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# Risk communication approaches for preventing private groundwater contamination in the Republic of Ireland: a mixed-methods study of multidisciplinary expert opinion

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## Abstract

The mechanisms of private-well groundwater contamination are uniquely complex, necessitating a multisector communicative approach to risk management, premised on behaviour promotion. In countries such as the Republic of Ireland (ROI), characterised by oftentimes high groundwater contamination risk and concurrently limited user awareness, incorporation of multidisciplinary, 'expert-based' knowledge may facilitate design of evidence-based, practical interventions. Expert interviews represent an efficient form of expert consultation, enabling ease of access to niche information and comparison of procedure, but remain under-utilised within the groundwater management literature. In response, the current study elicited opinion from 50 experts across four broad categories (communications, engineering/science, policy, and risk assessment) via a mixed-methods interview study. Semi-structured qualitative interviews were undertaken with experts from the ROI ( $n = 25$ ) and European/North American countries ( $n = 25$ ) and examined using thematic (qualitative) and bivariate statistical (quantitative) analyses. Experts noted financial cost, knowledge and social norms as primary barriers to adopting private-groundwater and other health risk-prevention behaviours. Lack of organisational knowledge as a communication barrier was significantly related to expert category ( $p = 0.034$ ) and highlighted by a majority of communications experts (95%) compared to policy (75%), risk assessment (67%) and engineering/science (50%) experts. The most frequently suggested communication activities comprised events (24%), radio segments (22%), workshops (24%) and community meetings (30%), allied with family-oriented, discursive approaches to information delivery. Study findings may be used by both national (Irish) and international stakeholders in myriad hydrogeological contexts to develop educational outreach strategies and contribute to the existing groundwater-management-knowledge base.

**Keywords** Behaviour change · Groundwater contamination · Groundwater management · Private wells · Risk communication

## Introduction

Approximately 2.2 billion people depend on groundwater for domestic use, with contamination of subsurface supplies thus posing a significant global health challenge and water

management issue (Green et al. 2011; Murphy et al. 2017). The escalating worldwide deterioration of groundwater quality stems in part from historical and progressively modern challenges in managing unregulated, largely rural private wells (Schwarzenbach et al. 2010; Funari et al. 2012). Due to the multitude of physical and temporal factors modulating contaminant ingress and significant volume of supplies in many regions, private groundwater is intrinsically difficult to manage on a broad scale (de Loë and Kreutzwiser 2005). The expanding footprint of exurban residential development, growing rural isolation from major administrative municipalities and presence of myriad local hazard sources—e.g. fertilisers, domestic wastewater treatment systems (DWWTs)—render centralised approaches (including 'integrated water resources management') increasingly unrealistic in nonurban areas (Fienen and Arshad 2016; LaGro Jr. et al. 2017). With shifting climate patterns and flood events

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accelerating the movement of enteric pathogens to and within the aquatic environment and projected to affect rural regions with increasing severity over the coming decades, there is a critical requirement for feasible solutions (Arnell and Gosling 2016). Despite implementation of a number of regulatory instruments—e.g. mandatory testing of private wells for arsenic during real estate transactions—in countries such as the United States (US), such measures are generally rare and geographically limited (Flanagan and Zheng 2017; Munene and Hall 2019). As the failure or absence of top-down management controls has placed the burden of supply protection on private well owners themselves, increased attention has been given to risk communication as a means of reducing private groundwater contamination (Fox et al. 2016).

Households failing to undertake direct well maintenance and associated measures (e.g. septic tank desludging) have frequently emerged as both agents and recipients of private groundwater contamination (Naughton and Hynds 2014). The Republic of Ireland (ROI) represents a relevant case study in view of the country's high groundwater reliance and geographically dispersed yet locally dense rural settlement pattern and typifies the need for improved end-user engagement. Approximately 16% of Irish residents (750,000 people) derive their drinking water from unregulated private wells, with many supplies vulnerable to pathogenic contamination due to their proximity to agricultural landholdings and onsite DWWTSs (CSO 2017). Owing to a recent increase in rural residential construction, ingress of effluent into private wells has become widespread and contributed to the rising national incidence of gastrointestinal illnesses such as verotoxigenic *E. coli* (VTEC)—presently nine times the EU average (Naughton and Hynds 2014; HPSC 2016). In 2012, because of the ROI's longstanding failure to regulate rural DWWTSs under the 1975 EU Waste Framework Directive (Dir. 75/442/EEC), the Irish Environmental Protection Agency (EPA) established the 'National Inspection Plan'—a national registration and inspection regime of DWWTS with an accompanying awareness campaign promoting septic tank and private well maintenance (EPA 2017). Although a number of engagement mechanisms and incentives (e.g. leaflets, domestic well improvement grants) were developed as part of the plan, to date, no coordinated, systematic risk communication strategy or public engagement policy specific to private well owners has been introduced in the ROI; moreover, rates of risk mitigation behaviours (e.g. DWWTS maintenance) have remained largely unchanged and in some cases decreased by 5% (Hynds et al. 2018a). A series of risk communication campaigns have been implemented across North America to address comparable private groundwater health risks, reported improvements in behaviour (e.g. well water testing) and awareness (e.g. contaminant knowledge) leading to measured increases of 46 and 48%, respectively (Mooney et al. 2019).

Effective risk communication comprises a key stage of natural resource management and policy and is widely considered to be predicated upon purposeful, two-way information exchange between the public and relevant groups/institutions (Covello 2003; Tavares and Santos 2014). In cases where public participation or 'bottom-up' reciprocal engagement is unfeasible or must first be preceded by one-way communication, enhanced importance is placed on the collective knowledge and alignment of 'top-down' (i.e. organisational) information disseminators. With respect to groundwater risk communication, current interventions have been noted as inadequate—categorised not only by detachment from the social and behavioural sciences, but limited consultation and integration of multidisciplinary expertise (Mitchell et al. 2012; Hynds et al. 2018b). Information pertaining to groundwater contamination risk draws from a multitude of sectors and disciplines (e.g. epidemiology, flood management, hydrogeology, microbiology) and may differ based on spatial and demographic characteristics (Re 2015). In order to gauge current communication competencies/opportunities and prompt greater synergy to this effect in groundwater policymaking, elicitation of expert observations and recommendations across associated and (perhaps) more developed fields of public engagement and risk management is necessary (Sprain et al. 2012). While several recent studies report discussion of potential private well outreach strategies in a series of multidisciplinary expert summits (Fox et al. 2016; MacDonald Gibson and Pieper 2017), additional means of expert consultation in this context, e.g. expert interviews, remain unexplored. Expert interviews have been adopted previously in broader water management spheres to highlight opportunities for stakeholder integration and capacity building and are cost-effective, providing convenient, enhanced exposure to specialist information and recommendations for practise (Flick 2014; Boholm and Prutzer 2017).

Accordingly, an exploratory interview study of 50 experts comprising national (Irish) and international participants was implemented to establish potential solutions and a basis for future groundwater communication strategies. The current study adopted an inductive mixed-methods approach combining thematic and bivariate statistical analysis and, to the authors' knowledge, represents the first attempt to elicit international, multidisciplinary expertise in the context of groundwater end-user engagement. The study sought to:

- Distinguish current intervention strategies and knowledge gaps in relevant communications, engineering/science, policy, and risk assessment spheres
- Establish central barriers to promotion and adoption of health risk prevention behaviours
- Identify optimal intervention measures to reduce contamination risk of private domestic wells

## Methodology

### Study design

Expert interviews are an effective means of attaining orientation in a novel or ill-defined field and, for the purposes of the current study, acquiring contextual, complementary information (Meuser and Nagel 2009; Flick 2014). Expert knowledge may be ‘technical’ (specialised, discipline-specific), ‘process-related’ (organisational, structural) or ‘interpretative-evaluative’ (everyday, subjective) in nature (Gläser and Laudel 2009; Flick 2014). Awareness of expert types is considered imperative in interview guide development as examined knowledge spheres often necessitate particular nuance in phraseology, question type and subject interaction depending on study objectives (Bogner and Menz 2009). The current study adopted an ‘inductive’ (qualitative) interview approach intended to optimise elicitation of in-depth observations and was not guided by theory or hypotheses as per ‘deductive’ research (Kvale and Brinkmann 2009; Flick 2014). A deductive approach typically assumes a premise and broad commonalities on the part of study subjects, which is at odds with the exploratory purpose of this study and thus is methodologically invalid.

Interviews were semistructured and accordingly employed open-ended questions, with interview guide tailored to account for information pursued and expert domain (Kvale and Brinkmann 2009). To enable comparison and aggregation of content, interviews followed a detailed thematic and topical structure for data standardisation. Final questionnaire design adhered to the ‘systematising’ expert interview paradigm, prioritising specialised knowledge derived from practice (Bogner and Menz 2009). Interview analysis followed a ‘sequential exploratory’ (mixed-methods) design in which quantitative methods are adopted to supplement qualitative data analysis via statistical analysis of key words/concepts (Terrell 2012). This analysis modality was chosen to identify and differentiate principal expert observations.

### Questionnaire structure

The questionnaire structure and codebook were developed by the lead author (SM) and independently assessed by two of the coauthors (SM, PH) until consensus was reached. Prior to commencement of the study, two pilot interviews were held with national experts in the field of health communication and policy to further refine questionnaire structure and identify necessary modifications based on question phraseology. The final questionnaire comprised six principal questions across three broad themes. Each question constituted a unique topic, as denoted in parentheses in Table 1. A series of supplementary questions (represented in italics) were formulated to yield more specific information, where necessary, and obtain

additional observations. A synopsis of groundwater contamination and associated risks in the ROI (as set out in the introduction) was presented to each study participant to contextualise the final section of the questionnaire.

