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Mapping hydro-ecological citizen science activities to inform research infrastructure design (Chess Catchment, UK)

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ABSTRACT

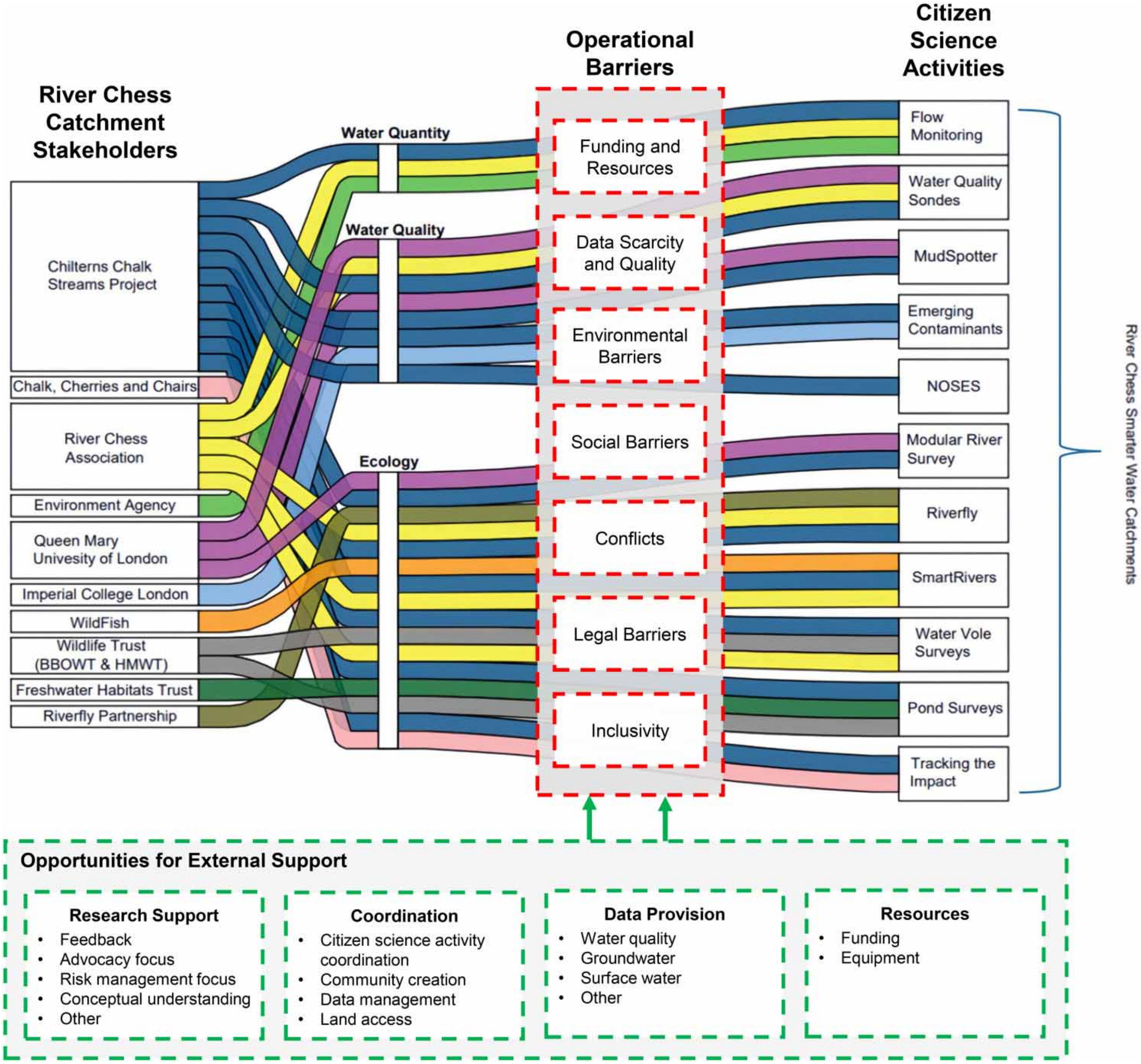
The UK's Floods and Droughts Research Infrastructure (FDRI) is a £38M government investment, aiming to catalyse hydrological research and innovation by improving hydrological datasets and providing a suite of supporting services. Citizen Science (CS) activities are now abundant in the UK and are a significant opportunity for integration if existing projects, their objectives, operational barriers and priorities for support can be identified. From user-design principles, we develop a multiple-methods approach mapping CS activities in the River Chess catchment, Buckinghamshire, using a literature review, 12 key informant interviews and thematic analysis. We identify six ecological and five hydrological CS projects. A shared priority among CS projects was that their data collection creates tangible impacts in science, policy or management. As such, the modal recommendation is for research support on practical questions. Delivery of quality research from CS activities can attract greater contributions of time, research and resources by satisfying objectives shared by citizen scientists and their supporting partners. We recommend replication of this scalable method as infrastructures expand, so that they capture opportunities to leverage existing CS projects with mutual benefits.

Key words: citizen science, floods, hydrological monitoring, research infrastructure, stakeholder mapping, user design

HIGHLIGHTS

- We demonstrate a simple, scalable method to map hydro-ecological citizen science activities and their support needs.
- We mapped stakeholders and 11 projects in the River Chess catchment.
- A key support need was research support, by facilitating connections between citizen scientists and researchers.

GRAPHICAL ABSTRACT



INTRODUCTION

The annual cost of damages due to flooding in England is estimated at around £1.1 billion (Bates *et al.* 2008; National Audit Office 2011; Blackmore 2015), and in 2022–2023, 5.7 million properties in the UK were at risk of flooding from all causes (Brisley 2021; House of Commons Committee of Public Accounts 2024). The risk of drought is also increasing (Bates *et al.* 2008), which is particularly a concern for the southeast of England, where 19 million people live in a region described by the Environment Agency (EA) as seriously water-stressed (EA 2021; Water Resources South East 2024). Issues of water quality are also now receiving more public attention due to recent high-profile cases of river and groundwater pollution (OFWAT 2022).

The multitude of challenges facing UK hydrology requires high-quality research and innovation to help design and inform solutions. However, hydrology remains a data-scarce field both spatially and temporally, which is a fundamental bottleneck to research (Hannah *et al.* 2011; Buytaert *et al.* 2014; Paul *et al.* 2018; FDRI 2022). Classical methods of hydrological data collection, such as statutory gauging stations, have declined in number due to decreasing agency budgets (Carlson & Cohen 2018), inadequate funding, operational challenges, issues of governance, and a lack of recognition of the value of long-term hydrological records (Mishra & Coulibaly 2009). Whilst hydrological remote sensing technologies such as satellite-based radar have improved to address some data gaps, they carry inherent issues of low resolution and high uncertainties (Berne & Krajewski 2013; Chan *et al.* 2020; Veness *et al.* 2025a). They are not a preferred method for use on their own, and ground measurements are vital to provide a more comprehensive understanding of hydrological processes (Chan *et al.* 2020; Veness *et al.* 2022), as well as calibrating and ground-truthing remote sensing monitoring data. A clear demand exists for cost-effective, innovative *in situ* hydrological monitoring techniques that can be adapted to local data requirements.

Citizen science in the UK Floods and Droughts Research Infrastructure

As part of the effort to address hydrological data scarcity through innovative approaches, the UK government announced in June 2022 a future £38M investment through the Floods and Droughts Research Infrastructure (FDRI; FDRI 2022).

Key components in the delivery of FDRI will include:

- the deployment of mobile and fixed hydrological observation equipment
- digital solutions for data discovery, access, and integration
- an innovation programme to catalyse development and research
- a capacity-building programme to foster skills sharing and collaborative working

Initial stakeholder elicitations in its early design have also emphasised the opportunity of the UK's growing hydro-ecological citizen science network as a knowledgeable and motivated community sharing FDRI's objectives, whose capacities could be integrated into the infrastructure.

