutions that a technical perspective alone cannot reveal.

1. Introduction

Urban flooding is expected to become more severe over the coming decades, as a consequence of both urbanisation and increased rainfall intensity associated with climate change (Miller and Hutchins, 2017). Heavy rain has a direct impact on homes and streets, but can also cause damage indirectly, when combined sewers become overwhelmed and dilute sewage overflows into rivers, streets, or homes (Mason et al., 2019). In England, JBA Consulting (2018) estimate that 2.5 million households are at risk of surface water flooding, with expected annual damages of £300 million. Figures from 2014 to 15 suggest that there were 4.2 incidences of internal sewer flooding and 2 incidences of hydraulic flooding in England and Wales every single day (PWC, 2015).

Existing adaptations to urban flooding are insufficient (Guerreiro et al., 2018). In 2019, the UK Committee on Climate Change rated urban flooding as one of the UK's more urgent adaptation priorities, suggesting that many surface water management plans are low quality, and only medium progress has been made towards risk reduction (CCC, 2019: 15). Most existing interventions to manage urban flood risk involve increasing storage capacity through the construction of additional infrastructure, either underground or through surface features such as Sustainable Drainage Systems (SuDS). SuDSs help to avoid peaks in sewer and river flow by retaining

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https://doi.org/10.1016/j.crm.2021.100390
Received 28 November 2020; Received in revised form 1 December 2021; Accepted 22 December 2021
Available online 23 December 2021

water for consumption, releasing it to the ground for infiltration and evapotranspiration, and/or detaining it for later release to the sewer.

Domestic raintanks (or 'water butts' as they are known in the UK) have long been used as a means of irrigating gardens, and are increasingly a feature of domestic supply in areas of water scarcity globally (Sofoulis, 2011; Woelfle-Erskine, 2015). The potential for raintanks to function like SuDS, managing urban rainfall and supplying water, is well understood (Zhang et al., 2012; Woods-Ballard et al., 2015; Butler, 2018; Quinn et al. 2020). In 2018, we began discussions with UK water utility managers about whether domestic raintanks could offer such additional water storage capacity, mitigating urban flood risks.[1] These conversations revealed two sets of concerns, one technical, the other social. Firstly, the timing of water supply and demand created practical problems: put simply, for a raintank to help prevent flooding, it needs to be empty at the start of a storm event. Water managers felt that this could not be guaranteed for many domestic raintanks, particularly in the UK's wet winters. Secondly, widespread participation would be needed for raintanks to have any impact on flood risk, raising questions about the public's desire to participate in such a programme.

These two questions are explored together in this paper. Conventionally, they would be separated, with a technical paper investigating the hydrological functionality of tanks and a social paper investigating the acceptability of water tanks to the public, and the cultural factors promoting or hindering their uptake. However, this paper explicitly contends that there are advantages to approaching these questions *together*, in that innovative new practical and intellectual approaches can emerge via such a transdisciplinary approach.

The research presented here was conducted as part of the Mobilising Citizens for Adaptation (MOCA) project, running for 18 months between January 2019 and June 2020. Our research methodology made ground-breaking use of action research which "involves researchers and other stakeholders ('co-inquirers') in critical and relational processes aimed at collaboratively producing scientifically and socially relevant knowledge and transformative action" (Bartels and Wittmayer, 2018). We worked with the flood authorities, as major stakeholders, to frame the project, select case studies, steer progress, and refine results. However, we also recruited case study communities as co-inquirers, drawing on their contributions to refine our findings and select means of local dissemination. This dual collaboration makes our project unique in the growing body of action research on sustainability. Furthermore, by exploring the social factors that enable and constrain community engagement in flood resilience, we are able to offer innovative suggestions regarding the organisation of such collaborations, which have relevance for future practice in water management and beyond.

2. Reviewing the problem: Types of tank and types of resilience

Many UK households already have ***Simple*** raintanks filled from downpipes and emptied periodically to irrigate gardens. This configuration offers limited benefits for flood storage because the raintanks are often full at the times when capacity is needed, particularly in the UK's cool wet winters, when water demand for gardening is low. However, alternative types of raintank can address this issue, including ***Dual*** systems, which slowly discharge stored water to the sewer (or to a raingarden), and ***Active*** systems which release water ahead of forecast storms, for example through smart technology or manual emptying (Fig. 1).

Dynamic modelling enables researchers to investigate the most effective type of tank to increase physical storage for flood mitigation. It models the changing volume of water in raintanks through storm events, taking account of antecedent conditions, inputs (the area of roof drained and the anticipated rainfall intensity), and outputs (overflows and demand for and/or draining of water) (Zhang et al., 2012). Previous studies investigating the impact of decentralised green infrastructure (rain gardens and rainwater harvesting tanks) found that they delivered either small but significant (Shuster & Rhea, 2013) or moderate improvements (Jarden et al., 2016) to runoff rate. The greater outflows enabled by ***Dual*** and ***Active*** tanks mean that they should deliver better outcomes for rainfall retention capacity than ***Simple*** tanks.

However, we also wanted to consider the social acceptability and utility of each type of tank to homeowners. We were particularly interested in whether ***Simple*** systems could be converted into ***Active*** ones via a communications system that would tell homeowners to empty the raintank in advance of a storm. Such a system, however, would rely on individual citizens taking action in order to contribute to collective flood resilience, suggesting a reformulation of the relationship between flood authorities and the public. Traditionally, flood mitigation has tended to be pictured as the sole responsibility of flood authorities, who undertake technical projects focused on the design, construction, and operation of infrastructure such as flood walls and drainage in order to reduce physical flood risk. These efforts are communicated in a top-down fashion with a public who are pictured as passive (Wamsler, 2016). Our model would shift this towards a wider community-oriented conceptualisation of resilience, characterised by a) interactive communication between authorities and publics b) coordinated actions between authorities, civic society organisations, and publics and c) an empowered, mutually trustful and motivated community.

Theoretically, this shift should not be alien for flood authorities. The responsibilities ascribed to urban flood managers by policy makers and academic commentators have broadened over the past two decades, moving beyond management of technical risk to include activities like the promotion of raintanks. Much has been written on the growth of a new concept of 'resilience' in which flood mitigation, the absorption of flooding shocks, and recovery after disaster and disturbance are encouraged via a sharing of responsibilities between authorities, civic society and an actively engaged general public (Johnson and Priest, 2008; Butler and Pidgeon, 2011; Challies et al., 2016). In such a model of flood prevention and preparedness, the public are encouraged to "take responsibility for their own flood risk" (McClymont et al., 2020, p. 1166–1167), though this change of emphasis is controversial, since it moves

[1] The discussion occurred at the Twenty65 Leadership Board on 23rd October 2018 and included contributors from Welsh Water and Northumbrian Water Limited, among other water companies and academics. The meeting minutes do not cover the discussion.