### Respondent selection

The majority of experts ( $n = 26$ ) were selected using “purposive sampling” (Fig. 1). Purposive sampling stipulates selection of participants based on their relevance to the phenomena investigated and is highly strategic, enabling robust correspondence between the research question and sample (Silverman 2015). Further interviewees were identified via snowball sampling (i.e. recommendation of additional contacts by existing study participants), undertaken during finalisation of initial interviews to identify pertinent but less overt expert contacts (i.e. nonacademics or infrequently published authors) and convenience sampling (i.e. preexisting contacts). Experts were chosen upon fulfilment of  $\geq 2$  of the following criteria:

- Prominent and/or active contribution to relevant, peer-reviewed academic literature
- Recognised professional experience and/or accreditation in a relevant specialist area
- Formal representation of an appropriate interest group/stakeholder

A target of 50 expert interviews was set, with 25 assigned to national experts (ROI) and 25 assigned to international experts. In order to ensure broad comparability with the ROI, international experts were selected from developed countries including: Canada ( $n = 2$ ), England, UK ( $n = 3$ ), Italy ( $n = 2$ ), Netherlands ( $n = 2$ ), Switzerland ( $n = 1$ ) and the US ( $n = 15$ ). Notwithstanding the existence and importance of place-specific factors (e.g. local geology, settlement patterns), the majority of developed countries are characterised by similar sources and pathways of groundwater contamination (Hynds et al. 2014). Behavioural and communicative impediments akin to those encountered in the ROI (e.g. financial barriers, rural isolation) are also noted in other developed regions (Ford et al. 2017).

Experts were drawn from 16 specialisation types across professional sectors (Table 2) and four broad categories: communications ( $n = 21$ ), engineering/science ( $n = 10$ ), policy ( $n = 4$ ) and risk assessment ( $n = 15$ ). The allocation was intended to reflect the multidimensionality of groundwater risk management and considered appropriate relative to knowledge type (negating potential over-saturation; Saunders et al. 2018). The nature of existing literature and study objectives dictated that the majority of experts with former or current involvement in groundwater and public

**Table 1** Expert interview questionnaire and thematic structure

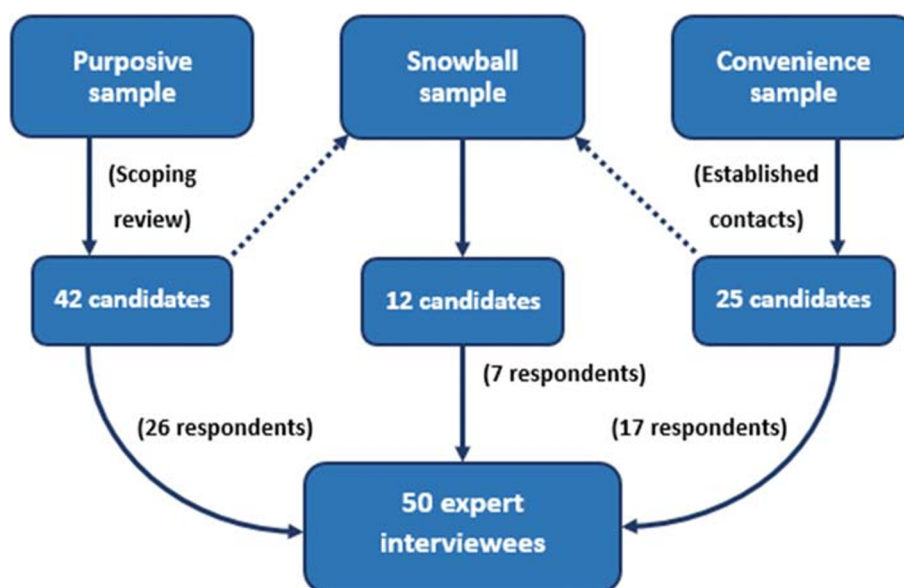
Questionnaire section	Questions
Section 1: current status	1. What existing efforts are being made to incorporate target audience profiles and/or communication theory in relevant interventions? [state-of-the-art] - Have you observed or made any efforts to enhance information legibility via 'message tailoring/framing'? - Have you observed or used any metrics to evaluate the effectiveness of interventions?
Section 2: barriers	2. To what extent are relevant interventions currently integrated with overarching management, policy or regulatory frameworks? [policy context] 3. What are some of the key challenges or disincentives preventing uptake of desired behaviours from target audiences? [target audience] 4. What are the main impediments to intervention development and success and how may these be addressed? [intervention coordinators] - Do you think the current extent of stakeholder collaboration in interventions is adequate? - In your opinion, has this intervention topic been given appropriate coverage in the media?
Section 3: optimal approaches	5. What reach or multi-scalar structure would you recommend a national private groundwater risk communication intervention adopt and why? [structure] 6. What intervention components (i.e. engagement mechanisms, strategies) may be most productive or viable in this context? [activities]

health outreach initiatives originate outside of the ROI. A recent global review by Mooney et al. (2019) identified 15 groundwater risk interventions in North America and an absence of such initiatives in Europe.

### Data collection

Experts were invited to take part in the study via email or phone and presented with a brief synopsis of the overarching research project, objectives and interview content, in addition to a

project-related link. The email/phone conversation specified recording of interview for transcription purposes and a guarantee of confidentiality. Upon receipt of confirmed participation and availability, experts were recontacted and provided the option of undertaking the interview via Skype, phone call or in person (national only). Interviews were undertaken from June to November 2018, with all audio files continuously anonymised and archived in a single, centralised digital file. Following completion of data collection and transcription, all identifiable data were deleted and oral recordings encrypted.

**Fig. 1** Schematic of expert selection protocol

**Table 2** List of interviewed experts by specialisation category, location, professional sector and specialisation

Specialisation category	Location	Case No. (country) <sup>a</sup>	Professional sector	Specialisation
Communications	International (IC)	IC1 (US)	Academia/research	Health communication
		IC2 (US)	Civil service	Health communication
		IC3 (Italy)	Consultancy	Science communication
		IC4 (US)	Academia/research	Environmental communication
		IC5 (England)	Academia/research	Flood communication
		IC6 (US)	Academic/research	Water communication
		IC7 (US)	Consultancy	Risk communication
		IC8 (US)	Academia/research	Communications management
		IC9 (US)	Academia/research	Environmental communication
		IC10 (England)	Academia/research	Flood communication
		IC11 (Netherlands)	Consultancy	Flood communication
	National (NC)	NC1 (ROI)	Civil service	Communications management
		NC2 (ROI)	Consultancy	Communications management
		NC3 (ROI)	Academia/research	Risk communication
		NC4 (ROI)	Civil service	Health communication
		NC5 (ROI)	Academia/research	Science communication
		NC6 (ROI)	Consultancy	Communications management
		NC7 (ROI)	Consultancy	Communications management
		NC8 (ROI)	Academia/research	Science communication
		NC9 (ROI)	Civil service	Flood communication
NC10 (ROI)	Civil service	Communications management		
Engineering/science	International (IES)	IES1 (Canada)	Academia/research	Microbiology
		IES2 (England)	Civil service	Hydrogeology
		IES3 (US)	Civil service	Microbiology
		IES4 (Canada)	Academia/research	Hydrogeology
		IES5 (US)	Academia/research	Hydrogeology
		IES6 (Italy)	Academia/research	Hydrogeology
	National (NES)	NES1 (ROI)	Civil service	Environmental engineering
		NES2 (ROI)	Civil service	Hydrogeology
		NES3 (ROI)	Civil service	Environmental engineering
		NES4 (ROI)	Civil service	Hydrogeology
Policy	International (IP)	IP1 (US)	Academia/research	Groundwater policy
		IP2 (Switzerland)	Civil service	Groundwater policy
	National (NP)	NP1 (ROI)	Civil service	Water policy
		NP2 (ROI)	Consultancy	Environmental policy
Risk assessment/ management	International (IRA)	IRA1 (US)	Academia/research	Water resource management
		IRA2 (US)	Academia/research	Water resource management
		IRA3 (US)	Academia/research	Health risk assessment
		IRA4 (US)	Civil service	Water resource management
		IRA5 (Netherlands)	Consultancy	Water resource management
		IRA6 (US)	Civil service	Water resource management
	National (NRA)	NRA1 (ROI)	Academia/research	Water resource management
		NRA2 (ROI)	Academia/research	Water resource management
		NRA3 (ROI)	Civil service	Health risk assessment
		NRA4 (ROI)	Civil service	Environmental assessment
		NRA5 (ROI)	Civil service	Water resource management
		NRA6 (ROI)	Civil service	Environmental assessment
		NRA7 (ROI)	Civil service	Water resource management
		NRA8 (ROI)	Civil service	Health risk assessment
NRA9 (ROI)	Academia/research	Health risk assessment		

<sup>a</sup> Numbers were appended to each case (expert) based on alphabetical order of surname

## Data analysis

### Qualitative data analysis

Interview transcripts were exported to NVIVO 12 Plus qualitative data analysis software (QDAS) for coding and thematic qualitative analysis. NVIVO emerged as the optimal QDAS due to its organisational tools (enabling management of large datasets) and reduction of manual tasks via search functions (AlYahmady and Alabri 2013). Prior to final, formal coding on NVIVO, ‘line-by-line’ annotations (guided by question topic/section) were used to refine the coding structure. Two ‘macro codes’ (subthemes) were formulated for each questionnaire topic, with ‘micro codes’ developed to identify frequency of key terms and processes and enable detailed comparison between ‘cases’ (i.e. interviewee categories). Codes were stored in NVIVO as ‘nodes’ (units of storage for code titles and content) in correspondence with the hierarchy set out in Fig. 2. Interview transcripts were divided into two broad cases (national and international) and accordingly grouped under predetermined expert specialisation category. Classifications were appended to each individual case (Table 2) to facilitate comparison via ‘queries’ (database searches based on interviewee attributes and values).