Citizen science (CS) is a method of collaborative research in which the public is involved in scientific projects at different stages, such as the collection, categorisation, transcription, or analysis of data (e.g., Bonney *et al.* 2009; Aceves-Bueno *et al.* 2017; Njue *et al.* 2019). Opportunities for citizens to participate in hydrological monitoring are emerging thanks to the internet, mobile communications, lower-cost environmental sensors, increasing commitments to community engagement, and a reduction in research budgets, incentivising innovative data collection solutions (e.g., English *et al.* 2018; Paul *et al.* 2018). Motivation to participate in hydrological research is rising due to concerns about the environment, increased public education on environmental issues, and a reduction in working hours or retirement with concomitant increases in leisure time and activities (Buytaert *et al.* 2014; Walker *et al.* 2020). In 2011, the UK government marked an evolution towards bottom-up water management practices by introducing the civil society-led catchment-based (CaBA) approach, in which voluntary sector organisations (for example, the Rivers Trust) lead collaborative partnerships to manage land and water (Collins & Morse 2021). A key component of CaBA is the use of citizen science projects to build social capital and improve the local hydrological evidence base. Since its inception, over 100 CaBA partnerships have been established in catchments across England, Scotland, and Wales. However, despite the success of the CaBA initiative, its partnerships have faced numerous operational challenges such as a lack of capacity, funding and governmental support (Collins & Morse 2021; EA 2023).

User-designing support for citizen science

FDRI aims to partner with local CS initiatives, providing a suite of operational support in exchange for contributions of time, data, ideas, feedback, research, and innovation by the CS community (FDRI 2022). For FDRI, this can be a cost-effective way to optimise capacity, data collection, research, engagement and social capital creation from its capital investment, whilst generating a range of co-benefits among the citizen science groups. However, to structure this support correctly, a user-driven design is vital, which can be achieved by elicitation of actual CS stakeholder support needs.

We are not aware of any studies to date documenting ex-ante (pre-implementation) stakeholder elicitations to understand how existing hydro-ecological CS projects should be externally supported. Whilst we identified a stakeholder elicitation framework for engaging with ecological citizen scientists, this has been for the purpose of co-creating new ecological activities in the Cairngorms National Park in Scotland (Dewhurst-Richman *et al.* 2020), rather than examining how existing activities can be supported and integrated into research infrastructure. Jollymore *et al.* (2017) note that studies have generally neglected to investigate CS from the perspective of citizens; rather, focusing on ex-post reporting of successful projects based on data results (Meyer & Drill 2019; Galanos & Vogiatzakis 2022; Siddiqi *et al.* 2023). Under the growing popularity of CS, Skarlatidou *et al.* (2019) note the critical need for understanding local complexities of CS implementation through stakeholder mapping, noting that this aspect is understudied, especially in terms of investigating barriers to participation (Wiggins & Crowston 2011; Roy *et al.* 2012; Göbel *et al.* 2017; Mazumdar *et al.* 2017).

Galanos & Vogiatzakis (2022) emphasise the importance of understanding the motivations of scientists and citizens to engage in collaborative CS projects. Similarly, user-design literature strongly recommends focalising infrastructure design on stakeholder objectives ex-ante, rather than providing infrastructure and evaluating if it meets user requirements ex-post (e.g., Garrick *et al.* 2017; Zulkafli *et al.* 2017; Cantor *et al.* 2021; Maxwell *et al.* 2021; Braud *et al.* 2022; Contzen *et al.* 2023). Starting from objectives, a user design should then identify activities towards those objectives, the barriers to engaging in those activities, and subsequent support needs to address identified barriers. Doing so establishes where and how the infrastructure can create value for citizen science project stakeholders to ensure mutual long-term engagement.

Research objectives

The objectives of this study are to undertake stakeholder mapping of those who may engage with CS, to establish their objectives, activities, barriers to engagement, and determine how hydrological infrastructure can be prioritised under FDRI to address those needs in an equitable, feasible, and cost-efficient manner. We use this sequence to present the results, which were generated from analysis of 12 semi-structured key informant interviews in the Chess catchment, with additional evidence from a grey and academic literature review.

We develop this approach in the River Chess catchment (Figure 1), Buckinghamshire, which is a 'test-bed' catchment earmarked for pilot studies and intensive data collection within the FDRI infrastructure (FDRI 2022). The chalk stream originating in the chalk aquifer has a rich biodiversity, passing through the towns of Chesham and Rickmansworth (EA 2024), but has notably experienced flooding (Grieve *et al.* 2022), groundwater shortages from over-abstraction (Heppell & Morrison 2022; Thames Water 2025) and water quality problems from sewage and agricultural discharges (Thames Water 2021, 2023; Heppell & Morrison 2022; Smarter Water Catchments 2022; Parry-Wilson *et al.* 2023; BBC 2024; EA 2024; Heppell 2024; River Chess Association 2024a). The simple approach implemented in this study intends to be easily reproducible and scalable, such that FDRI and similar hydrological data infrastructures can systematically scope citizen science initiatives for integration and locally adapted support as they expand to new catchments (Wagener *et al.* 2021).

METHODS

Stakeholder mapping procedure

Stakeholder mapping is an established method to systematically identify individuals, groups, or organisations that are affected by an initiative, or could influence its outcome, and gather their inputs and perspectives (Skarlatidou *et al.* 2019). Reed *et al.* (2009) describe the identification of stakeholders as an iterative process and recommend methods of literature review, focus groups, expert opinion, semi-structured interviews, snowball sampling, or a mixture of these methods. They note that, despite using this systematic method, there is a risk that stakeholders may be missed; snowball sampling can bias the participant group due to the social network of the first participant. Durham *et al.* (2014) recommend identifying potential stakeholders pre-interview by considering relevant groups, as this can stratify relevant questions for different stakeholders and improve the awareness of researchers of the groups requiring inclusion in the sample. For example, Göbel *et al.* (2017) in their framework recognise six key stakeholder groups relating to CS:

- Civil society organisations, informal groups, non-governmental organisations (NGOs) and community members
- Academic (higher education) and research organisations
- Government agencies and departments
- Individual participants (volunteers in CS)
- Formal learning institutions, such as schools (up to secondary school level)
- Businesses or industry

FDRI started this process in 2021, with initial consultations through two online workshops and a questionnaire that informed the infrastructure's overall design (FDRI 2022). This study follows up specifically on citizen science support needs using multiple qualitative methods. We have first completed an academic, grey and informal literature review, including social media content analysis (see section 'Literature review'). This analysis created a foundation of understanding of the stakeholder landscape upon which semi-structured interviews with key informants (see section 'Semi-structured interviews') were then completed (Rabionet 2011).

