Dear Editor and Reviewers,

Please find below our point by point response (blue) to the reviewers' comments (black). Comments from several reviewers regarding a similar point/issue (each new bullet point) were combined for clarity. Note that the page and line numbers indicated in our response refer to the manuscript document with edits displayed.

- **RC1:** The title is eye-catching, but the question that is being asked by the interviewee (water over bank vs. Armageddon) is about the magnitude of the event rather than about probabilities, while the paper is about transitioning to probabilistic forecasts.
  RC3: The citation in the title does not pertain to the theme of the manuscript.

  We think that the title captures the paper's content very adequately. Indeed, the question raised by one of the interviewees and used in the title: "Are we talking just a bit of water out of bank? Or is it Armageddon?" reflects the binary perspective of duty officers on this decision-making problem. This is a challenge at the heart of this paper and at the heart of the probabilistic forecast-lead decision-making process. This was clarified and tied in with paper results in Section 3 (P12 L425).

- **RC1:** While the concept of the paper is excellent, my major suggestion is to re-work the framing. As a reader, it is difficult to follow the logic of the paper. Often, it seems to be an interesting mix of quotes from interviews, lacking some analysis to identify relevant points and present them in a structured manner.

  We have restructured the paper as a whole. The Introduction was merged with the former Context section to provide a succinct yet thorough overview of the topic at heart and a clearer framing for the content of the paper (now Section 1). Section 4 was restructured to provide a storyline account of the current EA practice (now Section 3), emphasised by the numbered arrows added to Figure 2. Former Section 4.3 was merged with former Section 5 in a more thorough analysis and discussion of what might be the future EA practice given the transition (now Section 4). See responses below for more in-depth explanations.

- **RC1:** The introduction provides interesting context to the flood forecasting situation in the UK, but the details often seem disconnected. It is not quite clear how the authors are leading up to a solid research question. At the end of the introduction, it becomes clear that the EA is going to transition to probabilistic forecasts, and that the researchers will interview the forecasters about this transition. However, it is not really clear what the purpose is for the interviews. My suggestion is to re-write the introduction with a clarified mandate, leading up to the question that will be then answered in the paper.
  RC3: Re (i). The research, through the interviews, provides data that documents the view of various individuals at a single point in time, regarding a change in an organization's processes and procedures. I like to make the analogy with "observations" in the quantitative

sciences. Observations can be used to provide evidence of the plausibility of some hypothesis - or of the absence thereof. Such a 'hypothesis' element would greatly improve the quality of the manuscript - and provide a response to the "So What?" question that, post reading the manuscript, continues to linger in my mind. Re (ii). Based on the interview data, recommendations are phrased. While some of these may be very worthwhile indeed, I think recommendations can only be made based on an analysis where objectives are offset with achievements or projected achievements. Ergo, I think recommendations can only be made if the agency's objectives (with respect to the production and use of probabilistic forecasts) are described. Have these objectives been described in the 2016 National Flood Resilience Review that is cited, maybe? Or are documented elsewhere?

We have rewritten the Introduction and merged it with the former Context section to clarify the context and purpose of this paper, with a hypothesis on P6 L224-226.

- **RC1:** Similarly, the section 4 is very interesting; it is neat to have a window into the ways of working of these flood forecasters. However, the quotes and text do not form a coherent story for the reader.

  We appreciate that some readers may be unfamiliar with this format and have reorganised and rewritten parts of former Section 4 to make a more coherent story for the reader, following the chain of information Duty Officers lead ahead of a potential flood event (now Section 3). We have also numbered the quotes for cross-referencing.