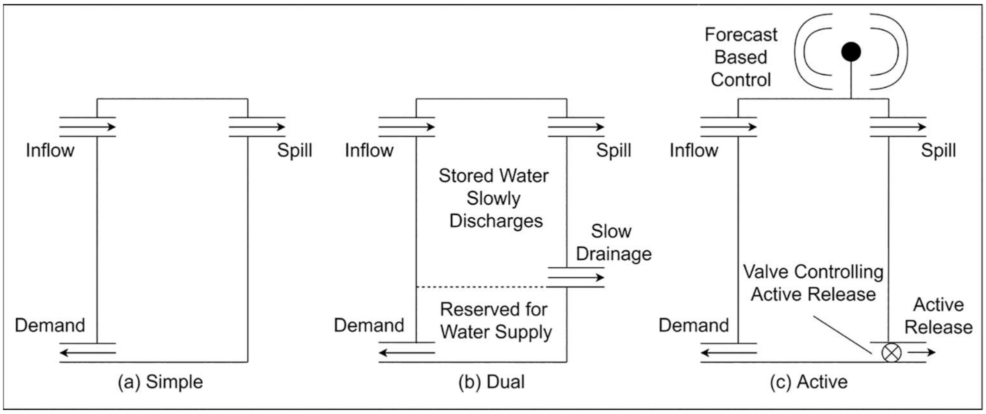

Fig. 1. Different forms of raintanks.

responsibility away from political actors and processes, and onto communities and individuals (MacKinnon and Derickson, 2012, 258-259). Furthermore, stakeholder engagement and public participation have an ever more prominent role in many flood policy statements (Challies et al., 2016).

Yet there are reasons to question whether much practical progress has been made towards these goals. Existing studies of how authorities are implementing flood resilience emphasise a top-down model, focused on one-way communications from authorities to public; instead, commentators promote two-way and interactive exchange. In their research on the role of flood communications in the English town of Corbridge, for example, Rollason et al. (2018) noted that communication was always one way, failing "to meet user needs in understanding flood risk or allowing personal judgements of how and when to act". In her review of climate resilience efforts in Bavaria, Wamsler (2016) similarly notes that 'two-way knowledge exchange is rare'. Likewise, Moon et al. (2017) discuss flood activities in an Irish context which were, "high on participatory rhetoric but low on meaningful engagement". A further point concerns authorities' assumptions about the public. Scholarship on the promotion of sustainable resource use indicates that many initiatives erroneously assume that participants are motivated solely by considerations of costs and benefits for an individual household (Watson et al. 2020). Brink and Wamsler, (2019) highlight how such assumptions would be inappropriate if applied to flooding, concluding, "economic considerations (e.g. low cost) are not the only motivation to adapt; the potential of an adaptation action to contribute to green, thriving surroundings and mitigate global climate change was found nearly as (and among female respondents, more) motivating".

By contrast, community-oriented flood resilience involves a greater degree of communication and coordination between flood authorities, community groups, and individual members of the public. This can take a multitude of forms, from co-design of initiatives to collective action (Mees et al., 2018). Research by Adger et al. (2016) on flood recovery indicates that communities are more willing to take individual resilience actions when they perceive that the authorities are making changes and improvements in the infrastructure. Meanwhile, Orr et al. (2016) emphasize that "individual infrastructure, such as property level protection, works better as part of a community resilience process or package rather than in isolation". Building collaborative approaches involves a shift away from the persistent image of a passive public protected by a powerful technically-oriented flood authority, towards a more active partnership, in which both parties perceive the other as making a meaningful contribution. Consequently, the extent of community capacity and connectedness may be a determining factor in the success of a more community-oriented model (Orr et al., 2016; Thaler and Levin-Kietel, 2016), indicating a potential role for community development and peer encouragement (Mason et al., 2019; Walker et al., 2010).

Raintanks offer a particularly interesting lens through which to approach these issues, since their logic is based on a collective contribution to flood prevention for a neighbourhood, rather than protection of an individual property (for example, by signing up for a flood warning). Could they offer a less individualistic approach to resilience, which empowers communities to take action without removing all responsibility from those in power? Could they foster what Wamsler (2016) has called 'city-citizen collaboration', which occurs "when the knowledge and capacities of both government and community participants contribute together to the design and implementation of measures"? Our study examines whether a raintank programme could be at the heart of such a collaboration, building what we have called 'community-oriented flood resilience'.

3. Methodology

The research presented in this paper falls into two parts. Firstly, a technical study uses hydrological modelling to investigate the effectiveness of different kinds of raintanks at reducing water flows and providing water supply. Secondly, a qualitative study explores the social feasibility of a community-oriented raintank programme. By considering the technical and social questions together, we are able to suggest an innovative new approach to community-oriented flood risk mitigation.

3.1. Case study selection and approach

Our initial research identified Hull and the East Riding as a target location for testing the feasibility of domestic raintank storage. The area has a history of severe surface water flooding: in 2007, over 100 mm of rain fell in a 24-h period, causing extensive pluvial flooding that damaged 8,600 homes and 1,300 businesses (Coulthard & Frostick, 2010). Uniquely in the UK context, the flood risk management authorities (two adjacent local authorities, the Water and Sewerage Company and the Environment Agency) had already formed a 'Living with Water Partnership' (LWW), which had been in operation for 18 months when our research commenced. Formed because of the difficulty of separating the estuarial, river and surface water flooding in Hull and East Riding, the LWW partnership had already invested in school-based education about flooding and sponsored a region-wide fun day for water. The severity of the flood risk in the area, and the openness of the authorities to new approaches suggested that this would make a suitable 'extreme case' (Flyvberg, 2006) to test whether domestic raintanks could contribute to flood resilience. Guided by the knowledge of our LWW partners, we focused our attention on Derringham (Hull) and Bilton (East Riding) (see Fig. 2). Both were areas with community facilities, both had been subject to flooding, and both were areas where water investment was either planned, or already underway, but at inaccessible upstream locations. Our study of rainwater tank feasibility therefore also provided additional benefits to our flood authority partners in the form of visible flood-related community activity.

