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Towards the coordinated and fit-for-purpose deployment of Unmanned Aerial Systems (UASs) for flood risk management in England

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ABSTRACT

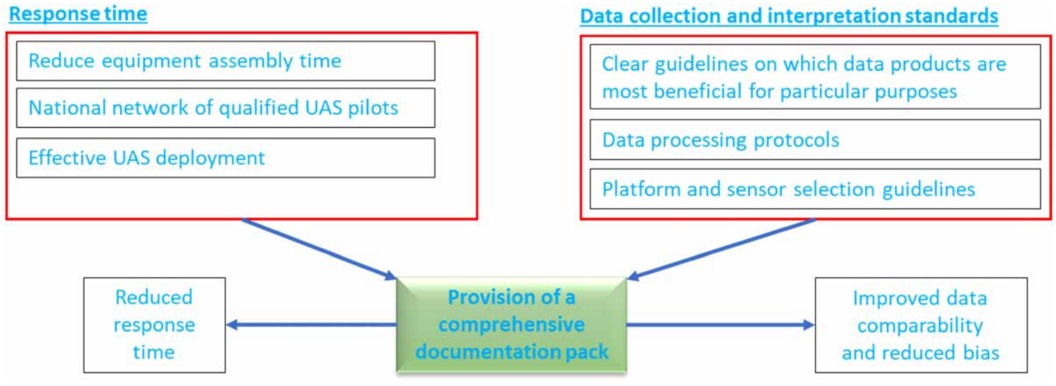
Preparedness for flood emergency response is crucial for effective flood management. The need for advanced flood decision support tools that aid flood management has been recognized by several authors. This work examines the variability that currently exists across England with regard to the Unmanned Aerial System (UAS) data collection and processing strategy in flood emergency events. Expert elicitation was carried out using a tailored questionnaire about UAS deployment in three flood emergency scenarios. The survey highlighted that reduced equipment assembly time, a national network of appropriately qualified UAS pilots and the effective UAS deployment when on-site, can reduce the response time to flood emergency. For improved comparability and reduced bias in data collection and interpretation, clear guidelines on which data products are most beneficial for particular purposes, processing time required, platform and sensor selection may also be necessary. We consider that releasing a comprehensive documentation pack, which includes guidelines, standards and protocols that detail the methods, tools, technology, quantity and quality of data, to UAS pilots on a flood emergency call, will enhance the timely response.

Key words: drone, flood risk, emergency, response time, UAV standards

HIGHLIGHTS

- There is significant variability across England with regard to UAS data collection and processing strategy in flood emergency events.
- Reduced equipment assembly time, a national network of qualified UAS pilots and the effective UAS deployment when on-site, can reduce the response time to flood emergency.
- There is a need to develop clear UAS data collection and processing guidelines for enhanced flood risk management

GRAPHICAL ABSTRACT



1. INTRODUCTION

Floods are among the most frequent natural disasters (46%) and cause much human suffering and loss to 78% of the population affected (Kugler & De Groeve 2007). Regions affected by floods during 1985–2003 comprise more than one-third of the Earth's surface, inhabited by over 82% of the world's population (World Bank 2005). The International Flood Network highlighted that from 1995 to 2004, approximately 94,000 out of 471,000 fatalities (20%) worldwide resulting from natural disasters and $16 billion USD (33%) of the total economic damages were attributed to floods (Adhikari *et al.* 2010). In the UK, recent flooding incidents occurred in February 2020, caused by Storms Ciara and Dennis. The high rainfall levels experienced, resulted in the wettest February since records began in 1766 (Met Office 2021), which resulted in at least 11 deaths and an estimated property damage of at least $150 million (Aon 2021). Additionally, in 2015 heavy rainfall (300 mm in 24 h) during storm Desmond resulted in flooding of 466 properties with Cockermouth, Carlisle, Kendal and Lancaster being among the towns and cities most affected (Rivas Casado *et al.* 2018). More recently (October 2021), Cockermouth was also impacted by flooding following another intense rainfall event (Times & Star 2021).

The increased risk of floods and droughts makes the need for advanced flood response frameworks and decision support tools more important (Şensoy *et al.* 2018). Recent studies have assessed the potential of Unmanned Aerial Systems (UASs) for use in flood monitoring and prediction activities. Their ease of use and high accuracy, when properly equipped and calibrated, make them very attractive for tailored surveying tasks. The UAS can also access areas inaccessible to manned aircraft or helicopters (Wang 2015; Rivas Casado *et al.* 2018). UASs have proved to be excellent tools for affordable flood extent and depth simulations (Annis *et al.* 2020), flood hazard mapping (Wing *et al.* 2017) or forecasting (Alfieri *et al.* 2017). Advances in UAS technology and associated processing methods have contributed to determining accurate Digital Elevation Models (DEMs) through the use of photogrammetric techniques, even without the use of Ground Control Points (GCPs) (Fonstad *et al.* 2013). The UAS can also capture fine-scale spatial data such as soil moisture, vegetation, topography and flow, with a fine temporal resolution, overcoming many of the constraints of the more traditional remote sensing techniques (Debell *et al.* 2015).

Studies have also examined the use of UAS to monitor post-event damage activities and conditions (Hlavčová *et al.* 2016; Rottondi *et al.* 2021). However, there are few reports on how best to use UASs within the different phases of a flooding event, that is, pre, during or post an event (Ward *et al.* 2015). To date, the only documented study proposing guidelines for UAS deployment before, during and after an event is that by Salmoral *et al.* (2020). These guidelines propose the use of the UAS for particular applications depending on the emergency response phase and the catchment response. Alsnih & Stopher (2004), have shown that when evacuating people at risk from flooding, the timing of the intervention can affect the access of emergency vehicles and equipment. Where people are located and their situations are also crucial, for example, vulnerable populations in remote locations (Tsang & Scott 2020). Therefore, in flood emergency situations, a clear purpose-driven approach which guides the efficient and effective deployment of the UAS to assist in the response is of paramount importance. This approach would help identify which UAS products are of benefit for a particular flood emergency phase. Salmoral *et al.* (2020) already highlighted that the deployment of the UAS in the UK is largely *ad hoc* and would benefit from a coordinated and fit-for-purpose UAS deployment strategy.

In the UK, the UAS used in flood response situations are largely provided by third party providers scattered across the country. Each provider uses a different combination of platform, sensors and data collection protocols. This poses a challenge when trying to compare the UAS-derived geomatic products to inform flood risk management decisions at local and national levels. There is a need to standardize data collection approaches to (i) increase data trust, (ii) increase data transparency, (iii) increase data robustness, (iv) enable data integration, (v) facilitate data sharing and (vi) achieve data democratization (Rivas Casado & Leinster 2020; Waterman *et al.* 2021).