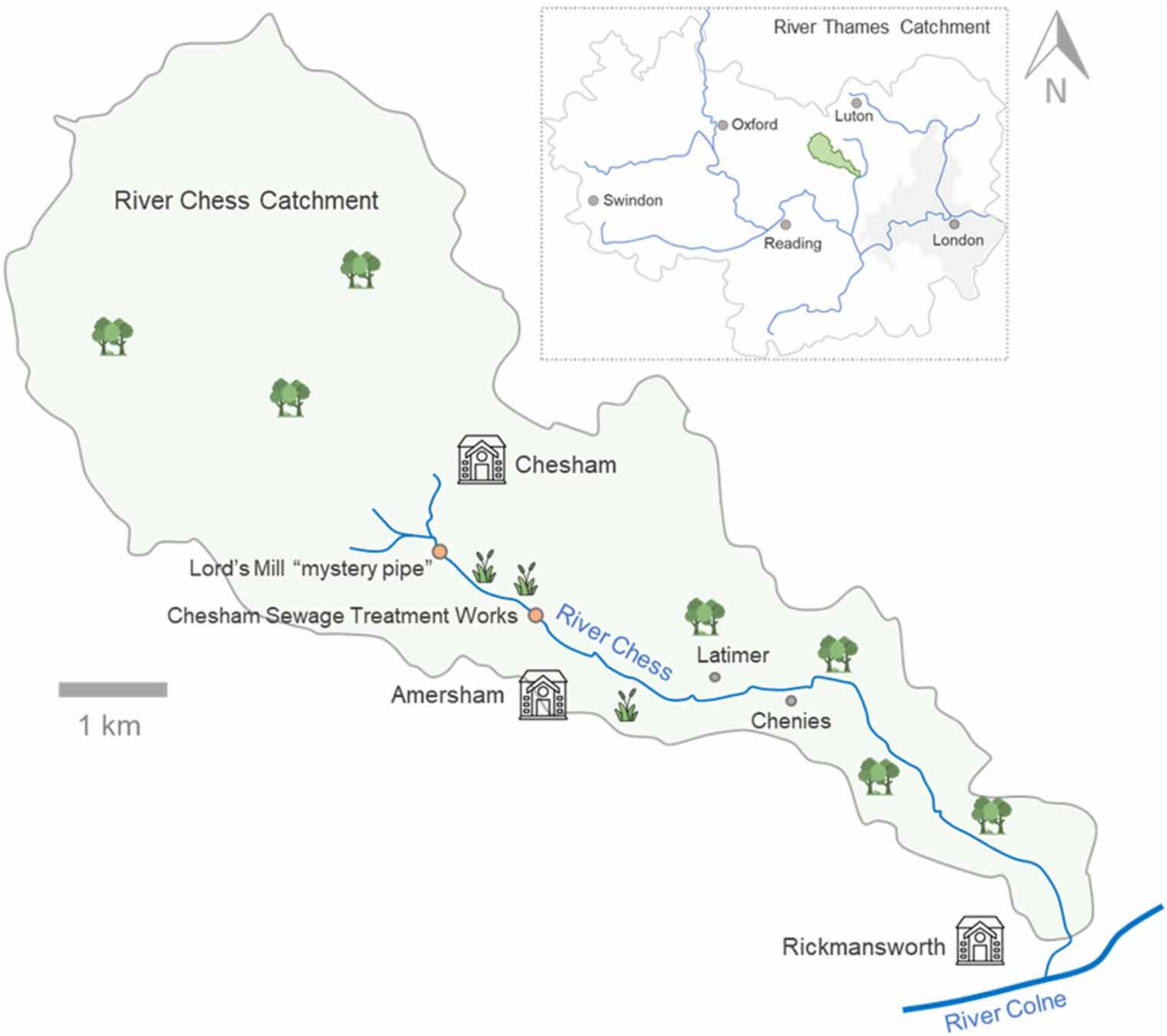


Figure 1 | The River Chess catchment. A 'mystery pipe' with artesian flow located at Lords Mill has been identified as the perennial head of the River Chess – the groundwater source of its flow is not well understood. Thames Water-owned Chesham Sewage Treatment Works (STW) is located downstream of Chesham and discharges into the main Chess channel.

Literature review

The coverage of hydro-ecological CS studies is limited in classic academic journals. Therefore, non-academic literature, stakeholder websites, grey literature documents posted on blogs and social media, and technical presentations were used in conjunction with academic literature to map CS activities and review results from previous studies. Whilst grey literature and particularly social media are not always reliable or peer-reviewed sources, they can triangulate research from other methods and gather background information that informs scoping research (Weichelt *et al.* 2020).

The primary collection of academic and grey literature followed the PRISMA methodology to systematically search through the Google Scholar database (Page *et al.* 2021). The keywords '*River Chess*' AND '*citizen science*' were required in the search results, which returned 21 studies to be included following screening of other studies based on titles, abstracts, and article content. To mitigate biased or unreliable work, the following inclusion criteria were established:

The work must be:

- An official presentation, report, document, or otherwise material directly originating from a stakeholder involved in CS in the Chess, or;
- From an official governing, regulatory, or local authority; a civil society organisation; or a reputable media source, and;
- Produced within the timeframe of active CS activities in the Chess.

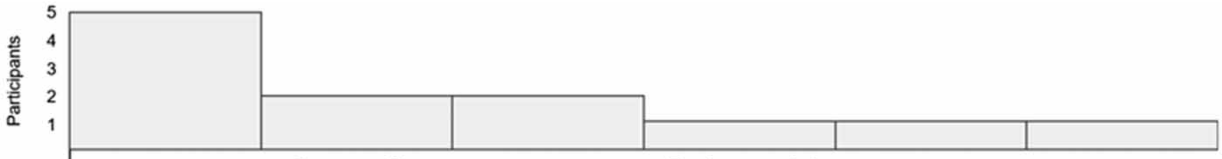
In the case of additional grey literature identified through input of the same keywords on social media (X, Facebook, LinkedIn), relevant search results were subjectively assessed in context for relevance, reliability and biased language, and filtered out if failing those criteria. In all these different formats of literature, the content specifically under review was evidence to inform a stakeholder map for the Chess catchment, including involved stakeholders, their objectives, activities, barriers to engagement and potential infrastructure support needs, which intentionally aligned with the questions asked in the semi-structured interviews. In the Results and Discussion, where literature is used as evidence in the blended multiple-methods analysis, it is included as an in-text reference.

Semi-structured interviews

Twelve semi-structured interviews were conducted with key informants involved in or possessing key knowledge of CS projects in the River Chess catchment. The semi-structured interview is the most common interview method in qualitative research (DiCicco-Bloom & Crabtree 2006), especially in CS studies, and it is recommended in stakeholder mapping frameworks (Reed *et al.* 2009; Durham *et al.* 2014; Göbel *et al.* 2017). The structured aspect of the interview ensured that objective-relevant information was captured, whilst remaining flexible for the interviewer to improvise follow-up questions based on participant responses (Rubin & Rubin 2005). This facilitates reciprocity between the participant and interviewer (Galletta 2012), providing opportunities for participants to share new knowledge outside the pre-defined scope of the interview (Kallio *et al.* 2016). The structured questions were asked as follows:

(1) Could you provide a background to your organisation and its objectives?/Could you please describe your personal objectives for getting involved in citizen science? (Citizen scientists were asked the second version to target personal goals and motivations, participants from all other organisational backgrounds were asked the first version).
(2) What citizen science projects are you aware of in the Chess catchment?
    (a) Which stakeholders are involved?
    (b) Are you/your organisation involved?
    (c) Please describe the objectives and activities of those projects.
(3) For citizen science project(s) that you are involved in:
    (a) What are the benefits for you/your organisation from engaging with the project? (incentives/reasons for engaging)
    (b) What are the benefits to your partner organisations, if applicable?
    (c) Do you feel there are any barriers to the project success, or realising the benefits which you have mentioned?
(4) What support do you need to overcome these barriers that FDRI could provide? How do you think FDRI could support you? (All participants were asked both questions)
(5) Beyond the projects that you are currently involved in, are there other hydrological data, research or other support services that you would like to see FDRI implement in the Chess catchment?