Thematic analysis was undertaken in accordance with criteria set out by Braun and Clarke (2014). Thematic analysis prioritises establishing meanings and themes across data sets and cases and is thus optimal for large-scale qualitative analysis. Themes, topics and subthemes were developed a priori (or deductively) based on study objectives and generic audience communication/engagement factors outlined by Rowe and Frewer (2005) and Atkin and Rice (2012). Micro-codes were developed part-inductively based on emergent phenomena deriving from interviewee responses.

### Quantitative data analysis

The NVIVO search query was used to establish the numeric frequency and occurrence of variables (interview codes) by expert location and specialisation. Dichotomous and continuous variables were imported to IBM SPSS Statistics 25 for statistical analysis. In light of the study’s small sample size ( $n = 50$ ), only nine variables were included for analysis. Significance of association between categorical variables (e.g. expert location and cited barriers) was measured using Pearson chi-square tests of independence. Independent samples t-tests were adopted to establish the relationship between expert location and scale variables (e.g. number of target audience barriers). One-way analysis of variance (ANOVA) and Bonferroni post-hoc tests were used to determine the significance of association between expert specialisation category and scale variables. All statistical analyses were performed using IBM SPSS 22, with the confidence level set at 90% ( $p < 0.10$ ) in consideration of the small participant sample size and probability of both type I and type II errors.

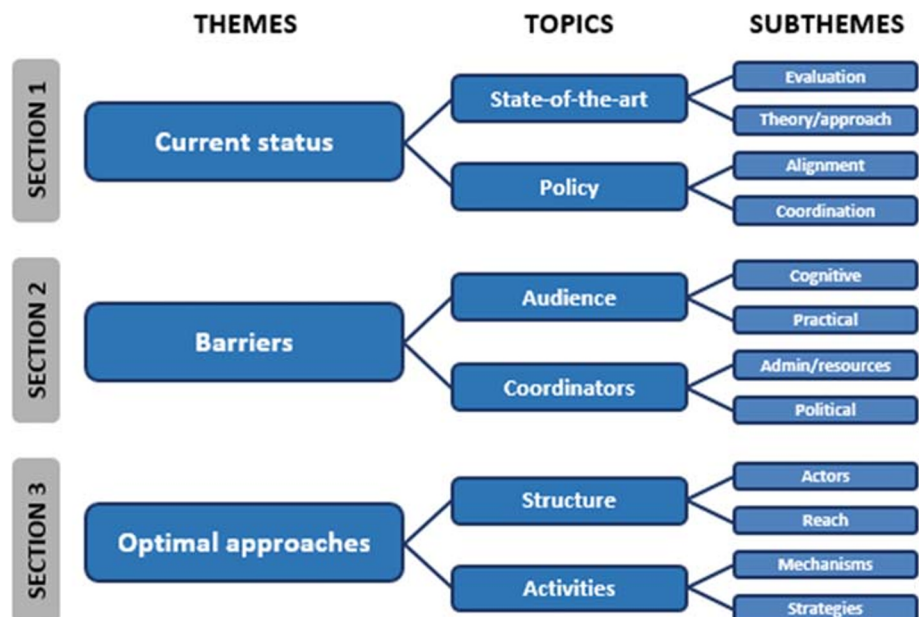
## Results

### Current status of interventions

#### Intervention approaches

Cited approaches to groundwater risk communication varied considerably, with international experts referencing a range of active initiatives including cooperative extension, electronic workshops and incentivised well testing services. Opportunities for private well user engagement within the

**Fig. 2** Thematic map of interview coding hierarchy



ROI were observed to be less frequent; national experts noted an absence of ‘push’ information (e.g. media advertisements) provided by government authorities. International groundwater policy experts (referring to the EU and US, respectively) posited that interventions and amenable policies may be situationally dependent. IP1 (policy expert, US) highlighted the importance of political discourse and differing geological or point/nonpoint-source-risk profiles in determining engagement opportunities with private well owners:

Every US state is different. In a number of the eastern seaboard states like New York and New Jersey, fracking has been one of the chief instigators of public participation over the last 5, 6, 7, 8 years. In Pennsylvania, they’ve had a similar kind of public discourse.

International experts operating within flood and health risk assessment spheres referred to development of an increasing number of interpersonal initiatives at municipal or sub county level in the context of risk communication. ‘Cooperative extension programmes’ were cited by 16% ( $n = 4$ ) and citizen science initiatives (e.g. participatory flood risk assessments) by 24% ( $n = 6$ ) of international experts. While desire was expressed for similar, interpersonal (i.e. face-to-face) forms of information exchange in the ROI among risk assessment experts, Ireland’s settlement pattern and county government structure were viewed as an impediment to local engagement by NRA8 (national risk assessment expert):

Local authorities have a role but something we don’t do well in this country is the breakdown of ‘below-local authority area’. We don’t have a framework in this country for doing that at all. We’ve actually got nothing at that lower level and maybe that’s part of what we’re missing.

### Intervention design and theory

Campaign design and evaluation metrics (e.g. post-intervention surveys) were observed to be most comprehensive and advanced in large-scale human health risk scenarios, with both national and international health communication experts citing established communication campaign procedures, e.g. ‘formative’, ‘process’ and ‘summative evaluation’. The majority of civil servants (67%,  $n = 14$ ) referred to data tracking methods such as website clicks but also noted under-utilisation of behavioural surveys and formative evaluation at government/state agency level.

Incorporation of formal procedures in communication campaign design was inconsistent across professional sectors. While both national and international civil servants within communications management referred to measures such as

adoption of ‘plain English’ guidelines to screen communicative information for legibility and clarity, application of communication procedures and campaign design was generally greater among consultants and academics. In the context of international flood risk, IC5 (communications expert – England) noted a clear dichotomy in approach between academia and government:

I think there’s been an ongoing divide between the work that’s going in academia, which is looking much more at models of knowledge exchange and co-generation around risk information and the models of communication that might be used by agencies around flood risk, which tend to be more of the broadcast model.

Behavioural, cognitive or communication theories were referenced by 14 experts (28%). The greatest number was provided by communications experts, of which 52% ( $n = 11$ ) mentioned  $\geq 1$  recognised theories (see [Appendix](#)). The proportion of experts citing theories was similar based on location (32% international vs. 24% national), though international experts presented a greater number of approaches (17 compared to 8 for national experts). In the ROI, adoption of theoretical measures was deemed minimal by NC3 (national communications expert):

In terms of a theoretical component, I’m not totally convinced that the risk communication material in Ireland has been informed by an in-depth appreciation of risk theories like protection motivation theory or the health belief model or any kind of theory that’s based on understanding what triggers a perception.

## Barriers

### Household barriers

A total of 20 distinct barriers to adoption of household risk mitigation behaviours were identified. Cognitive barriers to desired audience behaviour were cited by 92% ( $n = 46$ ) of experts and practical barriers by 80% of experts ( $n = 40$ ). The most frequently referenced barriers were financial cost ( $n = 30$ ) and knowledge ( $n = 30$ ), as outlined in [Table 3](#). No significant difference was observed geographically, with an equal proportion of national and international experts citing  $\geq 1$  practical barriers (80%). Effort (8/12) and financial cost (17/30) were considered primarily by academics/researchers and location (6/8) by civil servants.

Imperceptibility and capability were noted as important behavioural impediments by communications experts in multiple risk contexts. Communications experts noted that self-determined efficacy in executing maintenance actions and