An in-depth understanding of the variability that currently exists across England in UAS data collection and processing strategies is required to better define UAS operational standards. The current study has gathered evidence through expert elicitation to further expand Salmoral's *et al.* (2020) framework. The specific aim of this study is to identify pathways to increase the coordinated and fit-for-purpose deployment of the UAS for flood management practices. This will be achieved through the following objectives:

- To assess the range of approaches taken for UAS deployment, data collection and processing across England.
- To assess the challenges that the existing variability in UAS use across the country has on effective flood risk management.

- To identify key steps to overcome the challenges and limitations identified in (1) and (2) to obtain a coordinated and fit-for purpose use of the UAS for flood management practices.

2. METHODOLOGY

2.1. Site selection

Cockermouth, which is located in northwest England in Cumbria, UK (Figure 1), was selected as the study site. The town has a population of around 8,800 and 4,000 households, and two rivers (the Cocker and the Derwent) merge close to the town centre. The area selected is prone to severe fluvial and pluvial flooding with the most recent instances occurring in October 2021 and in December 2015 during storms Desmond (5–6 December 2015), Eva (24 December 2015) and Frank (29–30 December 2015) (Rivas Casado *et al.* 2018). The area was also flooded in 2005, 2008 and 2009. The 2009 event affected the whole community and flooded more than 693 residential houses and 225 businesses (Cumbria Resilience 2011).

2.2. Data collection

The variability in UAS deployment, data collection and processing strategy across England was assessed through a tailored questionnaire developed in Qualtrics Survey (Qualtrics, Provo, UT; Qualtrics 2020). The survey was distributed by email to UAS pilots through RUAS' extended network of contacts. RUAS is a commercial drone service provider and aviation training institute in Duffryn, Wales, UK, with 30 years of aviation and UAS experience. Responses were collected from April to August 2021. Reminders and incentives were offered to encourage respondents to complete the survey.

The survey had nine sections depicting a set of flood emergency scenarios for the case study area. The first section was an introduction which described the survey and was followed by section 2, which gathered participants' personal details and experience of piloting the UAS and flood emergency response (eight questions). Section 3 introduced the map of the study area depicting the buildings, rivers and road network. Three flood scenarios were then presented. The last section focused on general questions (nine questions) and the pilots' insights about flood emergency response and what they considered were important criteria in informing a UAS flight strategy.

Each scenario was described in terms of flood extent (Figure 2), along with information about the starting time of the flood event, weather conditions, time that pilots were alerted and any additional assumptions, for example, characterization of the airspace above the study area. The following paragraphs describe the scenarios:

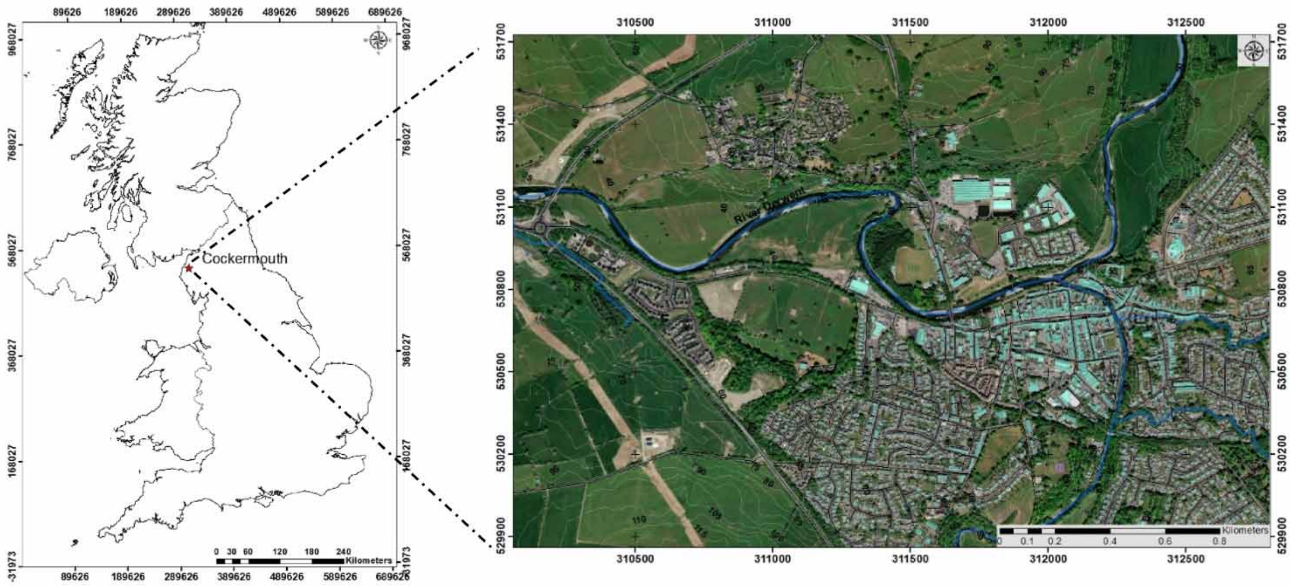


Figure 1 | Study area of Cockermouth town. (Basemap source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo and the GIS User Community).