We adopted an action research methodology, because such an approach aims "to address issues of concern to individuals and communities in the everyday conduct of their lives" (Reason, 2006, p. 191) and urges researchers to adapt their approach iteratively, as they learn from the communities and authorities involved (Wilson, 2019). We sought to determine whether community engagement would make a raintank programme feasible, mindful of the fact that such an initiative required action at both individual and collective levels. Though we used qualitative interviews with individual residents, we strove to elicit a community perspective in each area, which we could then use to guide further research. This work is pioneering within the water sector, introducing our LWW co-inquirers to new types of engagement practice. Following Reed (2008), we embedded a philosophy of inclusivity, empowerment, equity, trust and mutual learning into our approach. LWW played a pivotal role from the development of the research bid onwards. Four steering group meetings shaped the research, provided local contacts and context, and allowed opportunities to reflect together on early results. Community interaction was planned and largely undertaken by the research team, with LWW attendance and participation at some

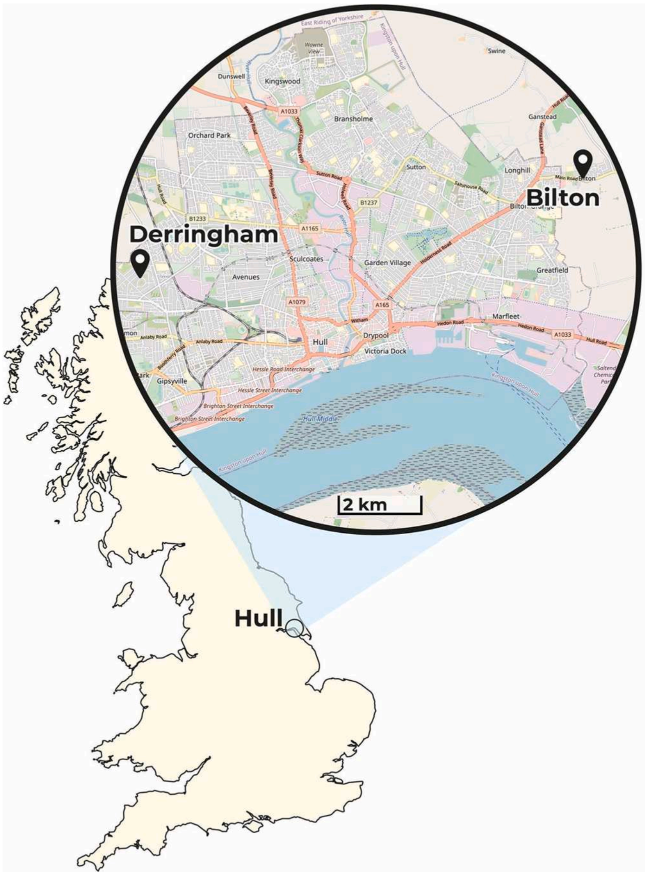

Fig. 2. Case study neighbourhoods just inside (Derringham) and outside (Bilton) the Hull City Council area. Map amended from OpenStreetMap Contributors (2015).

community events. Relations were generally very positive: close coworking on a public seminar and research publications enabled trust to be built and tensions negotiated (Sharp and Pitcher, 2021).

3.2. Interviews with LWW co-inquirers

Conversational 'rapport' interview techniques were employed throughout the project to foster equal relations between researcher and interviewee (Hayes, 2000). Six interviews (L1-6) with LWW team members (including a representative from each of the LWW partnership organisations) occurred before community engagement commenced. This developed a shared understanding of community engagement, informed the semi-structured interview schedule, and ensured that all participants had similar expectations from the research. A synopsis of each was shared with the interviewee to edit, which helped build trust.

3.3. Community engagement

We subsequently interviewed key individuals in each neighbourhood and scoped community events where we could engage residents. These interviews explored the nature of each area, and identified suitable community buildings on which we could install demonstration raintanks in a potential future project. Many of these activities led to further engagements, for example, a lay preacher in Derringham was enthusiastic about installing raintanks at a local church, where they could be used to irrigate raised vegetable beds. This led to further contacts with a local community orchard group and our involvement in a summer picnic event. To engage families, we developed child-friendly activities, including an interactive flood resilience game where children were invited to pump water away from model houses (representing Hull) into a water butt, while others poured on 'rain' using watering cans (Fig. 3). This enabled us to engage parents in conversation and to invite them to interview. Snowball sampling was then used to increase the number of participants.

3.4. Interviews with resident co-inquirers

We recorded a total of 26 semi-structured audio interviews with the community between June and October 2019. Ten of these were

Fig. 3. Children's activity used in community events when interviewees were recruited: one child provides rain via a watering can while another 'pumps' by bailing the pool with a cup.

in Bilton (with 12 residents and 2 ‘key individuals’ who acted as informal community gatekeepers, one of whom was also a resident, B1-13 below); sixteen were Derringham (with 18 residents and 2 key individuals, one of whom was also a resident, D1-19). The mode of recruitment means that interviewees were self-selected for their interest in a raintank programme.

Interviews lasted between 30 and 60 min and were conducted wherever interviewees felt most comfortable. Demographic data emerged during questioning: respondents included 9 males and 23 females, ranging in age between their twenties and their eighties. Housing tenure was varied (private and council tenants, and homeowners were represented), marital status was also mixed between single, married, and widowed. Levels of formal education, employment status, and income varied considerably. One interviewee identified as black.

In the course of the interviews, the interviewers explained the purpose of a raintank programme in flood mitigation, the different types of raintank, possible designs, and other forms of SuDS, such as a raintank planter and rain gardens. Questions also focused on communications about the need to empty raintanks before heavy rainfall. Background information was provided via the informed consent form, explanation by the researcher, flashcards, and pictures. Interviewees were given freedom to express their understanding of flood risk and their ideas and understanding of a raintank programme.

3.5. Analysis

All interviews were audio recorded, professionally transcribed, and then summarised to create a readable text, with the synopsis then shared with interviewees to verify the data, ensure anonymity, and instill trust. Further analysis of data was undertaken as soon as data collection was complete. Responses to straightforward questions were collated, before thematic analysis (Braun and Clarke, 2006) explored the more intangible research questions to develop a hierarchy of themes which reflected and summarised the data. Reflective notes and thematic maps were used alongside the themes to generate a narrative about the whole dataset.

3.6. Feedback

In response to resident preferences, we organized feedback events in community venues in Derringham and Bilton. Occurring in the early evening, our café style set up (providing snacks and drinks, as well as an activity table for children) sought to enable accessibility. Attended by researchers, a representative of LWW, and a total of 18 residents, we presented research findings, and facilitated discussion. Residents interested in having LWW install a raintank on their property provided their contact details.

A subsequent event in London fed the interim findings back to a practitioner community, with a further presentation to the LWW Technical Board in June 2020.

3.7. Hydrological modelling

Simultaneously, we conducted hydrological modelling to investigate the effectiveness of raintanks at both reducing water flows and providing water supply. We explored three systems: ***Simple***, ***Dual*** and ***Active*** systems (see Section 2).