- **RC1:** The section 4 does not seem well linked to the recommendations in section 5 – it is not clear to the reader how the interviews resulted in the recommendations. They read more like a policy brief than a research output; perhaps this would be better suited as a commentary than a research article? The recommendations in section 5 seem to be generally good practice recommendations for whenever a forecasting system might have some sort of change, but not necessarily linked to the research results. In addition, most of the recommendations do not seem to have any relation with the characteristics of this particular change in forecast systems; the fact that the new system is probabilistic rather than deterministic.
  RC2: The presentation and discussion of the answers of the interviewees to the last question, about the upcoming introduction of probabilistic flood forecasts, seems to me to be somewhat limited. This impression is fed by the sudden change in reporting format from in-line quotes to a wordcloud, summarising table (Table 1), and a reference to an Appendix, none of which are discussed in the manuscript text (lines 460-464). I may be overlooking something, and if not, you may well have chosen this approach for good reasons. If by design, then I would recommend to explain the reasons in the same section (Section 4.3.2). If possible, however, I would recommend continuing with the reporting format of the previous sections, or at least including a discussion of the wordclouds and Table 1. Also the Discussion and Recommendation section leaves me with a feeling that more reflection on the interview results can be done. It would be, for example, interesting to reflect on whether

the interviewees' answers to the first questions are in-line with, help explain, or not, their perceived opportunities and challenges (last question). The 10 recommendations in section 5.2 seem somewhat disconnected from the interview results (only Refs to literature are given). I would recommend to put in, in Section 5, more references to findings reported in earlier sections of the paper.
RC3: The manuscript's theme is the 'transition to probabilistic forecasting'. The amount of text that is dedicated to that theme, however, is relatively small. For example, the Results sections spans lines 190 through 464 - yet only as of line 425 are the probabilistic forecasts discussed. Similar observations can be made to the manuscript as a whole. In my view, the reader is distracted a lot from the main points.
SC1: Given the quotes listed in the appendix, I think the wording of table 1 could be stronger.

Former Sections 4.3 and 5 were merged and rewritten to provide a more thorough analysis and discussion of what might be the future EA practice given the transition (now Section 4), replacing the previous Table 1. We have used the same reporting format (text supported by quotes) as the current Section 3, as recommended by RC2. Section 4 is now structured in 5 sub-sections to reflect the structure and provide a better reflection of the current practice (Section 3). Each sub-section provides: several quotes to communicate the interviewees perceptions of how a particular topic may be affected by the transition, an analysis of these quotes and the current practice (cross-referencing quotes from Section 3, which are now numbered), literature findings on the given topic, which combined should logically lead to a clear and specific recommendation for the EA. We have rewritten and clarified the recommendations to reflect the findings of this paper.

- **RC1:** In particular, section 5 seems to bring in the idea of decision-makers, but all of the interviews were with forecasters and those responsible for issuing warnings. There was no analysis in section 4 of who the decision-makers are, what decisions would be made based on the warning, or how that affected the information that was released.
  SC1: Largely the paper considers the FWDOs as the decision makers as they are the ones issuing flood warnings. The latter part of the paper also introduced external stakeholders as decision makers, making decisions on the EA flood warnings. It would improve clarity to make it clearer when you are talking about internal and external decision makings. In particular this applies to the discussion around lines 500 and 540. Maybe also consider adding a definition of 'decision maker' to the glossary and recognising that decisions are made at various points during the forecasting chain. Similarly it is not clear who makes the decisions re increasing control room staffing or increasing field resources (e.g. for putting up flood defences). Is this the FWDO, the MFDO or someone else? And what time scale are these decisions made on/how will the change to probabilistic forecasts affect them?

  The Duty Officers interviewed are decision-makers at the heart of the forecasting chain. They collaboratively decide whether to issue flood warnings operationally and pass relevant information on to other decision-makers further down the chain (both internal and external to the EA; e.g. the public, flood incident duty officers and emergency responders). We have clarified their roles as decision-makers (and the roles of other decision-makers in the chain) in Section 3.1 (P8 L300-323). At the end of this section, we have also clarified that we refer to the Duty Officers when talking about decision-makers throughout the paper, unless stated otherwise. We have also added a definition of 'decision-maker' to the Glossary (P48). The timescales of response were clarified throughout Section 3 (e.g. P8 L327-328, P9 L338-350) and reflected on in Section 4 with regards to the transition to probabilistic forecast (P31-32 L1040-1059).