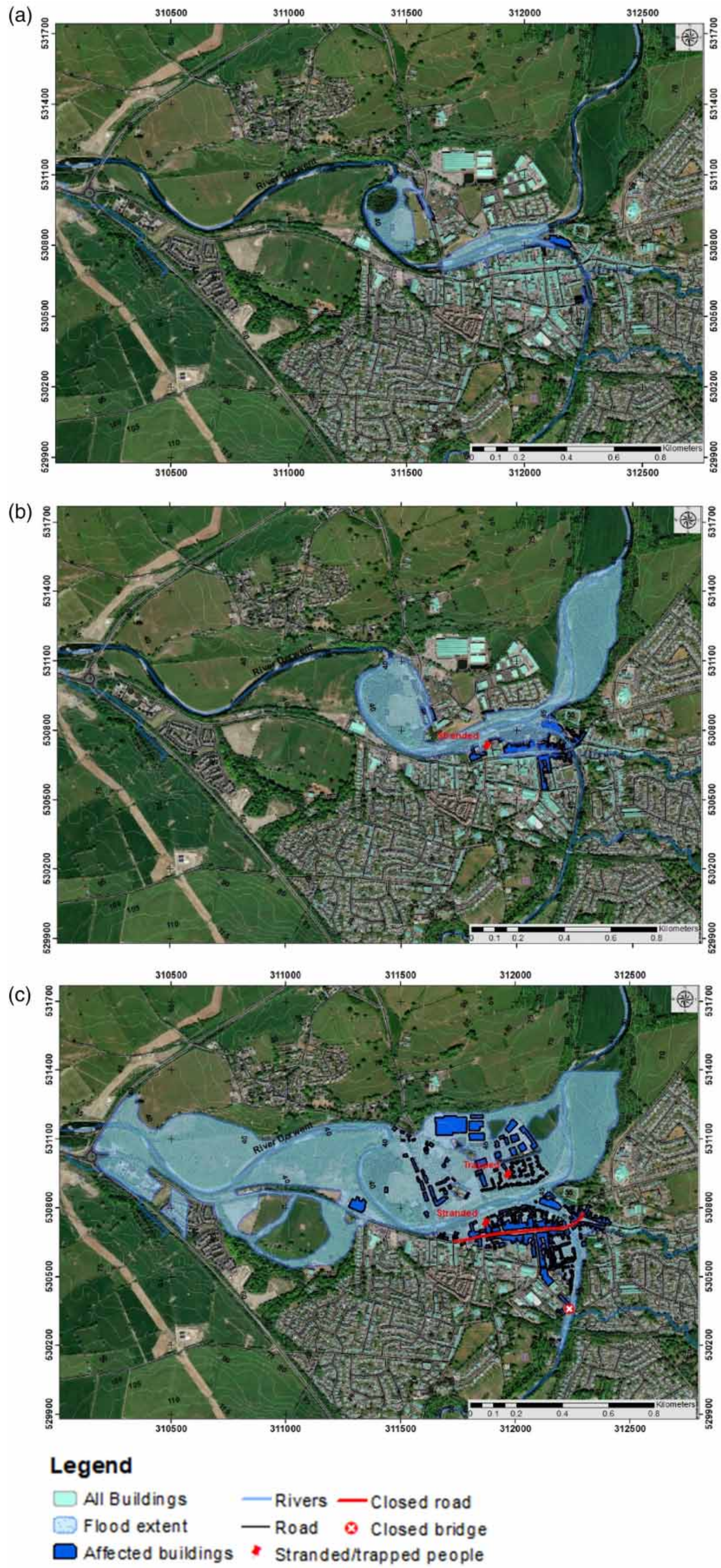


Figure 2 | Illustration of the flood scenario maps presented in the questionnaire. (a) Image describing flood scenario 1 (flood extent area=0.08 km^2), (b) image describing flood scenario 2 (flood extent area=0.31 km^2) and (c) image describing flood scenario 3 (flood extent area=1.03 km^2). (Basemap source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo and the GIS User Community).

Scenario 1. The flood event occurs in Cockermouth on 14 July and starts at 5:00 am. At 0:00 h into the event, the flood extent is described as in Figure 2(a). The weather conditions were as follows: wind speed variable from 8 to 15 knots, wind direction variable from 90° to 310°, prevailing visibility of 9,999 (greater than 10 km) with cloudy overcast conditions and a temperature of 10 °C. The UAS pilots were contacted at 5:00 am by an emergency responder requesting that they map the full flood extent. The emergency responder was also interested in knowing whether there were stranded people in the affected area. The airspace above the area of interest was classed as G.

Scenario 2. This scenario presented an increase in flood extent (Figure 2(b)) for the same case study area. The scenario was set 4.5 h into the flood event at 9:30 am. The weather conditions were described as follows: wind speed variable from 4 to 8 knots, wind direction variable from 70° to 180°, prevailing visibility is 9,999 (greater than 10 km), overcast and 8 °C. People were stranded and the emergency responders required information about (i) the flood extent and (ii) the situation and exact location/s of the stranded people.

Scenario 3. This scenario presents a further increase of the flood extent (Figure 2(c)). The scenario took place 9 h into the flood event at 2 pm. The weather conditions were as follows: wind speed variable from 4 to 10 knots, wind direction variable from 75° to 200°, prevailing visibility is 9,999 (greater than 10 km), overcast and 8 °C. People were stranded and trapped, and the emergency responders required information about (i) the flood extent and (ii) the situation and exact location/s of the stranded people.

A mixed methods approach was used to design the questions (Shorten & Smith 2017; Johnson *et al.* 2019). Quantitative data are better at answering questions such as 'how many batteries will you need?' while qualitative data can highlight 'how' and 'why' aspects. In the current study, examples of quantitative questions included 'how many ground-control points will you need?' or 'how much will you charge for the mission?'. Examples of qualitative questions on the other hand, were around 'which UAS would you select and why?', 'which camera would you select and why?', 'what type of data would you collect?'

2.3. Data analysis

Quantitative data were analysed through descriptive statistics, including measures of central tendency and variability when appropriate, in addition to bar plots, histograms and pie charts. Qualitative data were reviewed for the identification of patterns. Associations between qualitative and quantitative data were established when possible. Maps throughout this paper were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license.

3. RESULTS

3.1. Involvement of participants in responses to flood events

A total of 79 responses were received. Of these, only 18 were fully completed. Both fully and partially completed surveys were analysed. The lack of response to some of the questions did not invalidate the responses provided in other sections.

Most of the participants (57 out of 68) indicated they had not been involved in a flood emergency response with 11 out of 68 indicating they had (Table 1). The response to the question of whether they have ever collected UAS-derived data for flood risk management purposes was similar, with 57 people out of 68 responding that they had not and 11 out of 68 participants reporting that they had (Table 1). Of the 11 participants involved in flood risk management activities, five reported that flights

Table 1 | Responses of participants to whether they have been involved in or collected UAS data for flood management purposes (68 responses to both questions)

Question	Response (68)			
Have you been involved in flood emergency response?	Yes (11) (16%)		No (57) (84%)	
Have you ever collected UAS data for flood management purposes?	Yes (5) (46%)	No (6) (54%)	Yes (6) (10%)	No (51) (90%)

Percentages have been calculated using the total number of respondents for the specific question.