Dual systems partition the tank into a water supply volume (25% of tank size) and a water detention volume (75% of tank size) with a slow-release discharge outlet. Controlled release occurs when the water level is above the passive outlet, and the rate is determined by water level and the size of the orifice (Xu et al., 2018). In this case, the passive release outlet was sized to deliver a maximum outflow equivalent to 5 L/s/ha, considered comparable with the catchment’s pre-development runoff rate.

Active systems are either manually or electronically controlled to balance water supply and roof water delay functions. They use rainfall forecasts to manage the release of water (Xu et al., 2018). A perfect forecast is assumed, with emptying 24 h’ in advance of a significant storm.

We modelled each system using a Yield-After-Spillage (YAS) approach, which is the most conservative method of simulating raintank behaviour (Fewkes and Butler, 2000). We calculated the roof area at 30 m^2, equivalent to a typical terraced house. All tanks have a capacity of 0.21 m^3, in line with systems available for purchase in the area.

Two demand scenarios were modelled. Scenario 1 assumes a demand of 40 L/day, which corresponds to the likely demand from a rainwater tank supplying a downstairs toilet (Quinn et al., 2020). Scenario 2 assumes no demand and is a conservative estimate equivalent to unknown garden irrigation.

Local climatic inputs were obtained from RPS Services, the drainage consultant for Yorkshire Water. The 15 year Environment Agency gauged dataset was used as an input to TSRSim, a software tool that generates long stochastic rainfall series based on local observed rainfall records which was then adjusted to incorporate a climate change scenario P90 (probability of occurrence of 90%) representative of a plausible climate in Hull up to 2080. This generated a continuous series of 100 years of 5 min resolution data for the Cottingham area of Hull. The 25 year period used in the modelling represents the characteristics of the 100 year series.

In terms of stormwater management, the most popular performance metric is overall *retention efficiency* which quantifies the proportion of water prevented from entering the drainage network. However, SuDS may not be able to retain runoff completely, so another important performance measure is outflow controlled to pre-development runoff rate. This value is calculated as the peak rate of runoff due to rainfall falling on a given area of vegetated land. Quinn et al. (2021) proposed the metric *inflow control efficiency*, which is defined as the proportion of inflow controlled to pre-development runoff rate, to quantify this behaviour. Often, the effectiveness of rainwater harvesting as a stormwater management tool is evaluated on a long-term basis, but this may be misleading because metrics such as annual *retention efficiency* typically indicate far better performance than will occur during significant rainfall events (Quinn et al., 2021). Therefore, we have also chosen to evaluate both the *retention efficiency* and *inflow control efficiency* during a sample of significant events. In addition, the system's ability to provide control outflow events will be determined by calculating the *peak outflow* of each event. Finally, for water supply, which was relevant to Scenario 1 only, we additionally considered the overall annual *water supply efficiency* which was defined as the proportion of household water demand that was met using the harvested rainwater.

Here, we have selected the 25 most significant events over the 25-year time series in order to have an empirical sample indicative of events with an annual return period. Their characteristics are shown in the Supplementary Material. Events are separated by a dry period of 9 h. This approach is consistent with the event definition used by Yorkshire Water and is sufficiently long to allow for the time of concentration in sizable urban drainage systems. The ***Active*** systems are emptied 24 h in advance of these events. Events with an annual return period are of interest to drainage engineers as they can cause morphological damage to the catchment (Woods-Ballard et al., 2015). Although raintanks can reduce the frequency and/or severity of flooding, their impact on large events may be minimal. As such, we chose not to develop specific metrics for events with return periods higher than one year. What defines a 'significant' event depends both on catchment characteristics and on drainage guidance and regulations. We considered events with the largest 6-h rainfall depth as a definition for our 'significant' events.

Many different parameters will impact raintank performance, such as roof area, tank size, demand rate, and rainfall characteristics. However, as this study aims to illustrate the potential stormwater management of these systems, the impact of these variables on performance will not be examined further. If these systems are used as part of a surface water management plan, a more thorough performance assessment will be needed.

4. Results

4.1. Raintank types and impact: Social views

Residents were asked whether they would prefer a ***Simple*** raintank, a ***Dual*** raintank, or an ***Active*** raintank powered by smart technology (a smart ***Active*** raintank); they were also shown a version of the ***Dual*** raintank that included a tank-planter. Almost all residents preferred manual (***Simple*** or ***Dual***) raintanks to smart ***Active*** raintanks, and many also expressed a preference for the tank-planter (Fig. 4).

In relation to manually operated raintanks, all residents said they would be happy to be notified about when to empty their tank ahead of a storm, effectively transforming ***Simple*** and ***Dual*** tanks into ***Active*** systems. Most preferred notification by text, but two elderly residents preferred a phone call. Everyone interviewed understood the need for coordinated emptying, but people had varied views about the organization that should coordinate this (Fig. 5).

4.2. Raintank types and impact: Technical evaluation

Our technical modelling demonstrated the importance of examining the dynamics of raintanks during storms. Fig. 6 shows a box plot of event-based stormwater management metrics for both scenarios; it gives an overall indication of performance through the median values, and a range for performance across individual significant storm events. A non-technical summary of the detailed findings discussed here is available at the end of this section.

As Fig. 6 shows, the *retention efficiency* for both the ***Simple*** and ***Dual*** systems depends heavily on demand, with much higher values

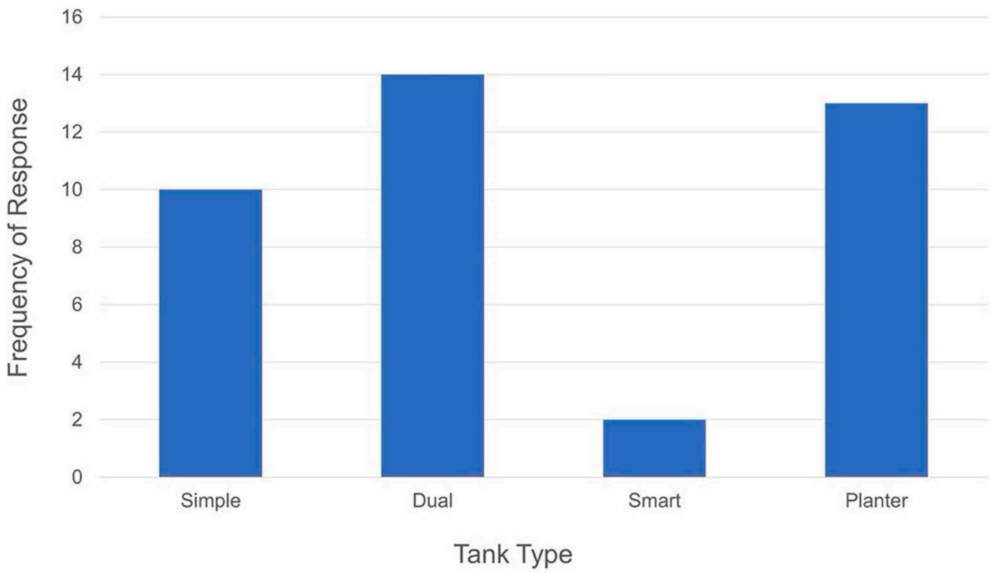

Fig. 4. Raintank type preferences (residents could choose more than one option).