**Table 3** Target audience barriers cited by experts based on expert category and location

Barriers	Expert specialisation categories																								
	Communications ( <i>n</i> = 21)					Engineering/science ( <i>n</i> = 10)					Policy ( <i>n</i> = 4)					Risk assessment ( <i>n</i> = 15)					All ( <i>n</i> = 50)				
	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)				
Cognitive (≥1)	11 (100)	8 (80)	19 (90)	6 (100)	4 (100)	10 (100)	2 (100)	1 (50)	3 (75)	6 (100)	8 (89)	14 (93)	25 (100)	21 (84)	46 (92)										
Awareness	4 (36)	5 (50)	9 (43)	3 (50)	1 (25)	4 (40)	–	–	–	3 (50)	6 (67)	9 (60)	10 (40)	12 (48)	22 (44)										
Education	1 (9)	1 (10)	2 (10)	2 (33)	–	2 (20)	–	–	–	1 (17)	1 (11)	2 (13)	4 (16)	2 (8)	6 (12)										
Experience	4 (36)	2 (20)	6 (29)	1 (17)	1 (25)	2 (20)	1 (50)	–	1 (25)	2 (33)	4 (44)	6 (40)	8 (32)	7 (28)	15 (30)										
Fatalism	2 (18)	2 (20)	4 (19)	–	1 (25)	1 (10)	–	–	–	–	–	–	2 (8)	3 (12)	5 (10)										
Imperceptibility	4 (36)	1 (10)	5 (24)	1 (17)	2 (50)	3 (30)	–	–	–	3 (50)	3 (33)	6 (40)	8 (32)	6 (24)	14 (28)										
Knowledge	5 (45)	8 (80)	13 (62)	5 (83)	2 (50)	7 (70)	1 (50)	–	1 (25)	3 (50)	6 (67)	9 (60)	14 (56)	16 (64)	30 (60)										
Mistrust	2 (18)	3 (30)	5 (24)	1 (17)	–	1 (10)	1 (50)	–	1 (25)	–	2 (22)	2 (13)	4 (16)	5 (20)	9 (18)										
Norms	6 (55)	3 (30)	9 (43)	4 (67)	1 (25)	5 (50)	2 (100)	–	2 (50)	2 (33)	5 (56)	7 (47)	14 (56)	9 (36)	23 (46)										
Optimism bias	2 (18)	–	2 (10)	1 (17)	–	1 (10)	–	–	–	–	1 (11)	1 (7)	3 (12)	1 (4)	4 (8)										
Short-termism	3 (27)	2 (20)	5 (24)	1 (17)	2 (50)	3 (30)	–	–	–	–	–	–	4 (16)	4 (16)	8 (16)										
Stigma	1 (9)	3 (30)	4 (19)	–	1 (25)	1 (10)	–	1 (50)	1 (25)	–	–	–	1 (4)	5 (20)	6 (12)										
Practical (≥1)	9 (82)	8 (80)	17 (81)	5 (83)	4 (100)	9 (90)	–	1 (50)	1 (25)	6 (100)	7 (78)	13 (87)	20 (80)	20 (80)	40 (80)										
Capability	5 (45)	3 (30)	8 (38)	–	–	–	–	–	–	–	–	–	5 (20)	3 (12)	8 (16)										
Conflicting info	2 (18)	1 (10)	3 (14)	2 (33)	–	2 (20)	–	–	–	1 (17)	2 (22)	3 (20)	5 (20)	3 (12)	8 (16)										
Effort	4 (36)	3 (30)	7 (33)	1 (17)	1 (25)	2 (20)	–	–	–	2 (33)	1 (11)	3 (20)	7 (28)	5 (20)	12 (24)										
Financial cost	6 (55)	5 (50)	11 (52)	4 (67)	4 (100)	8 (80)	–	1 (50)	1 (25)	5 (83)	5 (56)	10 (67)	15 (60)	15 (60)	30 (60)										
Lack of info	3 (27)	3 (30)	6 (29)	2 (33)	1 (25)	3 (30)	–	–	–	3 (50)	1 (11)	4 (27)	8 (32)	5 (20)	13 (26)										
Location	1 (9)	1 (10)	2 (10)	1 (17)	2 (50)	3 (30)	–	1 (50)	1 (25)	–	2 (22)	2 (13)	2 (8)	6 (24)	8 (16)										
Privacy	–	–	–	–	1 (25)	1 (10)	–	–	–	1 (17)	–	1 (7)	1 (4)	1 (4)	2 (4)										
Time	5 (45)	1 (10)	6 (29)	2 (33)	–	2 (20)	–	–	–	1 (17)	3 (33)	4 (27)	8 (32)	4 (16)	12 (24)										
Weather	1 (9)	–	1 (5)	–	–	–	–	–	–	–	–	–	1 (4)	–	1 (2)										

perceived benefit may strongly dictate willingness to adopt risk mitigation behaviours. Spatial and temporal factors were given particular weight by flood and science communication practitioners. In referring to dissemination of scientific information, IC3 (communications expert, Italy) regarded communication of gradual, less tangible risks as a particular challenge in encouraging behavioural change:

I don't trust when scientists say that the major barrier is scientific literacy. I don't accept this. So I wouldn't say scientific literacy is the biggest barrier to jump, to overcome—especially in environmental communication. In my opinion, the chief barrier is that most environmental issues, if they are not catastrophic (like groundwater contamination), are very subtle, very slow to happen.

Prior experience was considered a significant determinant of action by experts in flood communication. Experts specialising in environmental and health risk management also noted fatalism and 'active forgetting' on the part of previous flood victims, which may impede subsequent adoption of protective behaviours. Experts with experience in drinking water interventions pinpointed lack of information and social norms (i.e. established conventions or values) as key impediments to domestic drinking water stewardship. Household and cultural practices were observed to play a significant part in determining the extent of supply protection in both developed and developing nations.

Lack of technical knowledge in risk mitigation steps requiring direct maintenance or retrofitting was repeatedly referenced by engineers across flood, health and groundwater management contexts. Hydrogeologists and policymakers in the ROI viewed the nonbinding nature of well construction guidelines and absence of step-by-step maintenance information and as longstanding barriers to private well maintenance nationally, with similar views expressed by international experts. Experts noted imperceptibility of groundwater contamination risk as an additional impediment and highlighted the importance of organoleptic (sensorial) factors in determining well owner risk perceptions. Referring to risk of arsenic and geochemical contamination in groundwater, IC9 (communications expert, US) noted the following:

A lot of people are just not aware of arsenic – that it can be naturally occurring and that's it in their area and that it can be in their well. I'd say that drinking water is very aesthetically driven. So if it tastes good, if it smells good, if it looks good, people are not going to be very concerned about there being a problem because it just doesn't register.

In addition to knowledge and cost, experts in health and environmental risk assessment placed significant importance on

'short-termism' and 'social norms' as behavioural impediments. The relative novelty of health risks to householders was considered crucial as pre-existing, known risks were considerably more likely to be absorbed into heuristic structures (or cognitive 'rules of thumb') determining low level of personal risk. To this end, IC8 (communications expert, US) affirmed the need to demonstrate tangible benefits (and threats) to audiences:

They're going to take this time, it's going to disrupt their schedule, it's going to cost them money and, at the end, there will be nothing different in their minds. So you have to have some very clear indicators. Maybe you could have a personal water quality test that could be built in – so you can see that the quality of your water is better.

### Organisational barriers

Organisational barriers (i.e. impediments to current and prospective intervention coordinators) were divided into two categories (Table 4): administrative/political and resources. While resource-based barriers were referenced frequently (88%,  $n = 44$ ), all experts discussed  $\geq 1$  administrative/political barriers. The majority of experts (76%,  $n = 38$ ) alluded to a deficit of communication campaign expertise at government level and potential lack of stakeholder alignment. Communication practitioners most vigorously highlighted the comparative lack of communications experience in other disciplines. NC4 (national communications expert) stated the following:

I think lack of professional (in a theoretical way) communications expertise in organisations is a barrier. It tends not to stop people doing campaigns but it does impact on the nature and the quality of them. One issue that I feel strongly about is a lot of communications work in public service can be focused on output as opposed to impact and value.

Staff turnover was considered a universal challenge, particularly among civil servants and experts in risk assessment/management and communications, who cited over-reliance on specialist staff or 'champions' in design and implementation of campaigns. Lack of subsequent follow-through upon departure of key staff indicated an absence of long-term departmental structures or monetary streams to support campaign development.

In discussing barriers specific to private well outreach, experts collectively emphasised the need to persuade policymakers of the benefits of enhanced communication and recommended adoption of educational modules at government levels. The acknowledged lack of consistent, strategic groundwater risk information was also associated with limited consultation of nonstate

**Table 4** Organisational barriers cited by experts based on expert specialisation category and location

Barriers	Expert specialisation categories																								
	Communications ( <i>n</i> = 21)					Engineering/science ( <i>n</i> = 10)					Policy ( <i>n</i> = 4)					Risk assessment ( <i>n</i> = 15)					All ( <i>n</i> = 50)				
	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)				
Administrative and political ( $\geq 1$ )	11 (100)	10 (100)	21 (100)	6 (100)	4 (100)	10 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	4 (100)	6 (100)	9 (100)	15 (100)	25 (100)	25 (100)	25 (100)	25 (100)	25 (100)	50 (100)				
Audience heterogeneity	6 (55)	2 (20)	8 (38)	–	–	–	–	–	–	–	–	–	2 (33)	1 (11)	3 (20)	8 (32)	3 (12)	3 (12)	3 (12)	3 (12)	11 (22)				
Awareness	1 (9)	1 (10)	2 (10)	–	2 (50)	2 (20)	–	–	–	–	–	–	1 (17)	1 (11)	2 (13)	2 (8)	4 (16)	4 (16)	4 (16)	4 (16)	6 (12)				
Commitment	8 (73)	7 (70)	15 (71)	1 (17)	3 (75)	4 (40)	–	–	–	–	–	1 (25)	2 (33)	5 (56)	7 (47)	11 (44)	16 (64)	16 (64)	16 (64)	16 (64)	27 (54)				
Competing information sources	4 (36)	6 (60)	10 (48)	1 (17)	–	1 (10)	2 (100)	–	–	–	–	2 (50)	1 (17)	1 (11)	2 (13)	8 (32)	7 (28)	7 (28)	7 (28)	7 (28)	15 (30)				
Geographical location	1 (9)	2 (20)	3 (14)	–	1 (25)	1 (10)	–	–	–	–	–	–	–	2 (22)	2 (13)	1 (4)	5 (20)	1 (4)	5 (20)	5 (20)	6 (12)				
Interest	2 (18)	5 (50)	7 (33)	3 (50)	1 (25)	4 (40)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	4 (100)	3 (50)	4 (44)	7 (47)	10 (40)	12 (48)	10 (40)	12 (48)	12 (48)	22 (44)				
Knowledge	11 (100)	9 (90)	20 (95)	3 (50)	2 (50)	5 (50)	1 (50)	2 (100)	2 (100)	2 (100)	2 (100)	3 (75)	5 (83)	5 (56)	10 (67)	20 (80)	18 (72)	20 (80)	18 (72)	18 (72)	38 (76)				
Policy	2 (18)	2 (20)	4 (19)	4 (67)	3 (75)	7 (70)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	4 (100)	4 (67)	6 (67)	10 (67)	12 (48)	13 (52)	12 (48)	13 (52)	13 (52)	25 (50)				
Priority	1 (9)	3 (30)	4 (19)	4 (67)	2 (50)	6 (60)	2 (100)	1 (50)	1 (50)	1 (50)	1 (50)	3 (75)	2 (33)	5 (56)	7 (47)	9 (36)	11 (44)	9 (36)	11 (44)	11 (44)	20 (40)				
Public acceptance	9 (82)	7 (70)	16 (76)	2 (33)	1 (25)	3 (30)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	4 (100)	3 (50)	4 (44)	7 (47)	16 (64)	14 (56)	16 (64)	14 (56)	14 (56)	30 (60)				
Stakeholder alignment	6 (55)	7 (70)	13 (62)	3 (50)	3 (75)	6 (60)	2 (100)	1 (50)	1 (50)	1 (50)	1 (50)	3 (75)	4 (67)	8 (89)	12 (80)	15 (60)	19 (76)	15 (60)	19 (76)	19 (76)	34 (68)				
Resources ( $\geq 1$ )	8 (73)	8 (80)	16 (76)	6 (100)	4 (100)	10 (100)	2 (100)	2 (100)	2 (100)	2 (100)	2 (100)	4 (100)	6 (100)	8 (89)	14 (93)	22 (88)	22 (88)	22 (88)	22 (88)	22 (88)	44 (88)				
Funding	8 (73)	6 (60)	14 (67)	5 (83)	2 (50)	7 (70)	1 (50)	2 (100)	2 (100)	2 (100)	2 (100)	3 (75)	5 (83)	6 (67)	11 (73)	19 (76)	16 (64)	19 (76)	16 (64)	16 (64)	35 (70)				
Personnel	3 (27)	4 (40)	7 (33)	3 (50)	2 (50)	5 (50)	2 (100)	1 (50)	2 (100)	1 (50)	2 (100)	3 (75)	2 (33)	4 (44)	6 (40)	10 (40)	11 (44)	10 (40)	11 (44)	11 (44)	21 (42)				
Time	2 (18)	1 (10)	3 (14)	–	2 (50)	2 (20)	1 (50)	–	–	–	–	1 (25)	2 (33)	4 (44)	6 (40)	5 (20)	7 (28)	5 (20)	7 (28)	7 (28)	12 (24)				