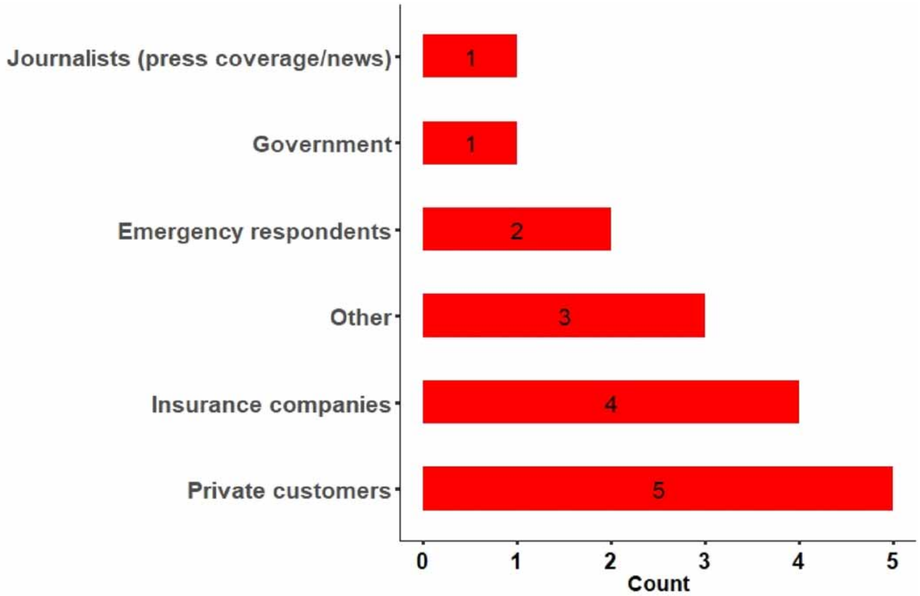


Figure 3 | Sectors commissioning UAS flights based on survey responses. The question asked was 'Who does usually commission your flood-related flights? Select as many options as required'. Note that from the 11 participants providing responses to this question, some selected more than one sector and this generated a total of 16 outcomes.

were commissioned by private customers with four by insurance companies (Figure 3). The responses obtained were similar between UAS pilots with and without experience of flood-related missions.

To the question 'when did you obtain your UAS qualification?', 50% of participants (29 out of 58), replied between 2014 and 2015. The response to the question when did the company obtain their 'Permission for Commercial Operation' (PfCO) is given in Table 2.

From a total of 63 respondents, the majority possessed a General Visual Line Of Sight (VLOS) permission and no additional exemptions from the Air Navigation Order (ANO). Seven had an Extended Visual Line of Sight operations (EVLOS) permission and two a Beyond Visual Line of Sight (BVLOS) permission (Table 3). Fourteen respondents held two or more permissions. Note that volume 3 applications are ANO exemptions (e.g., reduced distances, EVLOS or BVLOS) requested on a permanent basis.

Table 2 | Year when the respondent obtained their UAS qualification and PfCO

	When did you obtain your UAS qualification?		When did your company obtain PfCO?	
Year	**Responses**	**Responses as %**	**Responses**	**Responses as %**
2010	–	–	1	2
2014	10	17	8	15
2015	19	33	15	28
2016	9	15	6	11
2017	5	9	7	13
2018	6	10	6	11
2019	2	4	3	6
2020	4	7	4	8
2021	3	5	3	6
Total	58	100	53	100

Percentages have been calculated using the total number of respondents for the specific question as the reference.

Table 3 | Matrix showing the combined types of permission reported by the respondents

Combined permissions	Responses	Responses as %
VLOS	40	64
EVLOS	1	2
BVLOS	1	2
Volume 3	2	3
EVLOS × BVLOS	1	1
VLOS × EVLOS	2	3
VLOS × EVLOS × Volume 3	3	5
VLOS × Volume 3	8	12
No response	5	8
Total	63	100

Response to question: 'Which of the following permissions do you hold? Select the ones that apply'. Percentages have been calculated using the total number of respondents for the specific question as reference. Each response is counted only once in the table.

3.2. UAS and sensors preference among respondents

When asked about their preference for different UASs, the majority of participants stated they preferred Vertical Take Off (VTOL) systems to fixed wing devices (total responses: 44). DJI Series systems were chosen more frequently compared to alternative systems such as the Skywalker or the Falcon 8 (Table 4). DJI Matrice 600, Power Egg and Parrot Anafi were not selected by any respondent. The rationale for the particular choices included (i) this is the available drone that participants use, (ii) longer flight time, (iii) better wind resistance, (iv) water proofing, (v) deployment speed, (vi) number of pieces of equipment that can be attached and (vii) light weight.

Some respondents proposed the use of alternative platforms to those presented in the survey – that is, Wingtra One and Strix Stratosurfer. A total of 21 respondents selected multiple platforms as they needed more than one platform to fulfil the requirements of the scenarios. Only six participants required both fixed wing and VTOL platforms. The rationale for the particular choices included flight time and battery endurance, size, set up and deployment time, weather resistance, the capacity to mount additional equipment, zoom capacity and area coverage.

In terms of sensors needed for the operation, from the 45 responses received, the preferred sensors were a combination of a thermal camera with 20MP 1″CMOS Video: 4 K/60fps 100 Mbps (Table 5). Some respondents identified the need for

Table 4 | Platforms selected for the mission (scenario 1)

Preferred platform	Responses	Responses as %
DJI M300 series	19	24
DJI Mavic series	19	24
DJI Inspire series	12	15
DJI Phantom series	7	9
Other	7	9
DJI Matrice 210	5	6
Ebee	3	4
Skywalker	3	4
Skydio2	2	3
Falcon 8	1	1
Sirius Pro	1	1
Total	79	100

Response to question: 'Which UAS from the above list will you use for this mission? Select those you think are essential for the mission. Please, provide a rationale for your selection in the box below' Percentages have been calculated using the total number of respondents for the specific question as reference. From the 44 participants providing responses to this question, some selected more than one platform and this generated a total of 79 outcomes.

Table 5 | Sensors selected for the mission (scenario 1)

Preferred sensor or sensors combination	Responses	Responses as %
Thermal camera	29	27
Camera: 20MP 1″CMOS Video: 4 K/60fps 100 Mbps	16	15
Other	15	14
Camera: Zenmusse X4S, X5S, X5, X6, X7 Video: 6 K CinemaDNG/RAW (Zenmusse X7)	12	11
Camera: 20MP 1″CMOS Video: 4 K/30fps 100 Mbps	11	10
Camera: 48MP 1/2′ CMOS Video: 4 K/60fps 120 Mbps	9	8
Camera: 12MP 1/2 3″CMOS Video: 4 K/30fps 100 Mbps	6	6
Multispectral	5	5
Camera: 12MP 1/2 3″CMOS Video: 2.7 K/30fps 40 Mbps	4	4
Total	107	100

Response to question: 'From the sensors above, which ones will you select for the mission? Select as many as you require. Please, assume that all the sensors are compatible with the UAS you have selected'. Percentages have been calculated using the total number of respondents for the specific question as reference. From the 45 participants providing responses to this question, some selected more than one sensor and this yielded 107 outcomes.

multiple sensors to carry out the mission with 22 respondents selecting two sensors, three respondents, three sensors and two respondents more than seven. Some examples of the preferred sensor types in addition to those listed in the survey, include H20 series, H20T Zenmuse for M series, Sony Rx1R Mk2 (42Mp), Sony QX1 (24Mp), Sony A6000 (24Mp).