Initial key informants were identified from the literature review and prior stakeholder consultation activities (FDRI 2022). Participants were recruited by email for online interviews. Further stakeholders were identified by snowball sampling, where new participants were recommended and contacted through previous interviewees (Atkinson & Flint 2001). To mitigate the risk of snowball sampling creating a biased, unrepresentative sample, sampling was focused over time to address stakeholder or information gaps in the concurrent stakeholder mapping analysis (Durham *et al.* 2014). The final sample of 12 participants subsequently represented each of the six key CS stakeholder groups outlined in the framework of Göbel *et al.* (2017), with many also having ties to relevant academic institutions and civil society organisations outside of their main categorisation (Figure 2). This sample size was large enough to represent citizen scientists (five respondents) and major supporting stakeholder groups (seven respondents), such that significant overlap in responses was observed during thematic analysis within these groupings. Our study supports a small sample as a key objective was to demonstrate a cross-sectional approach that is feasibly scalable as research and data infrastructures expand to new areas. The scoping activity equally represents the



Organisation	Citizen Scientist	Conservation Board	Water Company	Environmental Regulator	Local Authority	Academic
Participants	5	2	2	1	1	1
Analysis Code	CS	CB	WC	ER	LA	SR

Figure 2 | Number of interview participants by stakeholder group, with associated code for pseudo-anonymisation in the analysis.

first round of stakeholder engagement in a long-term, iterative process of stakeholder elicitation by FDRI rather than a final, unchanging definition of stakeholders and their support needs (Veness *et al.* 2025b). Each participant was pseudo-anonymised in the analysis through a participant code representing their organisational background; for example, CS1 represents Citizen Scientist one.

To be recruited for an interview, participants had to meet the criteria of personal engagement with CS in the Chess catchment or a good knowledge of local activities and pressures. The study received ethical clearance through internal procedures at the UK Centre for Ecology and Hydrology, and each participant was provided with information sheets and a participant consent form to be signed prior to the interview. Each interview lasted 30–60 min and was video-recorded with participant consent for reference during thematic data analysis.

Thematic analysis

Taking an inductive, interpretive approach to thematic analysis (Walsham 2006; Park *et al.* 2020), qualitative codes were assigned to the interview responses before subjective categorisation into objective-relevant themes and sub-themes (Elliot & Timulak 2005). Two rounds of coding were completed to normalise codes and themes (Saldaña 2014), and responses to each question were coded separately. For each question, after the completion of interview thematic analysis, the literature sampled in the literature review was reviewed and relevant evidence was integrated into the narrative analysis presented in the Results and Discussion using in-text references. Visual presentation of the multiple-methods analysis used thematic plots and an interpretively designed stakeholder map. The design of the map was validated by research participants to ensure it was representative of Chess catchment stakeholders and activities. The subsequent analysis presented in the results is an interpretive narrative, subjectively written by the lead author and reviewed and edited by the study's co-authors, with some information interpreted as key from the interviews highlighted in vignette quotations (Elliot & Timulak 2005; Walsham 2006; Saldaña 2014; Park *et al.* 2020).

RESULTS AND DISCUSSION

Table 1 presents the objectives of those stakeholders and their subsequent benefits from engaging with CS projects. Outlining respective objectives in this way creates a basis for FDRI to understand where support can add genuine value to stakeholder goals (Garrick *et al.* 2017; Zulkafli *et al.* 2017; Cantor *et al.* 2021; Maxwell *et al.* 2021; Braud *et al.* 2022; Contzen *et al.* 2023). Table 2 additionally details the 11 identified CS activities and their associated objectives. After analysis of stakeholders, objectives, benefits, and their implications for FDRI infrastructure support (see section 'Stakeholder objectives and benefits of CS engagement'), we then present the barriers to engaging in those CS activities (see section 'Barriers to engagement with CS activities') and subsequent infrastructure support needs to address them (see section 'Stakeholder-Identified support needs'). A stakeholder map then presents CS stakeholders and their engagement with ongoing CS activities in the River Chess catchment (Figure 3).

Stakeholder objectives and benefits of CS engagement

The interview and literature review results both highlighted the critical role of the Chilterns National Landscape (CNL) body in coordinating CS activities in the Chess, including the Chilterns Chalk Streams Project (CCSP). Directly involved stakeholders in CCSP include Affinity Water, the Environment Agency, Thames Water, Chiltern Society, Chiltern Rangers,

Table 1 | Thematic summary of stakeholder objectives and their perceived benefits of engaging with citizen science (CS) activities in the River Chess Catchment

Stakeholder Description	Objectives	Perceived Benefits of CS Engagement
Chilterns National Landscape (CNL) CNL is hosted by the public body the Chilterns Conservation Board, setup to support environmental management of the Chiltern Hills region.	Conserve the natural beauty of the Chilterns and protect the landscape. Nature recovery and climate adaptation; for example, working with farmers and landowners to ensure more nature-friendly habitat [CB1]. Protect and enhance the health of the multiple chalk streams in the Chilterns [CB2].	• Data ○ Better understanding of local issues ○ Evaluating restoration projects • Environmental Benefits • Organisational ○ Part of meeting objectives ○ Public outreach • Community ○ Education (school and adult) • Increase engagement with activities
Chilterns Chalk Streams Project (CCSP) A partnership between statutory agencies, local authorities, and voluntary organisations hosted by CNL. The stakeholders involved in the partnership are CNL, Affinity Water, the Environment Agency, Thames Water, Chiltern Society, Chiltern Rangers, Buckinghamshire Council, and The Wildlife Trusts.	Conserve and protect the chalk streams of the Chilterns [CB2].	• Shared with Chilterns National Landscape (CNL).
Chalk, Cherries & Chairs (CC&C) A Landscape Partnership hosted by CNL.	Improve connections between the local community and the wildlife and cultural heritage of the Central Chilterns (Chalk, Cherries & Chairs, 2024a).	• Shared with Chilterns National Landscape (CNL).
Thames Water Private water company serving 16 million customers across London and the Thames Valley (Thames Water, 2024), responsible for treating the final effluent from Chesham Sewage Treatment Works (STW) [WC2].	Meet statutory obligations under the water industry national environment programme (WINEP), stakeholder value and compliance with the regulator Ofwat [WC2].	• Data ○ More data at low-cost ○ Validating models ○ Evaluating restoration projects ○ Higher resolution data • Environmental Benefits • Organisational ○ Management decision-making ○ Transparency • Community ○ Public outreach (e.g. education) ○ Land access ○ Trust, sharing and cooperation
Environment Agency (EA) National environmental regulator and public body completing environmental projects.	Protect the environment and improve the water body status to good in the Chess catchment [ER1].	• Data ○ More data at low-cost ○ Higher resolution data ○ Integrating value of local knowledge • Organisational ○ Meet objectives through improvements • Community ○ Trust, sharing and cooperation
Buckinghamshire Council A unitary authority covering the entire Buckinghamshire County.	Make Buckinghamshire a better place to live through a range of avenues such as schools, social care, roads, housing, and flood risk management [LA1].	• Data ○ Better understanding of local issues ○ Evidence-base for policy • Organisational ○ Reputation and relationships • Community ○ Education opportunity ○ Community co-benefits
River Chess Association (RCA) A civil society group formed in 2009 to advocate and actively protect the River Chess environment.	Monitor and protect the environment, raise public awareness and education, and lobby about pressures facing the Chess (River Chess Association, 2024b).	• Environmental Benefits ○ Benefits for the catchment from restoration activities ○ Restoring chalk stream health • Organisational ○ Increased credibility • Community ○ Public engagement with RCA ○ Education involvement
Wildlife Trusts – (BBOWT) and (HMWT)	Conserve wildlife, raise public awareness, and strengthen	• Data ○ Better understanding of local issues

(*Continued*.)