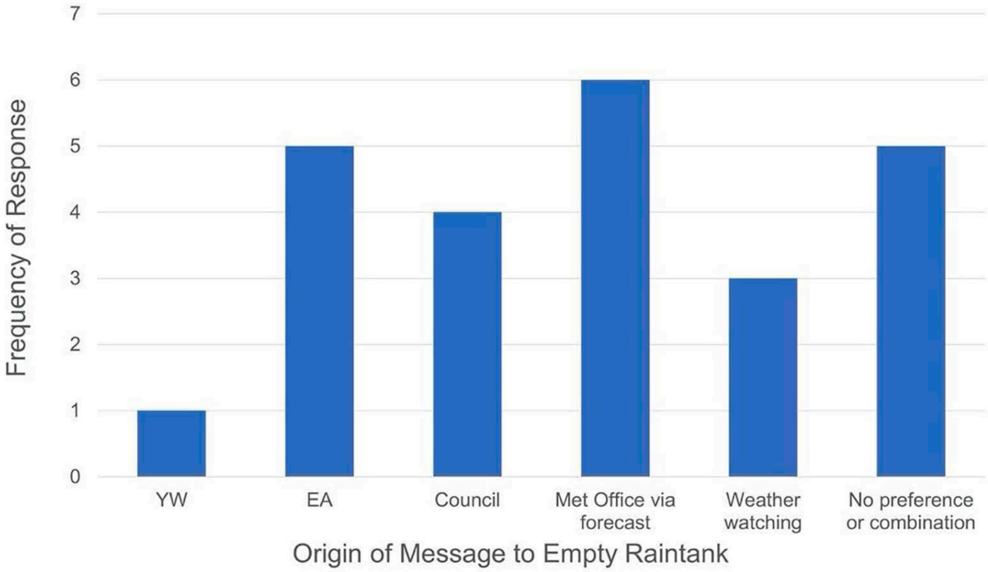

Fig. 5. Trusted sources for request to empty raintank (residents could choose more than one). Key – YW: Yorkshire Water (the water company and a key player in LWW); EA – Environment Agency.

observed for Scenario 1 (low demand) than Scenario 2 (no demand). The ***Simple*** system has a far higher median value of 0.11 for Scenario 1 than Scenario 2 (0.00), with similar results for the ***Dual*** system (medians of 0.06 and 0.00, respectively). For the ***Active*** system, the *retention efficiencies* are higher and relatively independent of demand (a median of 0.15and 0.14 for Scenarios 1 and 2, respectively). For both the ***Simple*** and ***Active*** systems, *inflow control efficiency* is almost identical to median *retention efficiency*. In contrast, the ***Dual*** system has higher median *inflow control efficiency* irrespective of the scenario (0.39 and 0.35). It is clear from Fig. 6 that both *retention efficiency* and *inflow control efficiency* can vary depending on the rainfall event. For example, an extensive range of *inflow control efficiencies* for the ***Dual*** system was observed, with values ranging from 0.18 to 0.56 depending on the event and scenario. No substantial reduction in *peak outflow* was observed; due to the tank generally being full when the most significant inflow rates occurred.

For *water supply efficiency,* the ***Active*** (0.79) system performs similarly to the ***Simple*** system (0.79) despite the ***Active*** system emptying in advance of significant events. This finding suggests that emptying should not adversely affect the water supply. However, this simulation assumes a perfect rainfall prediction, and forecasting errors may affect supply. The ***Dual*** system has far lower values for *water supply efficiency* (0.48). The water demand for Scenario 1 is just over half the volume of roof runoff (0.81 m^3/year/m^2), which indicates that the potential achievable *water supply efficiency* is 1.0 if a larger tank is used.

The findings demonstrate that no raintank system makes a significant difference to physical flood resilience: the contribution is far from that which is expected from SuDS in new build situations. Using a raintank of 0.21 m^3 in conjunction with a roof area of 30 m^2 implies that the maximum possible retention is equivalent to approximately the first 7 mm of any rainfall event, where the tank is empty. A more substantial impact could be achieved if each property had more or larger raintanks. However, Digman et al. (2012) stress the importance of seizing all potential opportunities to restore catchments to their pre-development hydrology when retrofitting SuDS in dense urban areas. From this perspective, all raintank proposals, however small, are worth considering. It should also be noted that, while current UK guidance for new build SuDS (Woods-Ballard et al., 2015) steers designers to consider significant rainfall events (e.g. 1 in 100 yr events, typically of the order of 60 mm in depth), it also strongly emphasises the value of implementing any SuDS that prevent the first 5 mm of rainfall from entering the drainage system to minimize water pollution (Woods-Ballard et al. 2015).

Another way of considering the apparently modest hydrological benefits offered by the rain tanks is to focus on the additional resilience they provide to extreme rainfall events. For the Hull area the historical rainfall depth for a one-hour storm with a 10-year return period is 22.3 mm, whereas for a 30-year return period it is 28.6 mm (Flood Studies Report, 1975). The difference in rainfall depths is 6.3 mm (or approximately 7 mm). If a flooding problem currently occurs every 10 years on average, then the retrofitting of rain tanks throughout the affected area could be expected to reduce the frequency of the flooding problem to once every 30 years, assuming that rainfall patterns do not change into the future and the tanks are empty at the start of the event. Alternatively, with higher rainfall expected in the future due to climate change, the retrofitting of rain tanks may help to futureproof the area, such that overall flooding frequencies do not increase. In addition, in Hull, it was found that removing 10% of roof runoff during a 1 in 5 year rainfall event (which takes into account climate change) reduces the number of properties flooded by 1,094 (RPS Group, 2018). This order of magnitude of change could be achieved by attaching appropriately sized tanks to every building in the catchment.