For scenarios 2 and 3, the majority of the respondents, did not alter their UAS selection from scenarios 1 and 2, respectively (Table 6). Three people, for both scenarios 2 and 3, had changed their preference and their updated selection was one of the MJ300, eBee and Skywalker platforms. The rationale provided for choosing the MJ300 was the extended flight time (no further rationale provided).

3.3. Travel time required to site and operational team

From a total of 45 responses received, 31 respondents highlighted that they would need less than 1 h to gather all the equipment, 13 indicated they would need 1–4 h while one person would need more than 4 h (mean: 1 h and 20 min, variance 16 min). The time needed to get to Cockermouth ranged from 1 to 4 h (25) to less than 1 h (three), while 10 people required between 4 and 6 h and seven people more than 6 h to arrive at Cockermouth.

According to respondents, the on-site operational team would most commonly comprise of one or two people with four respondents requiring a team of five or more people (Table 7). Overall, the preference would be to use one pilot (29 out of 46 respondents) when participants were asked 'Will you use multiple pilots?' Those participants (13) requiring more than one pilot highlighted the need for two (10 responses) or three (one response) pilots under the umbrella of their current employer, when asked 'Will all the pilots be employed by your company and work under your umbrella?'.

3.4. Type of mission, response time and preparedness

A total of 36 participants provided information about the type of mission they would carry out. Overall, the majority (31 responses) selected a VLOS mission with only a few respondents selecting EVLOS (four responses) and BVLOS (one

Table 6 | Number of UAS and sensor selections per scenario

	Scenario 1	Scenario 2		Scenario 3	
	Number of respondents	Number of respondents (Choices that differ from scenario 1)	Respondents with same selection as in scenario 1	Number of respondents (Choices that differ from scenario 2)	Respondents with same selection as in scenario 2
UAS selection	28	3 (3)	25	3 (2)	1
Sensor selection	45	28 (6)	39	20 (4)	24

Respondents were given the option to select more than one option. Each response is counted only once in the table.

Table 7 | Configuration of the operational team (scenario 1)

Operational team (including pilot)	Responses	Responses as %	Number of pilots	Responses	Responses as %
1	10	22	1	1	8
2	32	69	2	11	84
5	3	7	3	1	8
>5	1	2	>3	0	0
Total	46	100	Total	13	100

Response to questions: 'How large is the team you need to operate on-site including any spotters?' and 'How many pilots will you use?'. Percentages have been calculated using the total number of respondents for the specific question as reference. Each response is counted only once in the table.

response). The location of the take-off and landing site varied across respondents. From the 34 responses recorded, locations 6, 11 and 7 were the preferred ones (Figure 4). These were located at the north-west side (point 11), north (point 6) and north-east part of the town (point 7), all being situated in an open field. Less than 1 h would be needed by 17 out of the 34

Figure 4 | Top three most selected GCPs for scenario 1 (as indicated by the numbered red squares – 6, 7 and 11). (Basemap source: Esri, DigitalGlobe, GeoEye, i-cubed, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo and the GIS User Community).

respondents to deploy their UASs, while 13 people stated they would require between 1 and 4 h. The mean response time across all respondents was 1 h and 40 min, with a variance of 35 min. Three respondents required 3–6 h with one stating that they would need more than 6 h.

Respondents recognized the need to contact key people to obtain permission to fly over the emergency response area. From the 32 responses received, 21 would contact the respective landowner, only 11 responses identified the need to contact emergency response services (Table 8). A total of five identified the need to contact Incident Command and only two would inform the Environment Agency. One respondent stated that there was no need to contact anyone to fly over the emergency area. A total of 28 respondents out of 32 said that they would prepare a flight plan for this mission (scenario 1).

From the 32 participants providing information about collision avoidance strategies (Table 9), 16 identified the need to use a spotter to assist in the area, 12 replied they would always adhere to VLOS and 14 identified the need to establish communications with other air users in the area. A small number (six) of the respondents indicated they would rely on 'avoid and land' strategies and seven identified the need to make the drone ADS-B aware. Within this context, 'avoid and land' refers to the strategy followed by pilots that visually spot obstacles in the airspace and manually manoeuvre the platform to (i) physically avoid the obstacles or (ii) safe landing if avoidance is not feasible. ADS-B or Mode S equipped drones would be detected by specific receivers across the world. ADS-B equipped platforms would emit their exact position whereas Mode S equipped platforms could be tracked via multilateration (MLAT) (Park *et al.* 2020) when the signal is received by three or more receivers. Some respondents (six) suggested the use of LED beacons, and five the need to use obstacle avoidance systems (applications or sensors). A few identified the need to communicate with the ATC (one), check Notice to Airmen (NOTAMS) (two) or use the National Air Traffic Services (NATS) Drone Assist safety application, created to help drone pilots fly responsibly by providing a real-time summary of hazards in the survey area (three). Only four identified the need to contact emergency responders to share the Risk Assessment Methods Statement (RAMS) and flight plans with them and from those, only two mentioned the need to contact the Incident Commander. The use of situation reports (SITREPS) was mentioned by one respondent.

To the question, how will you fly the UAS to ensure you cover the full flood extent and identify all stranded people within the area, the participants (32) proposed using a mapping grid approach (16 respondents), with one respondent identifying the need to use zig-zag passes to scan the grid, a few (five) suggested the use of multi-pass patterns, while one person indicated that they would follow the river to assess the extent of the flooded area and the status of the river banks. Three respondents highlighted the need for low air speed flights and six would carry out an initial flight to gain situational awareness. Whether or not participants would deploy any GCPs in the area, 24 out of 34 replied negatively.