Table 1 | Continued

A federation of 46 charities with 900,000 total members protecting local wildlife.	people's relationship with the natural world (The Wildlife Trusts, 2024).	○ Advocacy evidence • Environmental Benefits ○ Biodiversity, density & health ○ Conservation • Organisational ○ Increased credibility ○ New members & engagement • Community ○ Public engagement ○ Education involvement
The Riverfly Partnership Network of organisations hosted by the Freshwater Biological Association.	Protect river water quality, further the understanding of riverfly populations, and conserve riverfly habitats (The Riverfly Partnership, 2024).	• Data ○ Advocacy evidence • Environmental Benefits ○ Conservation ○ Ecosystem health • Organisational ○ New members & engagement • Community ○ Public engagement ○ Education involvement
Affinity Water A private water supply company serving approximately 3.8 million customers in the South East of England [WC1]. They only supply potable water in the Chess catchment; they do not manage sewage. They have three groundwater abstraction sites in the Chess catchment [WC1].	Comply with WINEP and statutory obligations; not to abstract more than their license; stakeholder value; fulfil their WINEP commitments to try and improve the quantity and quality of the water flowing in the River Chess [WC1].	• Data ○ More data at low-cost ○ Validating models ○ Evaluating restoration projects ○ Higher resolution data • Environmental Benefits • Organisational ○ Management decision-making ○ Transparency • Community ○ Public outreach (e.g. education) ○ Land access ○ Trust, sharing and cooperation
WildFish Registered conservation charity working UK wide to protect fish populations.	Reverse the decline of wild fish populations and their habitats to create sustainable fish populations (WildFish, 2024a).	• Data ○ Advocacy evidence • Environmental Benefits ○ Conservation ○ Ecosystem health • Organisational ○ New members & engagement • Community ○ Public engagement ○ Education involvement
Academics – Queen Mary University of London and Imperial College London	Scientific research outputs, affect policy, environmental protection.	• Data ○ Improved data for research ○ Data to evaluate citizen science methods and outcomes • Organisational ○ Social responsibility & reputation ○ Basis for future research grants • Community ○ Opportunities for future collaborations
Chiltern Society A registered charity formed in 1965 working to care for the Chilterns landscape, hosting over 650 volunteers.	To conserve and care for the natural beauty of the Chilterns landscape through three key goals: celebrate, campaign, and conserve (Chiltern Society, 2025).	• Shared with Chilterns National Landscape (CNL) and citizen scientists.
Chiltern Rangers A Community Interest Company social enterprise formed in 2013 hosting conservation, education and volunteering efforts.	To provide communities in the Chilterns with rewarding experiences that conserve and enhance the local Chilterns environment (Chiltern Rangers, 2025).	• Shared with Chilterns National Landscape (CNL) and citizen scientists.
Smarter Water Catchments Partnership (SWC) A stakeholder-led 10-year plan funded by Thames Water. The organisations involved in this	SWC has six key strands: improving water quality, managing flow, managing invasive non-native species, improving wildlife corridors, involving people, and working together [WC2].	Aims to catalyse the listed benefits for its respective partners (incl. the Chilterns Conservation Board, CCSP, Thames Water, the EA, Buckinghamshire Council, the RCA, HMWT, Affinity Water, Queen

(*Continued.*)

Table 1 | Continued

partnership include the Chilterns Conservation Board, CCSP, Thames Water, the EA, Buckinghamshire Council, the RCA, HMWT, Affinity Water, Queen Mary University of London, and Chiltern Society.		Mary University of London, and Chiltern Society).
Citizen Scientists Volunteers from diverse backgrounds who participate in monitoring of the River Chess through fieldwork, data interpretation and/or data management. Most citizen scientists are involved in more than one activity; over 80% are trained in two or more methods (Parry-Wilson and Heppell, 2024). Citizen scientists are also analysed as a group to understand their objectives and align with the objectives of the organisations and other institutions.	To collect hydrological and ecological data in the River Chess. To improve the ecological health of the chalk stream and the local environment. Personal objectives (including motivations and goals for participating in citizen science) for individuals vary, including, getting outdoors, improving the local environment, desire for practical volunteering, professional relevance, relevance to hobbies, education and social opportunities.	• Environmental Benefits ○ Improve their local catchment ○ Ecosystem health • Organisational ○ Credibility for their organisations • Community ○ Education ○ Getting outdoors ○ Social benefits ○ Positive sense of contribution and achievement ○ Putting skills to positive use

Benefit themes are colour-coded into larger thematic groups of data, environmental, organisational, and community benefits.

Buckinghamshire Council, and the Wildlife Trusts. The CNL is managed by the Chilterns Conservation Board, a public-funded independent body established in 2004 to further conservation efforts and public benefits from engagement with the environment [CB1, CB2] (Chilterns National Landscape 2024). These activities are all being integrated into the Smarter Water Catchments initiative (SWC), funded by Thames Water in 2021 (Smarter Water Catchments 2024). The SWC initiative has chosen the Chess as one of its three pilot catchments, aiming to take a stakeholder-led systems approach to water and environmental management [WC2]. It has drawn in additional stakeholders, its full list comprising: Chilterns Conservation Board, Chilterns Chalk Streams Project, Thames Water, the Environment Agency, Buckinghamshire Council, the River Chess Association, Herts and Middlesex Wildlife Trust, Affinity Water, Queen Mary University of London, and Chiltern Society.

Stakeholder objectives and linked benefits of engaging with these CS partnerships and activities vary, but thematic analysis of responses identifies four common themes of data, organisational, community, and environmental benefits (Table 1). For the five citizen scientists, objectives and benefits from CS participation mostly reflect personal motivations and goals rather than institutional ones. Citizen scientists value a sense of environmental impact, an opportunity to remain socially and physically active, and being part of a like-minded, passionate community (Table 1; Bonney *et al.* 2016). The local authority representative observes that CS groups also particularly value the organisational credibility and potential impact from their activities being adopted by more formal CS partnerships [LA1].

The seven responses from the stakeholders supporting CS indicate that the respective benefits of engagement with CS vary according to background. Private water companies, such as Thames Water and Affinity Water, value additional data, the internal role of these data in organisational decision-making, and improved relationships with local communities through CS projects (Dewhurst-Richman *et al.* 2020; Butte *et al.* 2022) [WC1, WC2]. Data were also the modally identified benefit theme among respondents from environmental regulators, local authorities, academics and conservation boards. A conservation board representative highlights how the additional data can improve the characterisation of poorly understood catchment issues and further the evidence base for science, policy, and advocacy [CB1] (Sy *et al.* 2019; Dewhurst-Richman *et al.* 2020; König *et al.* 2021). These groups also have genuine, organisation-level interests in environmental benefits, which most of the CS activities actively work towards by informing practical management and policy [CB1] (Table 2). Community benefits were perceived by all supporting stakeholders. Water company representatives describe how collaborative projects help them to build networks, opportunities for collaborations, co-benefits in education and health, and improve public relations [WC1, WC2] (Silvertown 2009; Butte *et al.* 2022).

Table 2 | Citizen science (CS) activities listed in the stakeholder map (Figure 3) and their objectives