The results also clearly show the trade-off between the different types of systems, with the ***Active*** or ***Simple*** system (depending on the scenario) performing best in terms of water supply and retention and the ***Dual*** system optimal for controlling runoff rates. The ideal system will vary depending on the user's likely water demand and the dynamics of the receiving drainage system, so it is impossible to

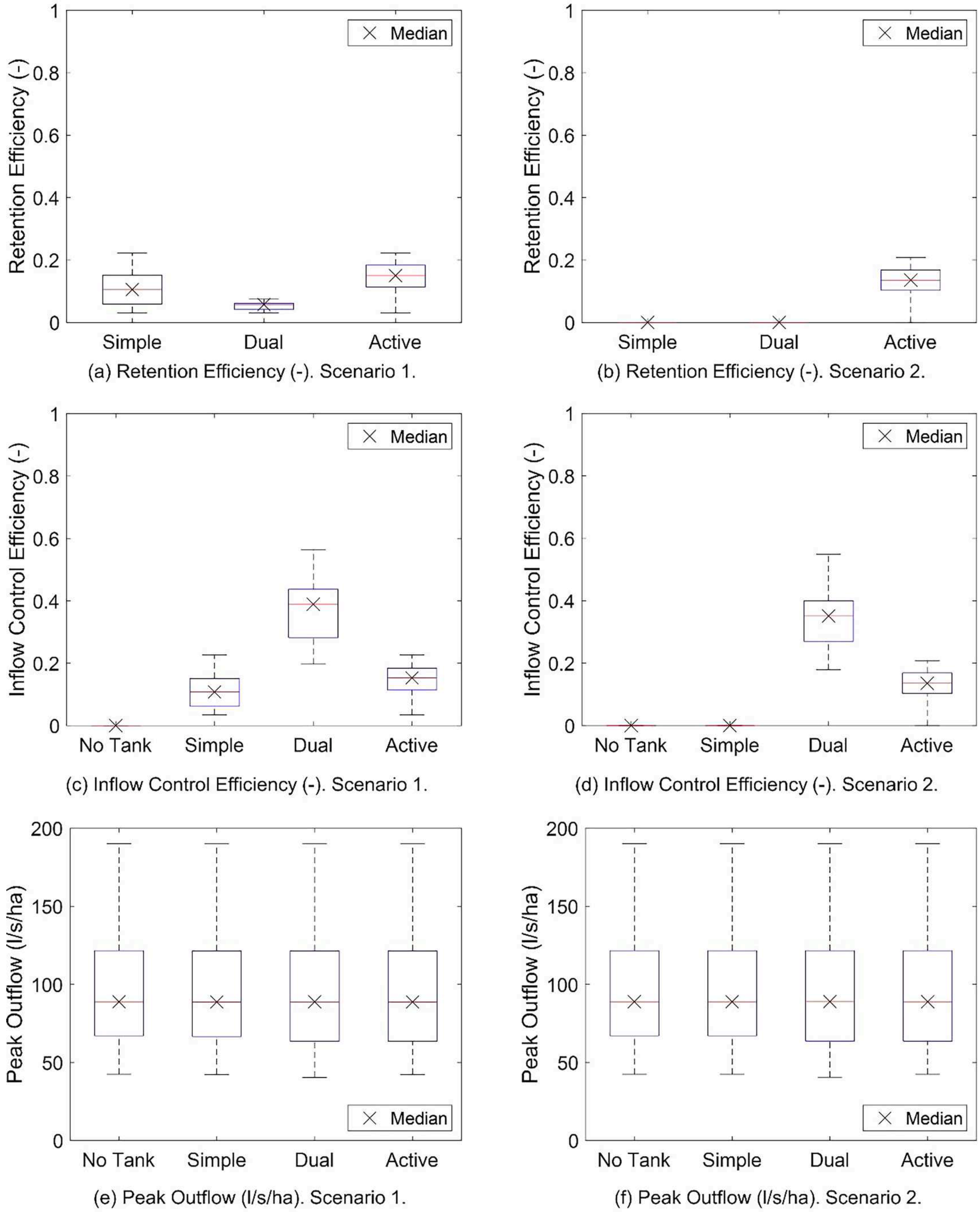

Fig. 6. Box Plot of Stormwater Management Performance Metrics During Significant Events. Scenario 1 - Demand = 40 L/day; Scenario 2 - Demand = 0 L/day.

recommend one system type universally.

In summary, household emptying can transform ***Simple*** or ***Dual*** systems into ***Active*** systems that retain significant amounts of water during storm events, even where there is little to no demand for rainwater. In addition, ***Dual*** systems can be used to control outflow rates with minimal actions from householders. While the total impact is not as substantial as many physical investments in flood infrastructure, the cumulative effect of large numbers of small interventions would be considerable, especially where co-benefits are also considered.

4.3. Raintank promotion and uptake

Many interviewees expressed anxiety about flooding, but this seldom led to resilience actions. Many residents did not know about flood warnings or property level protection. Four households were signed up for Environment Agency flood warnings: one had been previously flooded and the other two contained individuals with some responsibility for public safety. In line with the findings of Adger et al. (2016), many residents expected flood risk to be addressed by authorities, and were ambivalent about taking personal action to manage water:

"I can't stop it, basically. […] So there's a bit of me that thinks, "You know what? If it comes, it comes." (D13)

Moreover, negative emotions stimulated by flooding led some residents to avoid thinking about it.

Whereas very few of our interviewees were undertaking other flood resilience activities, all of them either had or intended to get a raintank:

"*When you told me that everybody having a water butt outside their house could really reduce the risk of flooding, I was, like, "What?" I didn't know there were things that you could do for yourself, or for your community, that would make a difference like that, because it feels like something that's out of your control."* (D19)

Responses were indistinguishable between Bilton and Derringham, and residents' willingness to engage was not contingent on previous experience of being flooded. Perceived environmental or social benefits were mentioned as a motivation by many. As one interviewee, who was not on a water meter, explained:

"Oh, God, yes, it's [using rainwater is] just better for the world. It's better for everything. It [having a raintank] wouldn't cost me any more or less, but it would still save water in general [… and] I've heard that rainwater is better for your garden than treated water from taps." (D8)

When participants were asked to identify groups who might not want to participate, responses varied wildly: people mentioned groups they deemed to be uneducated, but also those seen as overeducated; older people and younger people; and both wealthy and poorer groups! However, these judgements contrasted with a view voiced by one resident:

"Everybody around here has a garden, everybody around here will have room. I think the only objections around here would be if they didn't like them or didn't want one, but I don't see why they wouldn't want one." (D6)

Residents were also strongly in favour of maintaining green spaces and limiting concrete as part of flood management:

"They [residents] could dig up the front gardens, they could make gardens with soil, and not tarmac everything over. I like having grass because big open spaces soak all the water up. And trees are very good at stopping flooding." (B10)

Because residents were a self-selecting group, these views may not be shared by others in the locality, but they do indicate a degree of positivity towards raintanks. The positive benefits to gardeners, and sense of connection to a wider, collective good were motivating factors for many.