actors (e.g. well drilling companies, NGOs). With reference to groundwater communication in the ROI, NES4 (national engineering/science expert) reiterated the over-reliance on individual will to compensate for low risk prioritisation and absence or misalignment of stakeholders:

It's very ad hoc and it's very much on a 'who do you know' kind of basis. It's down to the personalities rather than someone at a fairly high level in government or a state organisation saying this is a function that really has to be done and undertaken.

### Associations between expert categories and cited barriers

The six most frequently cited barriers across organisational and target audience categories were included for statistical analysis (Table 5). With respect to expert location, there was no significant difference found across the six variables; however, citation of knowledge as organisational barrier was significantly associated with expert discipline category ( $\chi^2 = 8.686$ ,  $p = 0.034$ ). Knowledge was cited as an organisational barrier by 95% ( $n = 20$ ) of communications experts, compared to 75% ( $n = 3$ ) within policy, 67% ( $n = 10$ ) within risk assessment and 50% ( $n = 5$ ) within engineering/science. The difference in total number of cited organisational barriers based on expert discipline category was also statistically significant ( $\chi^2 = 2.361$ ,  $p = 0.084$ ). A mean number of eight organisational barriers were cited by policy experts, followed by six by risk assessment experts, six by communications experts and five by engineering/science experts.

### Optimal approaches

#### Recommended engagement mechanisms

The majority of respondents recommended adoption of both interpersonal and media-based means of communication in private well risk interventions (Table 6), with interpersonal mechanisms marginally preferred (76%,  $n = 38$ ). Community meetings (30%,  $n = 15$ ), event booths (24%,  $n = 12$ ), workshops (24%,  $n = 12$ ) and school programmes (20%,  $n = 10$ ) were the most favoured interpersonal mechanisms. With regard to media-based mechanisms (electronic and print), both traditional broadcast media and internet channels were recommended. Experts demonstrated the efficacy of radio segments (22%,  $n = 11$ ) and newspaper articles (16%,  $n = 8$ ) in ensuring wide audience coverage in rural areas, while also emphasising the importance of online channels as 'collateral' sources, accounting for less communal audiences and serving as information repositories. Water sample testing (14%,  $n = 7$ ) was the most frequently recommended service mechanism and recommended in conjunction with monetary incentives on four occasions.

**Table 5** Bivariate analysis of cited organisational and behavioural barriers by expert location and specialisation category

Variable(s)	Test statistic <sup>a</sup>	<i>P</i> value
Organisational barriers (no/yes)		
Funding		
Location	0.857	0.355
Specialisation category	0.283	0.971
Knowledge		
Location	0.439	0.508
Specialisation category	8.686	0.034**
Stakeholder alignment		
Location	1.471	0.225
Specialisation category	1.735	0.629
No. of organisational barriers		
Location	-0.866	0.391
Specialisation category	2.361	0.084*
Target audience barriers (no/yes)		
Awareness		
Location	0.325	0.569
Specialisation category	4.777	0.189
Knowledge		
Location	0.333	0.564
Specialisation category	2.490	0.477
Norms		
Location	2.013	0.156
Specialisation category	0.176	0.981
No. target audience barriers		
Location	0.673	0.504
Specialisation category	1.966	0.132

<sup>a</sup> Differences in No. of organisational and No. of target barriers by expert location were analysed via t-tests while differences in No. of organisational and No. of target barriers by expert discipline specialisation were analysed using 1-way ANOVA; all other variables were analysed via Pearson Chi-square tests

\*Significant at <0.10 level, \*\*Significant at <0.05 level

Community meetings and workshops were preferred among international communication experts compared to national experts but broadly highlighted by both as a means of information reciprocity and simplification through practical experience. Where referred to by international experts in the context of groundwater communication and policy, the importance of discussion in behavioural interventions was continuously emphasised. Two international experts proposed that public meetings, where allied with well maintenance services and incentives, may engender appreciable behavioural change. IES3 (engineering/science expert – US) noted:

Something that does get the message across indirectly is providing free well water testing. The counties pay for

**Table 6** Interpersonal/media mechanisms and services cited by expert category and location

Mechanisms and services	Expert specialisation categories																			
	Communications (n = 21)				Engineering/science (n = 10)				Policy (n = 4)				Risk assessment (n = 15)				All (n = 50)			
	Int. (%)	Nat. (%)	Total (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)	Int. (%)	Nat. (%)	Total (%)		
Interpersonal (≥1)	9 (82)	5 (50)	14 (67)	9 (90)	5 (83)	4 (100)	3 (75)	2 (100)	1 (50)	5 (83)	7 (78)	12 (80)	21 (84)	17 (68)	38 (76)					
Community meetings	4 (36)	1 (10)	5 (24)	4 (40)	3 (50)	1 (25)	1 (25)	1 (50)	–	3 (50)	2 (22)	5 (33)	11 (44)	4 (16)	15 (30)					
Doorstop canvassing	3 (27)	2 (20)	5 (24)	1 (10)	1 (17)	–	–	–	–	1 (17)	1 (11)	2 (13)	5 (20)	3 (12)	8 (16)					
Event booths	5 (45)	2 (20)	7 (33)	3 (30)	1 (17)	2 (50)	–	–	–	–	2 (22)	2 (13)	6 (24)	6 (24)	12 (24)					
Open days	1 (9)	1 (10)	2 (10)	1 (10)	–	1 (25)	–	–	–	–	1 (11)	1 (7)	1 (4)	3 (12)	4 (8)					
School programmes	4 (36)	–	4 (19)	1 (10)	1 (17)	–	2 (50)	1 (50)	1 (50)	–	3 (33)	3 (20)	6 (24)	4 (16)	10 (20)					
Theatre performances	1 (9)	–	1 (5)	–	–	–	–	–	–	–	–	–	1 (4)	–	1 (2)					
Workshops	3 (27)	2 (20)	5 (24)	3 (30)	3 (50)	–	–	–	–	2 (33)	2 (22)	4 (27)	8 (32)	4 (16)	12 (24)					
Media (≥1)	8 (73)	6 (60)	14 (67)	8 (80)	5 (83)	3 (75)	2 (50)	2 (100)	–	3 (50)	7 (78)	10 (67)	18 (72)	16 (64)	34 (68)					
Billboards	1 (9)	–	1 (5)	–	–	–	–	–	–	1 (17)	–	1 (7)	2 (8)	–	2 (4)					
Brochures	1 (9)	1 (10)	2 (10)	–	–	–	1 (25)	1 (50)	–	1 (17)	–	1 (7)	3 (12)	1 (4)	4 (8)					
Information packs	–	1 (10)	1 (5)	–	–	–	–	–	–	–	–	–	–	1 (4)	1 (2)					
Journal articles	–	–	–	–	–	–	–	–	–	–	1 (11)	1 (7)	–	1 (4)	1 (2)					
Leaflets	–	2 (20)	2 (10)	1 (10)	1 (17)	–	–	–	–	–	2 (22)	2 (13)	1 (4)	4 (16)	5 (10)					
Letters	1 (9)	–	1 (5)	–	–	–	–	–	–	1 (17)	1 (11)	2 (13)	2 (8)	1 (4)	3 (6)					
Maps	2 (18)	–	2 (10)	1 (10)	–	1 (25)	–	–	–	–	2 (22)	2 (13)	2 (8)	3 (12)	5 (10)					
Newsletters	–	–	–	–	1 (17)	–	–	–	–	–	–	–	1 (4)	–	1 (2)					
Newspaper articles	2 (18)	2 (20)	4 (19)	2 (20)	1 (17)	1 (25)	–	–	–	–	2 (22)	2 (13)	3 (12)	5 (20)	8 (16)					
Posters	–	1 (10)	1 (5)	1 (10)	–	1 (25)	–	–	–	–	–	–	–	2 (8)	2 (4)					
PSAs	–	–	–	–	–	–	1 (25)	1 (50)	–	–	–	–	–	–	–					
Radio segments	2 (18)	3 (30)	5 (24)	4 (40)	3 (50)	1 (25)	1 (25)	1 (50)	–	–	–	–	1 (4)	–	1 (2)					
Social media posts	1 (9)	3 (30)	4 (19)	5 (50)	4 (67)	1 (25)	1 (25)	1 (50)	–	–	–	–	5 (20)	6 (24)	11 (22)					
TV segments	–	–	–	2 (20)	2 (33)	–	–	–	–	–	1 (11)	1 (7)	2 (8)	1 (4)	3 (6)					
Text messages	–	1 (10)	1 (5)	2 (20)	1 (17)	1 (25)	–	–	–	1 (17)	–	1 (7)	2 (8)	2 (8)	4 (8)					
Videos	–	3 (30)	3 (14)	–	–	–	1 (25)	1 (50)	–	–	2 (22)	2 (13)	4 (16)	2 (8)	6 (12)					
Webinars	–	–	–	1 (10)	1 (17)	–	–	–	–	–	–	–	1 (4)	–	1 (2)					
Websites	1 (9)	4 (40)	5 (24)	4 (40)	2 (33)	2 (50)	1 (25)	1 (50)	–	1 (17)	2 (22)	3 (20)	5 (20)	8 (32)	13 (26)					
Services (≥1)	1 (9)	3 (30)	4 (19)	4 (40)	3 (50)	1 (25)	–	–	–	3 (50)	5 (56)	8 (53)	7 (28)	9 (36)	16 (32)					
Camera surveys	–	–	–	1 (10)	–	1 (25)	–	–	–	–	2 (22)	2 (13)	–	3 (12)	3 (6)					
Phone service	–	2 (20)	2 (10)	1 (10)	1 (17)	–	–	–	–	–	1 (11)	1 (7)	1 (4)	3 (12)	4 (8)					
Water sample testing	–	1 (10)	1 (5)	2 (20)	2 (33)	–	–	–	–	2 (33)	2 (22)	2 (13)	4 (16)	3 (12)	7 (14)					
Well improvement	–	1 (10)	1 (5)	–	–	–	–	–	–	–	1 (11)	1 (7)	1 (4)	2 (8)	2 (4)					
Well testing kits	1 (9)	–	1 (5)	–	–	–	–	–	–	–	–	–	3 (12)	–	3 (6)					