- **RC1:** Here are some examples of additional places where the text could be changed to present a clear research statement to the reader: Section 3.3 question 2 – as a reader first encountering this statement, I am not sure what you mean by this. Section 3.3 question 3 – when you say "potential impacts", what does this mean? As a reader, I can't anticipate what exactly you are looking for.
  RC2: Page 5 lines 182-184: Consider referring back to these research questions in your Conclusions section.

  The research questions were reworded into two aims which provide the structure for the results of this paper (Section 2, P7 L286-290). The aims were discussed in the Conclusions.

- **RC1:** The text would benefit from a few additional examples, if possible.

  Sections 3 and 4 were rewritten to provide a clearer storyline, and screenshots of FFC and EA products were added for clearer examples of the incident response process to support the text (Appendix B).

- **RC1:** Some additional points for clarification: Page 6 line 213: How is running the NFFS different from the information given by the FFC? How will those NFFS localized model runs update or change the flood forecast of the FFC? It would be helpful to have a worked example, of what was produced by the FFC, what was communicated to the forecasters, what additional data they gathered, and what warnings they then communicated to people and what decisions were made based on that information.

  The NFFS contains locally tailored hydrological and hydraulic models, which provide local flood forecast information, complementing the national and county scale information provided by the FFC, as previously mentioned on P6 L202-204. This was clarified throughout Section 3.2.2. We have rewritten Section 3 to provide a storyline of how Duty Officers process information and make decisions ahead of a potential flood event, supported by additional visual examples in Appendix B. However, as these visual examples were not available for a specific flood event (the EA does not keep all past forecast products, as added on P18 L623-620, "This database however does not capture catchment conditions or forecasts produced at the time the warning was issued") we had to keep the text fairly general, while constructing a clearer storyline.

- **RC1:** Page 6 line 234: What do you mean that they wait for the forecast to be "confident"? Is this not a deterministic forecast?
  RC2: p6 l234 'waiting for the forecast to be confident' Please explain how the forecast can become confident in the context referred to here (present practice).

  As previously stated in the Glossary, "confident" here refers to "A forecaster's expert judgement of how certain they are that the forecast is right". The forecast is composed of two scenarios, which might sometimes show very diverging outcomes. This may lead to the duty officer being less "confident" about the signal shown by the forecast and the decision to make. Furthermore, combining different sources of information (previously highlighted in Section 4.1.1, but also in Section 4.2; e.g. national/county scale forecasts, mode performance information, river level correlations), the FWDO will add some expert judgment to gauge whether they can "trust" what the two forecast scenarios show. The use of the term 'confident' was clarified in Section 3 (P11 L402-403) and in the Glossary under 'confident' (P48).

- **RC2:** The experience with the recent (2013/2014) transition from single forecast to 2-scenarios may be quite relevant for the perception of the interviewees and prospects of the upcoming change from two scenarios to probabilistic forecasts. Did you discuss this with the interviewees and could you perhaps elaborate more on this aspect in the paper?

  We did not discuss this explicitly during interviews as not all interviewees had experienced this transition. However, the breadth of the interviewees' responses could hint at the interviewees' experience with this past transition. This merits to be explored further. We have added a paragraph to highlight this in Section 4 (P36 L1253-1257).

- **RC2:** From reading the paper I get the impression that there is little known yet about what will be the procedures for preparing, communicating internally, and use in warning decision making of the probabilistic forecasts. Could you, for example in the Context section, elaborate on what is known, and what was known to the interviewees at the time of the interviews, about the upcoming transition to probabilistic forecasts? If nothing is known yet, the good thing is that the recommendation of co-design (recommendation 3) can still be taken up, and at the same time it might explain some of the perceived challenges associated with the upcoming transition to using probabilistic forecasts. I may have missed it, but could you include more information (and refs if available) on the probabilistic forecasting system that will be used? Is it based on meteorological ensembles or on another probabilistic forecast method? Will the MFDOs be responsible of running it through the hydrological models (as they seem to be now)? Will hydrological uncertainty also be included in the hydrometeorological ensemble, and how? etc. Please also reflect on whether this information on the features of the new forecasting system was known to the interviewees.