Residents agreed that visible examples of raintanks and rain gardens in public spaces, private gardens, or on community buildings would encourage others to engage by demonstrating the value of small-scale interventions and providing a visible sign of the effort made by both local authorities and other residents:

"I think we want to see it proved. Certainly, if the council said, "Oh, we're leading the way on water resilience. We're having all these things installed on public and municipal buildings," I think everybody would go, "Oh well, if the council are doing it, it must be good." (D4)

They also believed that personal interaction was a more effective way of promoting raintanks than generic information:

"I'd have people going around knocking on doors, because there's nothing better than a face-to-face conversation." (D1)

Further, they suggested that projects should begin with small groups and grow slowly through word of mouth and community events:

"I think, to start with, you just need a core group of people that are willing to do it and speak to others who live in their area. I think that's how this project could be possible." (D6)

Lack of visible activity on the part of the flood authorities, particularly in relation to drain cleaning, was mentioned as a reason for skepticism about their role:

".. as a child born in the 1950s ..the Council would come round and clean the drains out with those tanks .. [but] ..for the last 30 odd years you hardly ever saw them. After the 2007 floods, we did see some of these vehicles out, but I haven't seen one for ages now, not for years." (B11)

Even the moderate response of the local headmaster stressed the need for clearer communication:

"I'm not clear as to what the local council have done, and that's because they haven't supplied me with that information. It may well be that fantastic things are being done, but I'm unaware." (B12)

Referring to recently approved developments in their area, residents also expressed confusion and upset over local authority's planning decisions:

"I just think, if you know it's a floodplain, why do you even get permission to build on it?" (D12)

Although residents' concerns about flooding are not translated into other flood resilience actions, the responses reviewed in this section suggest that raintanks are positively perceived, have value to the local community in terms of their utility, and can form a basis for a more collective and community-oriented approach to flooding. However, conspicuous local action and clear communication from flood authorities may be necessary to encourage a collaborative approach. Participants also emphasized the need for raintanks to be made available free of charge.

4.4. Investment in a raintank programme

The interviewees in LWW were enthusiastic about the potential contribution of a raintank programme, but also concerned about how engaging communities via raintank promotion had the potential to be very resource intensive and would be hard to support within the existing norms of flood risk management practice.

As a coalition of flood risk authorities LWW are in a unique position within the UK in that they can offer a joined-up form of resilience. Interviewees from each of the constituent bodies were enthusiastic about small scale green solutions:

> *"We need more smaller scale, blue-green solutions. […] across the entire city, so everybody has them, not just in a few little places…" [L3]*

And are also seeking for these activities to be undertaken by the public:

> *"…We need people to be demanding that their new homes have SuDS built-in, and taking on that responsibility. We need people to not pave their drives and to be using water butts. That's the concept of Living with Water" [L3]*

Yet the interviews revealed that the LWW team tended to use the term 'engagement' interchangeably with 'education' and 'public information'. Their communications were mainly one-way, and focused on individuals rather than communities. The LWW team recognised a need to improve engagement practices, but also demonstrated the challenges this posed in a sector dominated by technical expertise.

There were contradictions in the way LWW participants pictured the public: some expressed a desire for residents to take ownership of flood resilient solutions, and wanted to encourage people to install property level flood protection: *"[…] you don't expect the police to come and fit your burglar alarm" (L3);* others expressed disquiet over the idea that someone might attempt a flood installation in their own garden, potentially putting others at risk: *"[…] technical aspects are best dealt with by risk management authorities" (L5)*. The need to consider public safety, and the historically technocratic relationship to the public, understandably lead to a default reaction that responsibility for flood risk management sits with the flood authorities, not the public.

Some LWW interviewees were concerned by a perceived lack of public engagement. As one explained, despite high levels of fluvial and coastal flood risk:

> *We know that in Hull a very small number of people are signed-up for flood warnings, indicating that there is a general lack of knowledge or understanding of flood risk. (L1)*

There was also an ongoing process of message evaluation:

> *"[…] it's just … what message do we want to spread? […] We don't want people to be scared and think: "Oh my, we need to leave Hull." We do need people to be prepared for when/if it floods so they know what to do," (L4)*

A large factor hindering pursuit of community engagement was lack of time and material resources, with flood authorities instead focusing on funding and delivering large-scale projects that provided predictable flood risk reduction:

> *"[…] "Why aren't we asking the community?" It's because it's really hard and it's really time consuming." (L4)*
>
> *"A lot of these little projects – I'm saying little projects in comparison to the other streams in LWW that are more operational and technical, but they take an awful lot of time to understand, and do, and make successful." (L4)"*

Alongside this, LWW interviewees also explained that any benefits of community engagement would have to be evaluated narrowly, in terms of their impact on physical flood risk, rather than against a wider conceptualisation of social resilience:

> *"I suppose one of the questions to ask ourselves is do we have the evidence to support the [putative future] investment [in a raintank programme]; even if it was delivered 100%, what are the benefits? I suppose it's the engineer in me, but if we had for example, 1,000 water butts working perfectly, is that actually going to change the flood risk?" (L2)*

Such a technical focus ignores both the contribution that smaller projects can make, and the more social dimensions of resilience, a problem highlighted in a recent Defra evidence review on resilience:

> *"peoples' perceptions and feelings of coping and resilience …. [are] generally not taken into account in assessing the outcomes of interventions designed to improve resilience to flooding and coastal erosion."* (Defra, 2020)

To conclude, these findings indicate something of a mixed response to a community raintank programme. On the one hand, there is enthusiasm for widespread local SuDS, for the public taking more responsibility for specific aspects of flood resilience, and for greater community engagement. On the other, there was recognition that such engagement could be resource intensive and time-consuming, ran counter to the dominant culture, and delivered a lower degree of physical flood risk reduction than more technical solutions.

5. Discussion

The findings from both sets of interviews demonstrate a degree of confusion over the roles and responsibilities of flood authorities and the public in managing flood risk. Residents tended to blame flooding on the authorities and expressed little sense of individual or community agency to protect from future floods. LWW interviewees expressed a genuine desire to work with the public, but prioritisation of a technical approach, considerations of public safety, and a top-down model of communication all tended to hinder the development of meaningful two-way interaction. As a result of these two positions, the area lacked capacity to develop and deliver collaborative and coordinated community-oriented flood resilience. While academic and policy rhetoric has shifted towards an emphasis on the role of social factors in flood resilience, working practices and public assumptions are still rooted in a more traditional technical mindset.

Our research suggests that a raintank programme has the potential to catalyse change for community-oriented flood resilience, working towards a situation in which many members of the public have the understanding, motivation, and capacity to take actions that augment flood resilience; where communications between flood authorities and the local community are interactive and two-way; and where both parties are empowered to develop coordinated actions to support flood resilience.

5.1. Empowering communities

Our hydrological modelling pointed to the potential for ***Dual*** and ***Active*** raintanks to have a cumulative neighbourhood effect, indicating that a raintank programme could legitimately claim to contribute towards flood resilience. However, the precise effect on flood risk will depend on the configuration of local drainage and the size, number, and type of tanks. Further research is required to develop our initial findings into more detailed neighbourhood modelling.