CS activity	Description	Objectives
Flow monitoring	Monitoring since 2016 with propeller flow meters in the upper reaches of the Chess to assist low flow alleviation schemes that the EA was considering [CB1, CS5]. Citizen scientists spot gauge in pairs [CS1]	Understand impacts of abstraction on river flows, both for risk of low flows and groundwater-dominated flooding [CB1]
Water quality Sondes	Established under SWC in 2019 [CB1] (Heppell 2022). Six sensors measure dissolved oxygen, pH, temperature, turbidity, and specific conductance [CB2]. Citizen scientists maintain the sensors [CS1, CB1], interpret data, and manage the water quality data dashboard [CB2, CB1]	Track impacts of sewage treatment works on river water quality and the surrounding ecosystem for accountability and advocacy [CB1]
MudSpotter	Photography of riverbanks to observe where fine sediments are occurring [CB1] for use in the design of sustainable urban drainage systems (SuDS) and other activities [CB1]	Identify sources of fine sediment inputs to the Chess
Emerging contaminants	Water samples taken at eight sites to identify up to 200 different chemicals [CB1] (Parry-Wilson & Heppell 2024)	Horizon scan new chemicals, particularly to detect if there are high-risk chemicals outside the regulatory process [CB1]
Nutrient ongoing scrutiny evaluation surveys (NOSES)	Collection of nitrate and phosphate data using portable handheld Hanna colorimeters [CB1, CB2]	Improve EA phosphate datasets by sampling at a higher spatial resolution [CB1] and understand unexplained increases in the lower reaches [CB1, CB2]
Modular river survey (MoRPh)	River habitat quality and invasive species assessment (Parry-Wilson & Heppell 2024) monitoring short 'modules' of the river less than 40 m in length (Shuker *et al.* 2017). Citizen scientists are trained through the platform Cartographer [CB1]	Measure the success of river restoration projects [CB1, CB2] and increase understanding of the habitats in the Chess [CB1]
Riverfly	Riverfly data have been collected by citizen scientists in the Chess since 2010, pre-dating the SWC initiative [CB1]. The project uses invertebrate populations as a proxy indicator for water quality	Understand spatial and temporal patterns of water quality issues such as pollution, low flows and siltation
SmartRivers	Water quality initiative by WildFish, surveying invertebrate populations in freshwater samples twice a year in spring and autumn using kick sweep samples (WildFish (2024)b) [CB1]. There are six monitoring sites along the length of the Chess	Monitor water quality pressures impacting rivers and their fish populations. Reverse the decline of wild fish populations and their habitats to create sustainable fish populations (WildFish (2024)a)
Water vole surveys	Monitoring of water voles through sightings and traces in the Chess catchment	Estimate water vole population and pressures on them (Parry-Wilson & Heppell 2024).
Pond surveys	Part of the SWC initiative [CB2], using CS to identify priority ponds, a habitat of high conservation value (Freshwater Habitats Trust 2024). Survey of over 70 ponds in the catchment, identifying important ponds for plant and invertebrate species to ascertain what conservation actions are needed (Freshwater Habitats Trust 2024)	Shared with Chilterns National Landscape (CNL)
Tracking the impact	Surveys of birds, butterflies, and plants to track their trends over time [CB1]. This activity was ongoing in the Chilterns and has extended to the Chess catchment with funding from SWC [CB2]	Evaluate the impact of wildlife conservation schemes (Chalk, Cherries & Chairs 2025)

The procedure of identifying objectives and benefits provides a useful basis of understanding for future engagements with those stakeholders, especially if a data or research infrastructure becomes actively involved in the high-level coordination of activities (Cantor *et al.* 2021; Widdicks *et al.* 2024; Veness *et al.* 2025b). For instance, topically sensitive water quality testing

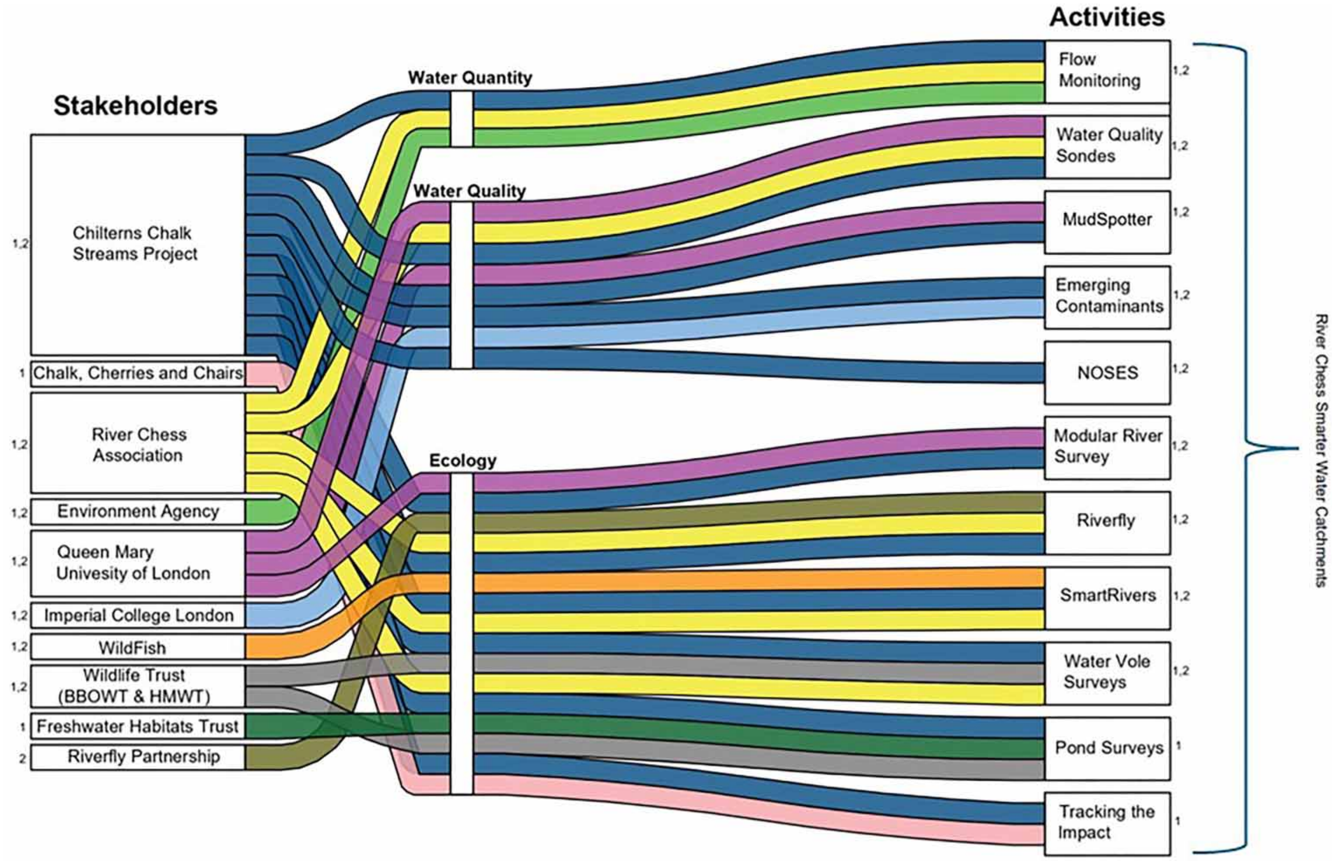


Figure 3 | Citizen science stakeholders mapped to their current activities in the River Chess catchment. The additional stakeholders listed in Table 1 (Thames Water, Affinity Water, Chiltern Society, Chiltern Rangers, Buckinghamshire Council) are stakeholders directly contributing to the Chilterns Chalk Stream Project partnership, whose activities are coordinated by the Chilterns National Landscape. These activities are now additionally being supported by the Thames Water funded 'Smarter Water Catchments' project. Subscripts 1 = identified through interview, 2 = identified through literature review.

activities such as Water Quality Sondes, SmartRivers and Riverfly (Table 2) primarily have an advocacy objective for many of the involved citizen scientists [CS4]. In contrast, Thames Water's interests in those projects through the SWC initiative are for improved datasets, fulfilment of environmental regulations, and public outreach in an area where they operate a sewage treatment works [WC2]. Recognising these differing objectives enables data and research infrastructures to appropriately tailor their communication and appeal to the different objectives of stakeholders in approaches for future partnerships (Veness & Buytaert 2025). Understanding stakeholder objectives in different CS activities can also prioritise projects for future partnership where the objectives of the CS project teams are most aligned with those of the external supporting infrastructure.

Barriers to engagement with CS activities

Identifying barriers to CS engagement is also key to understanding how FDRI can create value for stakeholders with enabling support (see section 'Stakeholder-Identified support needs'). Perceived barriers to engagement in CS activities were generally common across the different stakeholder groups (Figure 4).