that, they get their data and then a particular person holds public meetings and presents information. And so the public meetings where people are allowed to interpret their information in a public setting – that has worked well here when I think about it.

Experts considered school programmes and associated events to confer multiple benefits – namely encouragement of future custodianship and integration of groundwater science with preexisting environmental education initiatives at low cost. NES2 (national engineering/science expert) proposed that schools should constitute a central focus of future private well communication interventions:

We should be trying to get engagement with teenagers or the school-going populations in litter campaigns and health and safety or safe cross code. It happens at the school level. I've brought groups here on trips of 30 to groundwater sites, to boreholes and springs, and did a camera survey... and I've got huge feedback.

Despite over 67% ( $n = 34$ ) of experts recommending a media-based engagement mechanism, media channels were often scrutinised in relation to their efficacy in generating long-term knowledge and behavioural change. One expert suggested that criticism of media mechanisms may be attributable to the widespread misapplication of such channels and resultant stigma on mass media advertising or messaging. With reference to household drinking water risk, IC6 (communications expert, US) contended that media channels may be highly conducive towards encouraging behavioural uptake:

Media is very poorly understood in the water sector. The mass media is very powerful but the content of the mass media needs to be very well done. What I have seen happening in the mass media is that people don't know how to use it. The content is so dull that people conclude that the mass media doesn't work'. Well, it depends on what you do with it.

### Recommended engagement strategies

When posed the question of intervention scale in relation to private well risk, experts accentuated the benefits of a multi-level geographical structure. Regional and national-level media channels were considered integral towards generation of discussion and a means of preceding more intensive, interpersonally oriented well engagement activities. In view of frequent variations in local geology, low risk awareness and the consequent requirement for tailored information, experts recommended prioritisation of locally viable engagement mechanisms. Although local authorities and environmental health

inspectors were judged to be best-placed to facilitate such engagement, experts noted the importance of civil and community organisations, with convenient community venues (48%,  $n = 24$ ), schools (26%,  $n = 13$ ) and health centres (16%,  $n = 8$ ) cited as ideal settings for engagement. Trust and legitimacy among rural communities was regarded as a key determinant by NRA4 (national risk assessment expert):

People who live down the country are a lot more self-sufficient than people who live in cities and they'll very quickly get down to the practical questions. If someone is talking about stuff they don't really understand, they'll be quickly found out and then there'll be no trust. So you need a practical, easy-going expert that can talk to people one-on-one and get across the point that there is a real risk – that this isn't theoretical and it's not bureaucratic.

In proposing strategies for information delivery and messaging (both specific and non-specific to engagement mechanisms), experts distinguished a range of content and presentation styles. The quantitative occurrence of preferred content styles and modes of information presentation relative to recommended mechanisms is outlined in the [Appendix](#). The most frequently recommended styles of content comprised family oriented messages (26%,  $n = 13$ ), health-tailored information (30%,  $n = 15$ ) and local frames (20%,  $n = 10$ ). Discursive presentation of content (either face-to-face or in a passive, media-based context) was favoured by 74% ( $n = 37$ ) of experts, with feature stories (16%,  $n = 8$ ) and practical demonstrations (14%,  $n = 7$ ) also repeatedly recommended. Radio segments and videos incorporating feature stories about household well contamination were recommended in conjunction with family health frames, with the objective of resonating with audiences and advertising local, interpersonal engagement mechanisms. NC4 (national communications expert) summarised:

If you had a local homeowner who is available to do a feature story and get them to talk about their kids getting sick, it would absolutely get on the local radio. I think that could even be enough for a lot of people because they'd be getting a personal sense of the risk, which is what you want... and if that was done at the same time as, maybe, local advertising and a public meeting, a public event... but then the key is what do people do?

### Associations between expert categories and recommended engagement mechanisms

Community meetings, websites and workshops were the most frequently recommended engagement mechanisms and

accordingly included for statistical analyses (Table 7). While there was no statistically significant relationship between preference for websites or workshops among expert categories, community meetings were significantly associated with expert location ( $\chi^2 = 4.667$ ,  $p = 0.031$ ). Community mechanisms were recommended by 44% ( $n = 11$ ) of international experts compared to 16% ( $n = 4$ ) of national experts. Mention of theoretical models was significantly associated with expert discipline specialisation ( $F = 12.113$ ,  $p = 0.007$ ), with 22% ( $n = 11$ ) of communications experts referring to a relevant construct compared to 20% ( $n = 3$ ) of risk assessment experts; none were cited by engineering and science or policy experts.

## Discussion

As the onus to safeguard private groundwater wells typically lies with end-users (frequently displaying low levels of risk awareness and risk-averse behaviours), risk communication interventions are central towards encouraging greater supply maintenance (Naughton and Hynds 2014; Chappells et al. 2015). To this end, the current study employed a qualitative interview study of national (Irish) and international experts within four broad specialisation categories to identify impediments to and opportunities for rural private well risk communication. This

**Table 7** Bivariate analysis of recommended engagement mechanisms and cited theoretical models by expert location and specialisation category

Variable(s)	Test statistic <sup>a</sup>	<i>P</i> value
Mechanisms (no/yes)		
Community meetings		
Location	4.667	0.031*
Specialisation category	0.986	0.805
Websites		
Location	0.936	0.333
Specialisation category	1.354	0.716
Workshops		
Location	1.754	0.185
Specialisation category	1.519	0.678
No. of mechanisms		
Location	0.252	0.802
Specialisation category	0.931	0.433
Theoretical models (no/yes)		
Location	0.397	0.529
Specialisation category	12.113	<0.007**

<sup>a</sup> Differences in No. of recommended mechanisms by expert location were analysed, with differences in No. of recommended mechanisms by expert discipline specialisation analysed using 1-way ANOVA; all other variables were analysed via Pearson Chi-square tests

\*Significant at <0.10 level; \*\*Significant at <0.05 level

work addresses calls within risk communication and broader water resources management to incorporate social and communication sciences and effectuate more concerted, two-way engagement between information disseminators and target audiences (Lund 2015). The recent introduction of the subdiscipline and term ‘socio-hydrogeology’, which seeks to align hydrogeological investigations with rural participatory processes and interagency engagement, plots a course for design of private groundwater risk interventions in line with aspirational risk communication (i.e. two-way information exchange and stakeholder collaboration; Re 2015; Hynds et al. 2018a, b). Elicitation of expert opinion represents an opportune point of departure in the development of empirically informed, coordinated groundwater risk communication strategies and may constitute ‘applied socio-hydrogeology’, promoting increased alignment of hydrogeological and social investigations via stakeholder and expert analysis.