Table 8 | | Organizations identified as key contacts to obtain access to site

Organization	Responses	Responses as %
Landowners	21	26
Local council/authorities	17	21
Emergency response services	11	14
Police	10	12
Air Traffic controller	7	8
Incident Command	5	6
Firefighters	2	3
The Environment Agency	2	3
Land registry	2	3
Civil Aviation Authority	1	1
Flood prevention teams	1	1
Military low flying	1	1
None	1	1
Total number of organizations identified	81	100

Response to question: 'Who will you contact to gain access to the land for take-off and landing purposes?'. This question was open text. The number of organizations identified is larger than the number of respondents (32) as many identified multiple options in their response. Percentages have been calculated using the total number of organizations identified. Each organization identified is counted only once in the table.

Table 9 | Collision avoidance strategies

Collision avoidance strategy	Total responses	Responses as %
Spotter	16	20
VLOS adherence	12	15
Communication with other users within the area	14	18
Avoid and land	6	8
ADS-B awareness	7	9
Lead beacons	6	8
Obstacle avoidance systems	5	7
ATC communication	1	1
NOTAMS	2	2
National Air Traffic Services (NATS) Drone Assist safety application	3	4
Contact Incident Commander	2	2
Contact emergency responders and share with them Risk Assessment Method	4	5
Use situation reports (SITREPS)	1	1
Total number of strategies identified	79	100

Response to question: 'How will you avoid collision with other drones within the same airspace?'. This question was open text. The number of strategies identified is larger than the number of respondents (32) as many identified multiple options in their response. Percentages have been calculated using the total number of strategies identified. Each strategy identified is counted only once in the table.

3.5. Equipment, data collection and processing

In terms of the equipment capability and out of 28 responses, 15 would use an UAS with a battery life of between 10 and 30 min, seven people would choose batteries providing 30–45 min flight time, with only five people saying that flight times would be between 45 and 60 min (Figure 5). Out of 26 responses received, only nine respondents reported that battery life was not a limitation to carrying out multiple flights as they had on-site charging capability.

Although RGB imagery was the main type of data the pilots would collect, followed by video and thermal imagery, the responses varied based on the task at hand (Table 10). From a total of 28 respondents, most indicated that they would collect RGB imagery for both flood extent mapping and the detection of stranded people. This was followed by the use of video and thermal cameras, with only few respondents reporting the proposed use of multispectral imagery. An increase in the use of video recording was observed when respondents were requested to spot stranded people (Table 10). The majority of responses identified the need to combine two or more camera outcomes (e.g., video and RGB). Additionally, when collecting imagery to

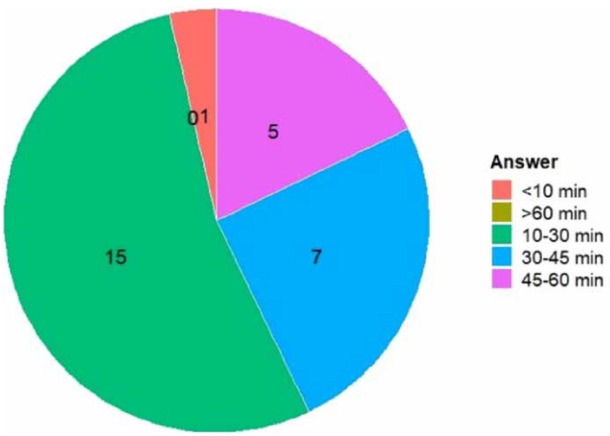


Figure 5 | Battery duration (pie chart). A total of 28 participants provided a response to the question 'What is the life endurance of your batteries?'.

Table 10 | Type of data collected by respondents under scenario 1

	RGB	Video	Multispectral	Thermal	Total
Flood extent	25 (41%)	20 (33%)	6 (10%)	10 (16%)	61(100%)
Stranded people	17 (31%)	21 (38%)	0 (0%)	17 (31%)	55(100%)

Respondents were able to select more than one option. A total of 28 participants responded to this question. Percentages have been calculated using the total number of types of data selected for the specific question as reference.

detect flood extent, the overlap between consecutive images along and across the flight path reported by 14 respondents ranged from 20%:20% (two respondents), to 80%:80% (one respondent). A similar pattern was observed for the overlap values reported for the detection of stranded people with four respondents identifying a need to decrease the overlap and one respondent reporting an increase when compared to their values for the flood extent estimation. Four respondents reported the need to overlap the imagery when detecting stranded people. The imagery resolution (ground sampling distance) reported by nine respondents ranged from 0.91 to 3 cm for flood extent estimation and from 0.37 to 10 cm for the detection of stranded people.

With regard to waypoints, 19 participants out of 28 pointed out that they would collect the data following pre-programmed waypoints. The use of waypoints indicated the need for planning of the flight plan to ensure the area of interest is surveyed in full. Nine respondents declared no need for waypoints, indicating an ad-hoc approach to the collection of information within the area of interest. Most people (24 out of 28) stated that the collected data will require post-processing while only four respondents said post processing was not required. Some (15 people out of 24) would choose a laptop close to the site for data processing, with four people stating that they would need to process the data within their office environment, and five that they would undertake on-site data processing. No-one proposed real-time data processing capabilities integrated on the UAS.

The data processing time required varied across the 24 responses received (Table 11). Two respondents reported that data processing would be completed within 30 min, nine that it would take between 30 and 60 min, four that it would take 1–2 h, four said 2–5 h and five that it would take around 5 h. Fourteen of the 24 respondents identified the need to process the imagery using photogrammetry to identify the flood extent with only two requiring this for the detection of stranded people. The majority of the respondents would use a mapping software such as Pix4D/Drone deploy (seven responses) to estimate the flood extent, while others would post process the images or carry out comparisons to a non-flooded survey (seven responses). With regard to cost of service, 13 respondents replied that they would charge £1,000–£3,000, eight participants less than £1,000, while seven participants would charge between £3,000 and £5,000.

It is worth noting that for most of the survey questions, responses did not differ between the three scenarios. The questions that participants showed some marginal differences in relation to the three scenarios were about the size of the team, the selection of take-off and landing locations, and the choice of the GCPs. The size of team tended to increase with flood extent, while the selection of the locations also moved to the outskirts and to open fields, as the flood extent enlarged.

Table 11 | Required processing time

Processing time	Total responses	Responses as %
<30 min	2	8
30 min–1 h	9	37
1–2 h	4	17
2–5 h	4	17
5–24 h	5	21
>24 h	0	0
Total	24	100

Response to question: 'How long will it take for the data to be processed as a rough estimate?' Percentages have been calculated using the total number of respondents for the specific question as reference.