Funding and resources barriers were raised in 75% of responses, including both citizen scientists and supporting stakeholders. The five citizen scientists all shared concerns about uncertain future funding from SWC following its 10-year pilot, with water companies operating under 5-year asset management plan cycles [CS1, CS2, CS3, CS4, CS5]. Other organisations, such as environmental regulators and private water companies, struggle to make additional resources available for citizen science in the current context of growing costs and decreasing agency budgets [CB1]. Related to this, four participants stated a need for additional resources dedicated to a full-time citizen science coordinator [CB1, CB2, CS1, CS3].

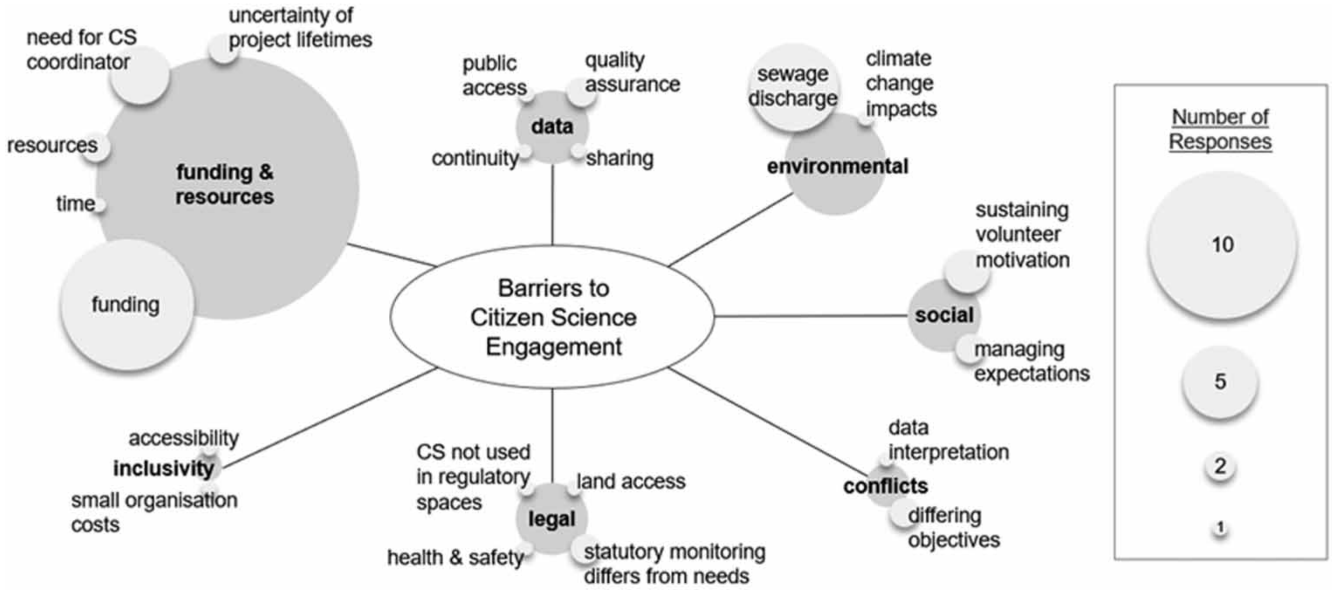


Figure 4 | Perceived barriers to engagement with CS activities, with the number of participant responses linked to each code shown.

'From what we have built up, we now understand that you certainly can't carry on these activities without a full-time citizen science coordinator that's talking to the citizen scientists, enthusing them, providing feedback, and acting between the research and data monitoring side' – [CB1]

The need for a full-time, high-level coordinator is considered causal to other barriers [CB1, CB2], notably the *social* barrier of sustaining volunteer motivations. As CS groups collect data on a voluntary basis, maintaining their enthusiasm is essential to keeping projects going and generating continuous data.

'The challenge will be to keep engagement and interest. And a lot of that will depend on the guidance from the project itself' – [CS2]

Land access is a considerable *legal* barrier requiring facilitation by coordinators, as monitoring is frequently conducted on third-party land [WC1]. Where access is legal, there can also be health and safety threats, such as safe physical access and toxic levels of water pollution in the River Chess. Water pollution is considered a serious *environmental* barrier to conducting hydro-ecological CS downstream of Chesham Sewage Treatment Works, both due to issues of safety and its adverse impacts on local ecology. Climate change is also considered an *environmental* barrier to the long-term advocacy efforts of CS activities, specifically through the intensification of weather patterns [CS4], which can pose health and safety concerns to carrying out CS activities and difficulties in interpreting findings. Challenges of *conflicts,* through differing stakeholder interests and data interpretations, are further barriers. Conflicts can arise when data interpretations presented publicly for advocacy or decision-making are disputed by another stakeholder. Supporting CS stakeholders in their capacities to interpret data through shared methods fosters a shared understanding, reducing the potential for conflict [WC1]. *Accessibility* is considered an additional barrier to the inclusivity of CS activities, particularly for those where entry to the river is required [CB2]. This can be addressed through flexibility in CS volunteer roles, tailoring activities to the needs of individuals with more accessible opportunities [CB2].

Data-related barriers include quality assurance, which is a concern for all parties [CS1, WC2] (Jollymore *et al.* 2017; König *et al.* 2021).

'we need to think of [quality assurance] rules, methods and standardisation nationally' – [WC2]

To mitigate error or bias in the sampling, documentation, and interpretation of CS data, training sessions and standard operating procedures have been provided by CNL; however, quality assurance is especially important for CS data to be perceived as usable in science, policy and management [WC2] (König *et al.* 2021; Stephens *et al.* 2024). The involvement of the local environmental regulator in quality assurance has been helpful; however, they have been unable to ensure continuous data collection for complete records [ER1].

> *'Having the continuation of data is the most valuable thing – that's where we've had problems in the Chess in the past – there's been a project, you do it for a year, it stops. And you've just got these bits of data where joining them up is next to impossible'* – [ER1]

Stakeholder-Identified support needs

Our respondents identified many opportunities for external support to address existing barriers to CS engagement, categorised into four major themes: *research support, data provision, coordination*, and *resources* (Table 3).

Research support is the most common theme of support needs reported by participants. This need arises from a shortage of technical capacity within CS projects to design and conduct research that addresses the more complex research questions of interest to CS groups in the Chess catchment (Table 3). The sub-themes are split into the major research objectives – CS groups want support with research that furthers conceptual understanding of their local hydrology, supports risk management and analysis that supports their advocacy on environmental issues (Table 3). Citizen scientist respondents especially noted that generating good research findings and seeing tangible outcomes from their efforts is central to their motivation to participate [CS1, CS2] (Table 1; Njue *et al.* 2019).

> *'It keeps you going to know what you're doing is contributing to something. Having feedback on how the project is going and any results is a good thing.'* – [CS2]

[LA1] and [CB1] suggested support that actively connects professional researchers with citizen scientists for research support. Infrastructure support through events, such as workshops and site visits, can lead to collaborative exchanges of research capacities, knowledge and data for mutual benefits (Blaney *et al.* 2016; English *et al.* 2018).

Research support can also help CS groups with access to resources and funding. While infrastructures like FDRI may provide support through rental equipment, training and citizen science events, it does not have the capacity to fund individual citizen science initiatives (FDRI 2022). However, the infrastructure and its network can support the development of research outputs that evaluate the contribution of CS activities [CB1] (Meyer & Drill 2019; Dewhurst-Richman *et al.* 2020). An example of this is Tracking the Impact (Table 2), which is evaluating the impact of local conservation schemes on local biodiversity to exemplify their value to the environment and social capital. Supporting CS stakeholders and activities in evidencing and communicating their value proposition can support them towards accessing future funding opportunities (Garrick *et al.* 2017; Meyer & Drill 2019; Dewhurst-Richman *et al.* 2020).

Data provision is also an opportunity to support CS projects, especially datasets that are not feasibly collectable through citizen science [CB2, SR1] (Veness *et al.* 2025b). For example, collecting groundwater level and quality requires access to abstraction points [SR1]. Equally, the collection of complex chemical or bacterial contaminants, flow gauge data, and satellite data such as rainfall and soil moisture can exceed the financial and technical capacities of citizen scientists [WC2].