## Groundwater risk and communication: the current scenario

The high level of sophistication in communication campaign design demonstrated by experts within academia compared to government and state agencies epitomises the importance of multisector expertise. While the communication campaign literature is vast and cross-disciplinary, an increasing number of studies (e.g. Atkin and Rice 2012; Werder 2015) have collated key principles applicable to broad information campaign design. Increased adoption of this literature may be beneficial in the context of private well risk communication given the documented failure of top-down information sources to communicate groundwater-specific scientific and risk information strategically and intelligibly (Kreutzwiser et al. 2011; Chappells et al. 2015). Moreover, greater engagement is required between academics, civil servants and hydrogeologists in the context of groundwater (and other associated risks) to reach consensus regarding the potential feasibility or combination of communication approaches (Limaye 2017). Given the absence of subcounty forms of local government in the ROI and increasing trend towards bottom-up, collaborative interventions in other regions, it is imperative to examine the effectiveness of communication initiatives in multiple risk contexts (e.g. flood protection). Cooperative extension programmes, repeatedly referenced by experts in the US, may represent an appropriate model for wide rural engagement given their historical incorporation of local government and academic sectors and well-established presence at the community level (Franz 2014).

## Impediments and potential solutions: target audience

Experts cited lack of awareness, lack of knowledge, financial cost and social norms as primary barriers to behavioural uptake in multiple risk contexts, with imperceptibility of risk and

longstanding social norms regarded as central to private groundwater maintenance. The importance of organoleptic (i.e. sensorial) factors and values (e.g. perceived purity of groundwater) towards well maintenance has been repeatedly reflected in behavioural surveys of private well owners and correspond with expert observations in the current study (Malecki et al. 2017; Munene and Hall 2019). As organoleptic factors are often correlated with cultural and experiential factors, acknowledgement of groundwater aesthetics and visual cues to this effect warrant attention in design of information materials (de França Doria 2010; Figueroa and Kincaid 2010). Experts within hydrogeology and risk assessment noted the importance of demonstrating tangible risks and benefits in order to overcome these barriers, suggesting a lack of direct and systematic approaches to groundwater risk conveyance. A greater focus on the existing visibility and perceived quality and trustworthiness of groundwater risk information may shed light on current low rates of behaviour change (Morris et al. 2016). Behavioural models such as ‘expectancy-value’, ‘value-action gap’ and ‘COM-B’ (capability, opportunity, motivation and behaviour) models may serve as useful frameworks by conceptualising behavioural uptake relative to preexisting attitudes, competencies and perceived benefits (Michie et al. 2011; Atkin and Rice 2012).

### Impediments and potential solutions: information disseminators

As was the case in the context of household barriers, knowledge and cost were the two most frequently cited organisational barriers. However, the significance of association between knowledge as a cited organisational barrier and expert specialisation ( $p = 0.034$ ) indicated a clear discrepancy between different expert categories in terms of communicative capacity. This discrepancy is reflected in much of the existing risk communication literature and may stem from prioritisation of target audience characteristics at the expense of communication practitioners and stakeholders. As non-expert reactions to risk typically differ from expert-led responses (Renn 2008), risk communication research has extensively employed the concept of risk perception, which posits that judgements about risk characteristics are inherently subjective. While risk perception and associated models/theories (e.g. mental noise, trust determination) have proved valuable and important behavioural predictors, much of the underlying research has focused on characterisation of at-risk populations at the expense of communication practitioners and stakeholders (Ferrer and Klein 2015). As private well risk mitigation is multifaceted, encompassing inspection, testing and treatment, householders will likely need to avail of multiple points of contact (e.g. well drilling companies, water testing laboratories) throughout a supply’s lifespan (Chappells et al. 2015). It is vital going forward that such stakeholders are

made aware of their potential role as information disseminators and policymakers and integrated into emergent and existing drinking water policy paradigms such as the ‘multi-barrier approach’ in Canada (Plummer et al. 2010). Strategic and timely incorporation of professionals such as hydrogeologists or well drillers and relevant opinion leaders and policymakers into information dissemination activities may foster greater accountability and trust—lack of which was noted as a barrier by 60% ( $n = 30$ ) of experts.

Lack of key personnel and organisational capacity with respect to private groundwater outreach was cited repeatedly by experts within hydrogeology and risk assessment, indicating the issue’s low or fluctuating policy importance at government level. While local authorities are often considered best-placed to facilitate such engagement, decentralisation of water policy responsibilities from central to local government and restructuring in departmental funding and staffing have been observed to undermine the importance public engagement as a groundwater policy focus (de Loë and Kreutzwiser 2005). This lack of synergy between government tiers is arguably evident in the ROI as local authorities have thus far been provided limited direction in designing their own private well engagement activities/materials under the ‘National Inspection Plan’ (EPA 2017). National experts noted that existing staff in local authorities (e.g. awareness officers, health inspectors) were often ill-equipped to partake in or develop county-based engagement strategies due to existing responsibilities or lack of expertise. In light of this, it is important that communication practitioners at government level look outward to other policy communities and interest groups and explore the long-term potential of citizen science initiatives and modes of local capacity-building to address groundwater resource management (López-Gunn 2012; Little et al. 2016). In the absence of an appropriate policy climate or catalyst event such as the 2000 Walkerton tragedy in Ontario, communication practitioners may need to take advantage of other connected policy agendas and existing social capital in order to circulate private well risk information (de Loë and Kreutzwiser 2005).

### Groundwater risk and communication: suggested approaches

Although a slightly higher proportion of experts preferred face-to-face or interpersonal modes of engagement (76%) compared to passive, media-based mechanisms (68%), radio segments, newspapers articles and websites were among the most cited of both categories. There was a general consensus among experts that intensive, local and interpersonal engagement mechanisms such as workshops, school programmes and community meetings paired with a multi-scalar (i.e. national and subnational) media-based information campaigns may constitute a viable strategy for groundwater risk



communication. This line of thought runs contrary to recent observations among risk communication practitioners, who have increasingly questioned the efficacy of media-based risk information campaigns and promoted a shift towards more participatory, decision-focused and two-way risk communication (Renn 2008; Kasperson 2014). While it is undoubtedly important to acknowledge historical communicative shortcomings and the significance of dialogue between target audience and traditional information disseminators, it may be contended that the geographical scale or multidimensionality of risks such as groundwater contamination may hinder such participatory approaches or negate their impact. As noted by several experts in this study and elsewhere, traditional mass media and broadcast forms of public engagement should not be quickly dismissed and may prove efficacious where applied accordingly (Figueroa and Kincaid 2010; Lundgren and McMakin 2013). Dual approaches incorporating interpersonal and media-based mechanisms have proved effective towards stimulating health behaviour changes (Pasick et al. 2004). Furthermore, utilisation of local media sources, e.g. newspaper in combination with localised, incentivised forms of well user engagement has proved conducive to engendering markedly higher rates of private well testing and risk knowledge in the US (Paul et al. 2015).

Within the broader health communication literature, it is well observed that large-scale communication campaigns attaining a level of behaviour change as low as 5% over the long term may be considered successful (Werder 2015). While patience will be required in the context of private groundwater risk communication given the prevalence of rural norms surrounding groundwater aesthetics and safety, coordinated engagement at local level(s) and appropriate tailoring and delivery of information may foster enduring behaviour change; enhanced opportunities for community engagement have been demonstrated to correlate positively with health information seeking and risk prevention behaviour (Basu and Dutta 2008). Across the ROI and other rural regions, the challenge may lie in establishing appropriate ‘points of entry’ for local engagement and highlighting the need at government level for sub-county, community-based initiatives (Plummer et al. 2010). Although many national experts highlighted the importance of local engagement, community meetings were recommended by 44% of international experts in contrast to 16% of national experts ( $p = 0.031$ ). A more focused media framing of groundwater contamination as a localised, family health issue and personalisation of risk (via feature stories or discussion) may hold the key towards generating greater emotional resonance and, by extension, willingness to partake in recommended measures such as workshops and events. In the absence of existing public engagement initiatives and in an insufficient policy climate, experts additionally acknowledged the documented efficacy (and importance) of groundwater education initiatives at primary and secondary school levels

in encouraging future custodianship and community buy-in (Thornton and Leahy 2012). Establishing a long-term rapport with local community organisations and engendering trust at the bottom-up level may represent the ideal starting point in commencing such activities and communicating an inherently complex, often place-specific risk.

In spite of attaining the set target of 50 interviews (25 international, 25 national), the present study was nevertheless characterised by several limitations. While a deductive approach was deliberately avoided due to study objectives and the novelty of groundwater as a subset of intervention science, the inductive methodology selected limits the study’s comparability to associated literature. Interviews with interested participants were carried out on a first-come first-serve basis; as such, policy experts were under-represented. With respect to qualitative data presentation, a number of disadvantages in NVIVO QDAS software are noted (AlYahmady and Alabri 2013), namely its limited utility in generating visual materials (e.g. schematics, graphs) and the absence of automated analysis (e.g. key terms based on statistical composition of text). The small sample number posed an additional limitation in increasing the likelihood of bias in quantitative analyses.

## Conclusion and recommendations

Experts within the current study recommended a systematic approach to design of private-well maintenance materials (e.g. educational and risk management media for non-experts) to address longstanding groundwater norms, gaps in scientific literacy, specify the various maintenance steps and necessary points of contact (e.g. regional laboratories, local authorities, etc.). A suite of local and community-based interpersonal mechanisms comprising workshops, school programmes and events were recommended to foster long-term custodianship and trust, instil greater practical knowledge of maintenance, and demystify mechanisms of groundwater contamination. Experts additionally proposed the concurrent use of both regional and local media mechanisms (e.g. radio segments and newspaper articles) allied with personalised, family health frames to promote risk awareness and acknowledgement among broad rural populations. While alignment of existing stakeholders (e.g. local authorities, well drilling companies) was widely observed to be lacking in development of groundwater communication and related policy, approaches such as ‘cooperative extension’ were highlighted as a potential means of integrating key information disseminators. Future research within groundwater and broader risk communication spheres should explore current and future policy roles of relevant stakeholders and opportunities for as well as modes of multisector-led interventions.