4. DISCUSSION

4.1. Effective use of the UAS

Current UAS deployment for use in flood emergency responses in England is limited by the availability of UAS pilots that can respond in a timely way to the on-set of an event. Flood risk managers and emergency respondents typically need to subcontract UAS services at short notice and may appoint any operator that responds to the request irrespective of their operational background and experience. During a widespread major flooding event many pilots would potentially cover the multiple locations affected. One would expect the current number of registered UAS companies (>5,000) to be able to cater for this demand (CAA 2021). However, the lack of adequate training on UAS data collection for flood risk management purposes, the specific equipment requirements for the UAS missions and the time taken for people to deploy on-site UAS dramatically reduces the number of pilots that can complete the mission and collect fit-for-purpose data. For example, results presented here show that a large proportion of UAS pilots/companies (57 out of 68 responses; 83%) have never been involved in data collection for flood emergency response activities. Some pilots and companies would most likely struggle to deliver the required geomatic products for some of the missions due to equipment limitations (e.g., platform or sensor availability and capability) or distance to site. The site deployment times could affect the effectiveness of a response, with 10 of 45 respondents needing 4–6 h to travel to Cockermouth and seven stating that it would take more than 6 h to reach Cockermouth.

The use of the UAS can facilitate better planning for and responding to flood events. If there is to be widespread and beneficial use of the UAS for such applications, there will need to be strategic investment in training to enable more UAS companies and pilots to respond to flood events in a timely and effective manner. Reducing the time of response can be achieved through (i) a reduction in the time the pilot takes to assemble all the equipment (<30 min), (ii) a comprehensive and accessible national network of UAS pilots appropriately qualified to respond in a timely way (<1 h) to events and (iii) effective deployment when on-site. The speed of response could also be facilitated by a clear specification for the equipment required to obtain the necessary type and quality of data for flood emergency response purposes or the provision of standard sets of equipment distributed across the country that any qualified pilot with the right permissions could use for the task in hand. The correct equipment could be distributed across the country in key locations (e.g., the Environment Agency offices). A comprehensive and accessible network of UAS pilots qualified to the required standards across England will take time to establish. This will limit the number of operators that can respond to an emergency call on-time. A geodatabase of UAS providers will help flood managers and emergency responders to target their survey calls to those that hold the required qualifications and are in close proximity to the flood event. Agreements established with operators prior to flood events taking place will also enable a faster response to fulfil monitoring needs.

Effective and timely site deployment can be achieved by facilitating access to the area to be surveyed and through the early identification of and access to the take-off and landing sites. For our case study area, the average time respondents said they would need to gain access to site was around 1 h and 40 min. Access to site and permission to fly over the affected area could be facilitated by and coordinated with the emergency responders and the Incident Command. However, only 16 of the total of 32 respondents were able to identify the appropriate approach for gaining prompt access to the site via emergency respondents and Incident Command. A large proportion of approaches identified by the majority of the respondents to gain access to site were not appropriate or would not be effective. Respondents identified firefighters, ATC, local council, landowners and flood prevention teams as suitable avenues to obtain prompt access to site. One respondent indicated there was no need to liaise with anybody. Guidelines on how to gain access to sites including the identification of take-off and landing areas will have to be made available to the network of UAS pilots. On the go detection of take-off and landing areas could also aid in flood emergency responses (Popescu & Ichim 2016; Shah Alam & Oluoch 2021). Providing near real time, information about the flood extent, could improve emergency response provision during an event, for example, in detecting stranded people and pointing out possible evacuation routes.

4.2. Technology uptake

The number of missions UAS pilots are tasked to carry out in relation to flood risk management activities was reported to be less than 10 per year, in all responses obtained. Small (one-person) UAS companies consciously avoid engagement in activities that do not provide a continuous stream of income or do not provide sufficient financial income to allow them to recover their investment.

Another factor limiting capital investment is the need to obtain BVLOS or EVLOS operations exemptions from the ANO to have a competitive edge in the market for flood-related missions. These exemptions increase the ability of pilots to collect wide area information. However, the costs associated with the submission of the application (e.g., ≈£2,000 approximately for BVLOS) and the time required to complete and obtain approval reduce the number of companies that can afford to obtain such approvals. UAS companies also face difficulties when building their portfolios to obtain BVLOS exemptions due to the limited number of areas where BVLOS flight training can take place. This could explain why only few respondents reported that could provide a BVLOS capability. A comprehensive spatial coverage of UAS pilots with the required exemptions in place will only be achieved if (i) the administration tasks around the submission, review and approval of ANO extensions are adequately managed to speed up the process and (ii) pilots are able to develop their competencies to EVLOS/BVLOS level through designated programmes and training facilities.

4.3. UAS data and processing standards

Respondents identified a wide range of data processing methodologies, with some reporting that there was no need to process the data. The use of photogrammetric processing is generally recommended when generating data outputs and products of relevance for flood management purposes. The geomatic products obtained from the photogrammetric pipeline (i.e., point clouds, DEMs and orthoimage) are used to derive accurate information about flood extent and impact. They are used for flood modelling and calibration purposes, in addition to their use in loss-adjustment models. The implementation of inappropriate data collection and data processing methodologies will result in bias in data products and in ill-informed flood management/response decisions. Similarly, a large proportion (≈70% across all scenarios) of the respondents did not identify the need to deploy GCPs within the affected areas. If GCPs are not used there could be significant differences in the geomatic products obtained by different pilots surveying the same area. The lack of clear guidelines on the data products that are most beneficial for particular purposes and the processing this requires means that the data collected often is not comparable across the country.

Rivas Casado & Leinster (2020) have showed that comparable UAS outcomes across England can be obtained when the five pillars of standardization are implemented. These are as follows: (P1) deployment, data collection and flight-related regulatory requirements; (P2) data processing, data merging and outputs; (P3) the introduction and use of innovative approaches and technological integration; (P4) use of outputs for public engagement and (P5) policy development and governance. In Europe, recent studies have provided and disseminated operational guidance to ensure best practice for UAS data collection and interpretation. This could provide a useful reference for future studies to guarantee the reproducibly of the data and results obtained (Manfreda *et al.* 2018; Tmušić *et al.* 2020).

From a technological perspective, battery endurance is a limiting operational factor with only nine participants reporting that they would have on-site charging facilities. Recent studies (Rivas Casado *et al.* 2018) have reported a 142 ha coverage post-flood event with two flights carried out with a platform that had a flight endurance of 50 min under ideal operational conditions. Platform endurance will vary depending upon the battery type and platform selected. Flood affected areas usually extend across a wide area (e.g., ≈1 km^2 for scenario 3) and therefore, multiple batteries and flights are needed to fulfil data collection requirements. Provision of on-site charging points would enable pilots with restricted platform endurance to charge their equipment and carry out longer missions. A central point with spare battery supplies could also facilitate longer surveying capability.