Coordination support is desired in the River Chess primarily through supporting the provision of a citizen science coordinator [CB2]. Regular engagement is key to maintaining motivation, as well as ensuring that activities continue to meet purposeful research goals [CB1]. Integration of CS projects into a professionally coordinated infrastructure is also desired to validate data and findings through approved quality assurance procedures, clearer boundaries in roles and responsibilities, and assurance that continuous long-term datasets are collected [ER1, WC2] (Bonney 2020). Data management support through integration with other hydro-ecological datasets can also increase the use of CS data by stakeholders beyond those directly involved in projects. Increasing the ease of sharing and using data can save time in CS projects and improve the quality and quantity of associated research outputs, which is central to the fulfilment of CS objectives (Tables 1 and 2).

Generalisability of findings

Whilst many specific support requirements are Chess catchment specific, many of these broader themes of support align with the results of other studies. The demand for research support, data sharing and community creation has also been identified by FDRI's UK-wide scoping activities (FDRI 2022; Veness *et al.* 2025b), and multiple international studies in Europe and

Table 3 | Citizen science infrastructure support needs perceived by key informants, showing the frequency of sub-themes and codes within key informant responses

Theme	Sub-theme	Code (frequency)	
Research support	Research support to further conceptual understanding	Understanding the losing reach	(2)
		More understanding of the springs	(2)
		Understanding the mystery pipe	(2)
		Spring discharge drivers	(1)
		Aquifer modelling and hydrogeological understanding	(1)
		Recharge studies and land use impacts	(1)
		Further conceptualisation of the catchment	(1)
		Understanding of flows in different sections of the river	(1)
		Understanding the parallel streams	(1)
		Understanding of the winterbourne sub-catchment	(1)
	Risk management	Future climate change scenarios	(1)
	Research support	How flexible abstraction can help mitigate floods and droughts	(1)
		Investigating groundwater flooding and risk to houses	(1)
		Role of urban infrastructure during high flows	(1)
		Relationships between river water quality and drinking water	(1)
		Road runoff	(1)
		Understanding of sewage discharges	(1)
	Feedback on findings	Feedback on progress and results	(4)
	Research support for advocacy	Changes due to anthropogenic activities and climate change	(1)
		Stronger evidence base for action with abstraction	(1)
		Understanding groundwater infiltration to the sewer network	(1)
		Understanding nitrates in the upper catchment from agriculture	(1)
	Other	GW models that are up to date with observation data	(1)
		Publishing scientific work for public awareness	(1)
Data Provision	Water quality	Evidence base for new chemical contaminants	(2)
		More groundwater quality monitoring in the lower Chess	(1)
		Bacterial content	(1)
	Groundwater	More groundwater data	(1)
		GW monitoring at better temporal scales to measure flooding	(1)
	Surface water	Flow gauging during extreme events	(1)
		More field data in critical flood zones	(1)
		Expanding the flow monitoring in the lower Chess	(1)
	Other	Monitoring the wider surrounding habitat	(1)
		Rainfall data	(1)
		Soil moisture deficits	(1)
		Higher frequency monitoring	(1)
Coordination	Citizen science Coordination	Supporting a full-time citizen science coordinator	(4)
		Presence of unbiased third-party technical group	(1)
		Catchment scale approach	(1)
		Sustainable monitoring past the life of a project	(1)
	Community	Engaging the opinions of citizen scientists	(1)

(*Continued.*)

Table 3 | Continued

Theme	Sub-theme	Code (frequency)	
		Fostering social aspect alongside the work	(1)
		More engagement with local groups	(1)
		Creating links with the farmers' group	(1)
		Creating links with research	(1)
	Data management	Embedding environmental agency data with CS	(1)
		Maintaining current records	(1)
		Standardised approach for collating datasets	(1)
		Centralising the data into a digital tool for public access	(1)
		Sharing hydrological data to support farming	(1)
	Land access	Land access agreements (under time and resources)	(1)
Resources	Funding	Funding	(5)
		Resources	(1)
	Equipment	Innovative tech to meet appropriate infrastructure needs	(1)
		Automatic loggers for GW monitoring	(1)
		Low-cost technology	(1)

North America have emphasised the need to prioritise community creation and research support services for infrastructures to maintain a sustainable value proposition (Prokopy *et al.* 2017; Gaillardet *et al.* 2018; Holzer *et al.* 2019; Meyer & Drill 2019; Peek *et al.* 2020; Cantor *et al.* 2021; Tate *et al.* 2021; Galanos & Vogiatzakis 2022; Sartorius *et al.* 2024; Widdicks *et al.* 2024; Veness *et al.* 2025b). Whilst concurring findings with other studies is a useful addition to the evidence base, specific CS support needs are very specific to context and the existing activities taking place in the catchment (Veness *et al.* 2025b). Therefore, the key contribution of this research is its demonstration of a cross-sectional, ex-ante method for identifying hydro-ecological CS stakeholders, their activities and their support needs that are scalable in capturing context-specific needs as research and data infrastructures expand to new areas.

CONCLUSION

Through integrated analysis of key informant interviews, grey, and academic literature, we have constructed a detailed stakeholder map of local citizen science stakeholders, their objectives, and their activities in the River Chess catchment. Five hydrological and six ecological citizen science activities are identified, which are all principally coordinated by the publicly funded Chilterns National Landscape independent body. Our additional mapping of stakeholder objectives and their perceived benefits of engaging in CS indicates how external research and data infrastructures like FDRI can support the interests of respective stakeholders, by supporting CS projects in delivering data, environmental, organisational, and community benefits to their stakeholders. We further find a range of barriers to CS project engagement, including key issues of stakeholder motivation, project coordination, funding and environmental pollution. Understanding these can additionally guide the design of support by public infrastructure to address specific operational barriers.

The modal recommendation for support is help with conducting quality research. As CS volunteers in this study are motivated by a passion for the environment and a desire to make an impact, assistance through the full process of robust research design, data collection, analysis and interpretation can ensure that they see quality outputs with genuine use in science, advocacy, policy or practical management. If CS groups can also be supported with research that evaluates the impact of their activities, our respondents recognise that they will be better able to attract future funding, volunteers and resources through a better evidenced value proposition.

There is also demand among CS-supporting stakeholders in the Chess catchment for better high-level coordination of CS activities and their data, through the provision of a long-term, full-time CS coordinator. A dedicated coordinator can manage procedures for CS projects to share their data, with protocols for data use and quality assurance. A CS coordinator can also help satisfy CS groups' demands for additional data, through the return of additional datasets and research findings from those supporting partners.

We have presented a reproducible and scalable method for stakeholder mapping of local-scale CS projects and their support requirements. Our method enables an external infrastructure or similar initiative to approach an existing landscape of CS stakeholders with a necessary understanding of where it can add value, whilst being aware of current local issues, the potential for contrasting objectives, and existing operational barriers. We recommend systematic replication of the procedure as research and environmental data infrastructures such as FDRI expand to new areas, so that any opportunities to leverage the capacity, motivation and knowledge of existing CS projects are captured by environmental data infrastructures and considered for closer partnerships towards common objectives.

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AUTHOR CONTRIBUTIONS

W.B. and W.V. conceptualised the research. W.V. and C.F. developed the method, C.F. carried out the literature review and semi-structured interviews, and C.F. and W.V. carried out thematic analysis. C.F. and W.V. wrote the manuscript with input and critical feedback from all authors. W.B. and W.V. supervised the project.

ETHICS STATEMENT

Free and informed consent of the participants or their legal representatives was obtained, with participants provided with a participant consent form and information sheets prior to interview, and the study protocol was approved by internal ethics procedures at the UK Centre for Ecology and Hydrology.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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