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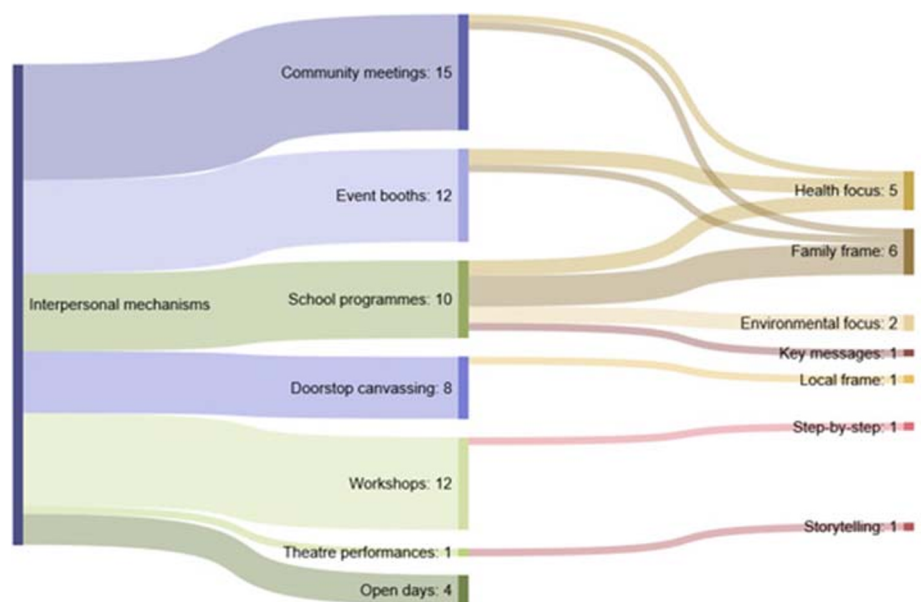
## Appendix

**Table 8** Behavioural, cognitive and communication theories cited by experts and specialisation category

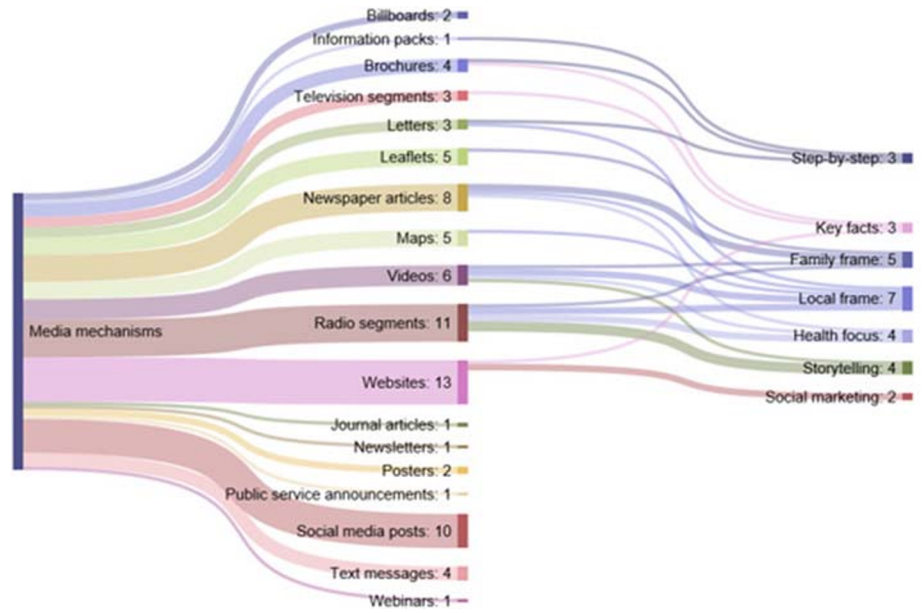
Specialisation category	International	National
Communications	Attitude-behaviour gap <sup>(IC4)</sup> , diffusion of innovations <sup>(IC8, IC6)</sup> , empty vessel theory <sup>(IC3)</sup> , expectancy-value theory <sup>(IC8)</sup> , family systems theory <sup>(IC8)</sup> , individual choice model <sup>(IC8)</sup> , information deficit model <sup>(IC3)</sup> , locus of control <sup>(IC10)</sup> , mental models <sup>(IC10)</sup> , network theory <sup>(IC8)</sup> , self-efficacy and response efficacy <sup>(IC11)</sup> , social cognitive theory <sup>(IC1)</sup> , social marketing <sup>(IC8)</sup> , symbolic reasoning <sup>(IC1)</sup> , system 1 and system 2 <sup>(IC6)</sup> , theory of planned behaviour <sup>(IC8)</sup>	Behavioural economics <sup>(NC7, NC4)</sup> , co-production <sup>(NC8)</sup> , dialogic model <sup>(NC8)</sup> , health belief model <sup>(NC3)</sup> , protection-motivation theory <sup>(NC3)</sup> , social marketing <sup>(NC4)</sup>
Engineering/science	–	–
Policy	–	–
Risk assessment	Mental models <sup>(IRA3)</sup>	Kinaesthetic learning <sup>(NRA3)</sup> , polder model <sup>(NRA8)</sup>

Note: Expert specialisation category abbreviations (e.g. IC4) outlined in full in Table 2

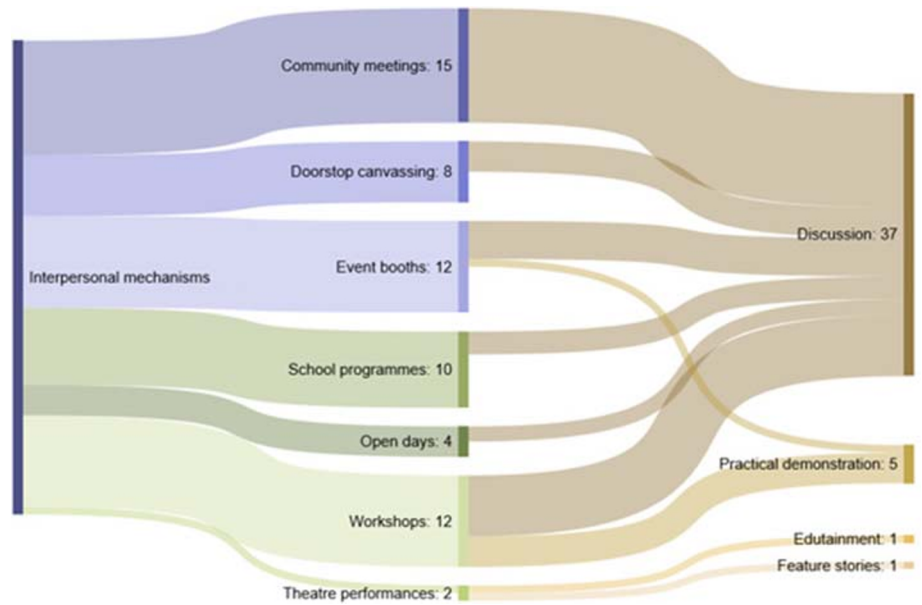
**Fig. 3** Sankey diagram displaying relationships between recommended interpersonal engagement mechanisms and content style



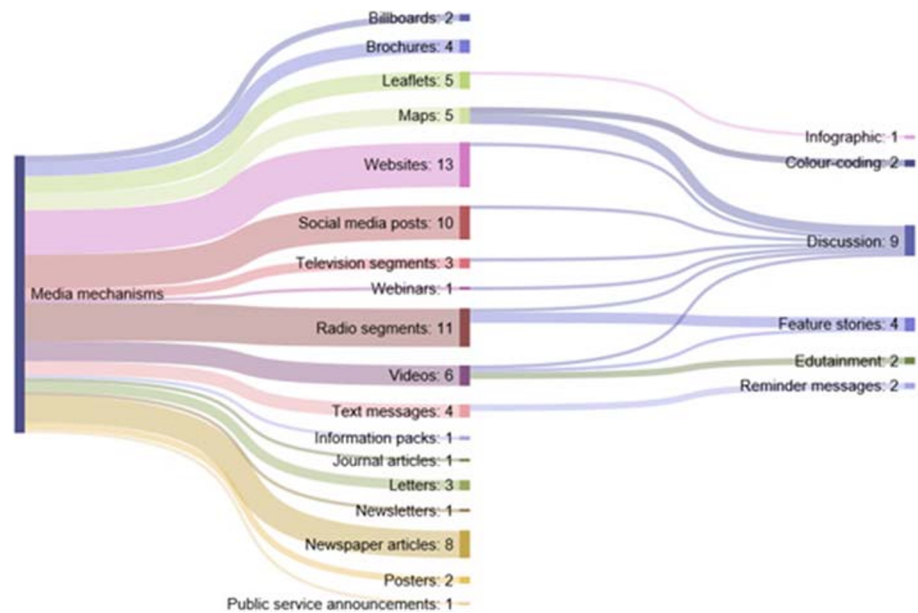
**Fig. 4** Sankey diagram displaying relationships between recommended media engagement mechanisms and content style



**Fig. 5** Sankey diagram displaying relationships between recommended interpersonal engagement mechanisms and information presentation



**Fig. 6** Sankey diagram displaying relationships between recommended media engagement mechanisms and information presentation



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