The use of both VTOL and fixed wing platforms was identified by multiple respondents. The acquisition of multiple platforms may be costly and out of reach for some small companies or sole operators. Hybrid platforms, such as the Wingtra One proposed by some respondents, combining VTOL and fixed wing capabilities could be a suitable and cost-effective option. However, there are only a few hybrid platforms in the market and these may not be accessible for all operators due to their high cost. Affordable hybrid platforms would offer the combined benefits of VTLOS (hover capability) and fixed wing (wide-area coverage). Further technological developments in this field are required to increase the market offer and provide competitively priced platforms and spares.

Overall, respondents did not provide consistent responses with regard to their selection of platforms, sensors, mission type (e.g., VLOS, EVLOS, BVLOS), collision avoidance strategies, imagery overlap and ground sampling distance. There needs to be a tighter definition of the types of platform and sensors that are appropriate for use to collect specified data before, during and after flood events.

Effective collection and processing of UAS data for flood risk management will require the development of clear guidelines and specifications detailing how to conduct a successful mission and generate any data and geomatic products at the required quality. Such guidelines could be defined through standardized protocols that detail the methods, tools, technology to be used in addition to the quantity and quality of the outcomes to be produced, and in addition to the expected costs for flood-related UAS missions. Results of this study also showed that the price variability across service providers was significant (from £1,000 to £5,000).

Clear standards and guidelines would also stabilize prices across UAS service providers and identify additional financial premiums UAS companies could charge for collecting and processing data to the required standards. UAS companies could be requested to comply with these standards to ensure comparable information and flood risk assessments are carried out across England. UAS providers would be requested to follow, apply and accredit their companies against such standards. Flood managers and UAS service users would rely on such accreditations to commission flood-related surveys and only companies that meet these requirements would be used. This approach would require a sound database that provides information about the location of the pilots, their accreditation levels, their data collection and processing capabilities and their experience in flood-related missions, so that the right team can be called on-site when flooding occurs.

4.4. Limitations of the study

The survey was distributed to UAS pilots through RUAS' extended network of contacts. Only a small proportion of the respondents had experience of flood-related missions. We used our experience over the last 10 years with flood risk managers and emergency responders to sense-check the results (personal communications) and ensure they were representative of their personal experience. The sense-check demonstrated that across England there is a limited number of companies able to collect fit-for-purpose data pre-, during and post-flood events. The survey results are therefore representative of the current situation in England with regard to UAS data collection within the context of flood risk management and flood emergency response. However, the results presented here should be interpreted in the context of the pilot's direct experience of flood-related missions and their general flying and surveying work. For example, some operators mainly using UAS for agricultural missions may select their sensors (e.g., hyperspectral) based on their daily practice and availability rather than their specific suitability for a flood mission. Recent research (Huylenbroeck *et al.* 2020) identified that although the use of LiDAR increased during the 2000s, the popularity of RGB/GS outputs can be explained by their low cost and widespread availability, including time series. It is interesting to note that participants did not mention the use of LiDAR sensors, possibly due to the associated costs. Further research should be carried out to ascertain the use of UAS LiDAR sensors as well as to better understand the rational for selecting a specific type and number of sensors.

This study describes the current situation regarding UAS operations for flood missions in England. The outcomes presented here have been interpreted in line with the regulatory context that applies to flood risk management and UAS airspace in England. They are useful and transferable to other countries with similar airspace regulatory constraints (e.g., EASA driven regulation in Europe). Lessons learnt can be used to inform the development of flood monitoring guidelines and UAS airspace regulation in countries that currently have a more flexible UAS operational protocols than England. Further research should investigate whether the patterns observed in England are similar in other countries.

4.5. Recommendations

The survey reported here has indicated a clear need for greater standardization and guidance in the way in which UAS data are collected if it is to be used to greatest effect in flood risk management activities. Standards for aspects such as: UAS deployment; data collection; flight-related regulatory requirements; data processing; data merging and outputs; platform and sensors combinations and configurations for particular applications.

Such standards would give confidence to those commissioning flights and data collection that the information provided will be fit-for-purpose and to the required standard. In addition, the data and information provided by one supplier can be merged with that collected by others maximizing the benefits. A database of firms that can provide the necessary services could also be a useful aid for commissioners. Providers will also be able to make investments in the knowledge that they are purchasing equipment that will be suitable for the work being commissioned.

The survey highlighted a need for specific training on the equipment to use and how to collect UAS data for flood management/emergency response. There is also a need for EVLOS/BVLOS training programmes and facilities and a streamlining of the submission, processing, approval, review of EVLOS and BVLOS applications. Technological developments in hybrid platforms would clearly be beneficial in reducing data acquisition costs through combining both hovering and wide-area capabilities.

5. CONCLUSIONS

The use of the UAS for flood risk management and emergency response activities is still in its initial stages of development. The route map for an effective, efficient and fit-for-purpose uptake of the technology within this context will require substantial effort and investment. However, the benefits obtained upon implementation are expected to offset any initial investment through provision of increased property level flood resilience in urban environments. This study has reviewed and analysed the responses of UAS pilots about the data collection and processing strategies they would use in a flood emergency response. The number of pilots that can complete flood surveying missions to the required standards is greatly constrained by the lack of training on UAS data collection, the particular equipment requirements and the spatial coverage of timely UAS provision. The study demonstrates that a well-established and documented network of pilots would increase the preparedness and reduce the reaction time to respond to a flood emergency. Investment in training provision and specifying the type of platforms and sensors that are appropriate for particular circumstances will aid flood emergency responses. The wide range of responses obtained highlighted the need to provide standardized guidance for UAS flood risk management surveying missions to ensure data collected across England is to a consistent, fit for purpose standard that properly informs the event response and enables the data to be combined or compared between locations. This could also be extended to data processing methodologies and software. In addition, monitoring protocols that consider the standardization of equipment for generating particular geomatic products, the use of GCPs and flight plans and the post processing workflow will increase the reliability, comparability and transferability of any outcomes generated. Comparable UAS outcomes across England will only be obtained when the standardization at multiple levels (e.g., data collection, processing, communication) is implemented. A coordinated response to UAS data collection, processing and interpretation will require substantial resource investment; multiple organizations will have to work together following an integrated approach to facilitate technology uptake. The outcome could significantly inform flood management and emergency response decisions.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

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