In terms of social feasibility, our research findings suggest that raintanks could motivate the local community to become involved in flood resilience. In keeping with findings from Asset Based Community Development (Kretzmann, 1993), the local community were more motivated by positive outcomes, such as collecting water for gardening, than by negative messaging focused on the desire to avoid the property damage contingent on flooding. These findings may be more widely applicable, since neither Bilton nor Derringham has a strong history of drought or notable links with gardening. Indeed, our work suggests that even past experience of surface water flooding may be less important in motivating people to install raintanks than the desire to garden and/or to help the community.

Our resident co-inquirers told us that a raintank programme was more likely to succeed when promoted via community mechanisms and word of mouth. This finding is in line with the observation of Orr et al. (2016) that flood resilience measures work better when promoted within a community setting. While a few resident co-inquirers believed that a raintank initiative would be popular with everyone in their neighbourhood, the majority presumed that some groups would not participate. The wide variation in the 'others' named may indicate a limited sense of collective agency.

As Walker et al. have observed in relation to community energy projects, working together on a shared goal can enhance people's connection to their neighbourhood and belief in their community (2010). Methodologically, community understanding and willingness to participate grew through the project, suggesting that the approach adopted in this research was effective at building connections between residents.

In conclusion, the research provided considerable evidence that a raintank programme could contribute to helping residents feel empowered and able to take action in relation to flooding.

5.2. Improving collaboration between flood authorities and public

A raintank programme could provide opportunities to change the ways in which the public is conceptualised by flood authorities, creating new possibilities for flood mitigation. For example, our project raised the possibility that residents could be asked to empty a domestic raintank manually, a variation on the remotely controlled 'smart' raintank that had not previously been considered. The communication systems required by this offer the potential for ongoing dialogue, which could potentially create a sense of shared endeavour and partnership, though the reliance on voluntary public action may prove disquieting for engineers accustomed to having control over systems. However, such a project would also allow opportunities to communicate other, less visible flood resilience activities undertaken locally, since domestic raintanks offer a small-scale demonstration of the principles behind LWW's larger storage lagoons and sustainable drainage features. Projects using water supply raintanks in Australia (Sofoulis, 2015) and the US (Woelfle-Erskine, 2015) provide a precedent for their use to engage residents in understanding the local water context.

There was some evidence that our feasibility study was already transforming attitudes towards the public amongst key members of the LWW:

> *"I think MOCA, for me, is helping me understand what 'right' looks like, if that makes sense. You and I have discussed how you can bring people with you. You don't do stuff to people. I think all the organisations involved in trying to help have been guilty of doing that." (L6)*

As a consequence, LWW are currently pursuing more interactive engagement over their flood resilience planning for the city, though they lack the resources to undertake the type of community engagement we employed during this project. Part of the problem lies in national policy, where a stated commitment to community engagement is undermined by an overly complex web of funding mechanisms for new capital schemes in which community collaboration is seldom considered.

5.3. Coordinating transformative action: The role of action research

Our research exemplifies the ways in which research projects (including government sponsored pilot projects and community sector initiatives) can act as change agents, drawing together new resources, skills, and methodologies to achieve evidence-based innovation. Action research is arguably especially well placed to achieve this, since it involves close and collaborative working with both relevant authorities and communities. Indeed, recognition of the potential contribution made by active and reflective learning appears to be at the heart of recent Defra policy statements:

> *"They [practitioners] need to be empowered to recognise the importance of these kinds of resources and develop strategies to work with communities to build them. Training courses may have a role in promoting this kind of change but the design of active learning processes that enable those involved to reflect on how change is happening, identify obstacles and work out ways to overcome them is likely to be more supportive and effective for all involved."* (Defra, 2020)

Action research can thus provide a supportive context for institutional change, transforming the public from passive victims of flooding to actively engaged partners in strategies for flood resilience.

However, to be truly co-productive such action research requires inputs of resources from the flood authorities, in a context where these are highly constrained. Although project goals, methods and outcomes were developed between LWW and the research team, resource availability limited capacity within LWW to deliver engagement activities on this specific project. Securing more significant input of flood authority time would be more readily justified if the research contributes directly to a performance goal, achieves customer commitment, or addresses agreed objectives (Pitcher, 2021).

Furthermore, although the team agreed research aims and methods with LWW from the outset, the extent to which the research gaze fell on LWW itself was not fully anticipated by our industry partners. Our outputs may also have been less prescriptive (e.g. concerned with specific elements of messaging) and more systemic than they had expected. However, such 'surprises' are perhaps to be expected when social research methodologies are applied to areas previously deemed as largely technical: the onus is on social researchers to demonstrate and develop insights from their work (Westling et al., 2014).

6. Conclusion

The contribution of this paper is three-fold.

Firstly, it illustrates both the technical and socio-cultural feasibility of using raintanks to increase flood resilience. By considering these two aspects together, rather than in separate papers, it suggests new solutions, such as manual emptying of tanks in advance of storm events.

Secondly, the paper demonstrates the transformative value of a community-oriented approach to flood risk resilience, and particularly its potential to change the relationship between the public and flood authorities away from a traditional model that pictures the former as passive, towards a process of mutual learning and two-way communication. Our research illustrates that this is not merely a matter of 'good practice', but a shift that can produce new practical solutions that a technical perspective alone cannot reveal.

Thirdly, our findings suggest that action research can make a valuable contribution to evidenced-based policy and institutional cultural change, modelling and supporting new ways of working in contexts of constrained resources. Such efforts are only likely to be sustained in the long-term, however, if there is also a shift in national policy, formal responsibilities and internal cultures of flood authorities towards prioritising interactive community engagement.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to express our heartfelt thanks to the residents of Bilton and Derringham for letting us participate in their events and for engaging in our interviews. We would also like to pay tribute to those working in the Living With Water Partnership for being willing to work with us on this project and being admirably open and reflexive about their own practices. We are also grateful for the input of our co-investigator, Caroline Wadsworth and to Isabel Shaw and Kiera Chapman and three anonymous referrees who provided useful comments on drafts.

The research described in this project was funded by the UKRI's Strategic Priority Fund for Climate Resilience, NE/S016589/1. As well as the funders, the authors would like to thank the Climate Resilience Champions who helped us understand the role of our project within the broader context of climate resilience actions in the UK. A debt of gratitude is also owed to investigators and partners in the TWENTY65 research consortium, EP/N010124/1, whose deliberations contributed to the development of this project, and to colleagues from municipalities across the EU NSR BEGIN project, whose ideas helped develop our thinking.

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