What was (un)known about the transition to probabilistic forecasting at the time of the interviews was clarified in the Introduction (P5 L206-210) and in Section 4 (P25 L846-848), with supporting references for the readers to find further information (as this does not fall within the scopes of this paper).

- **RC2:** You focus on the benefit of probabilistic forecasts of increasing lead time (e.g. p1 l14 and l36, p3/4 l124/125, while other benefits include the potential of increasing the probability of detection of floods (reducing missed events), and supporting risk-based decision making. Could you reflect on this in the text? E.g. adding advantages or explaining why you refer mainly to increasing lead time.

  The benefits of probabilistic forecasting were clarified in the Introduction (P4-5 L166-178).

- **RC2:** Interview findings indicate that in the current practice final decision of issuing a warning is often based on nowcasts with lead times of only a couple of hours and/or on observations (e.g. page 7 line 267 and page 11 line 397/398). Do the interviewees and/or you think that the introduction of probabilistic forecasts is going to change this practice? Could you reflect on this in the paper?

  We indeed think that the introduction to probabilistic forecast should change this practice and reflected on how the lead times of response based on probabilistic forecasts might change from the current practice in Section 4 (P31-32 L1040-1059).

- **RC2:** Some of the duty officers (DOs) seem to be concerned about how the probabilistic forecasts will be received by the action response units. Does this mean that in the current practice, forecast hydrographs are send along with the warning to action response units? Please clarify in the text.

  What was known to us and shared by the EA about the exchange with emergency responders was written in Section 3 (P8 L317-320).

- **RC2:** When reading Table 1, I do not perceive a strong concern about the upcoming introduction of probabilistic forecasts, while when reading the quotes of Annex C I do sense a strong concern among the Duty Officers interviewed. This concern seems mainly to be that probabilistic forecasts will put all the responsibility of taking a decision with themselves (rather than with the forecasters or with the action response units). Could you note and discuss this in Section 4.3.2.? And then elaborate on recommendations on how to prevent/manage that? For example, Recommendation 9), setting guidelines on '..the forecast confidence at which certain decisions and actions should be made..', may also not be the answer, because the DOs indicated in the present-day practice the value of local expert judgement in issuing warnings and seem to appreciate having the freedom of applying such expertise. Prescribing decision making rules, may, therefore, be a step too far in taking away forecast interpretation responsibility from them.

Table 1 was adapted into text (see Section 4). We discussed the Duty Officers' concern about having more responsibility to interpret the probabilistic forecast to making a decision in Section 4 (P30-31 L1001-1029). At the end of this paragraph, we make a recommendation to tackle this.

- **RC2:** Could you reflect on whether the interviewees see the probabilistic forecasts as an additional input to their flood forecast confidence assessment? The DOs are already communicating a confidence level with the warnings they send-on down the line. One quote in Appendix 3 confirms seeing this as an opportunity, but it would be interesting to read from you what is your impression on this for the other interviewees.

  The MFDOs indeed see probabilistic forecast as a potential source of additional confidence when communicating the forecast with FWDOs. This was explored further in Section 4 (P28 L931-960).

- **RC2:** Page 4 line 130/131 refers to the EA already using probabilistic coastal flood forecasts. Why not learn from the experiences of that earlier transition (perhaps too long ago), or at least from the user experiences. Could you elaborate a bit more, e.g. whether or not you think that would be interesting for other researchers and the EA to pick up.

  This was not explored during these interviews as not all interviewees were familiar with coastal flood forecasts (given the non-proximity of some of the EA centres where interviews were carried out to the coast). However we think that the EA could take inspiration on the current coastal flood forecast decision-making to design probabilistic forecast-based decision-making rules. This was discussed in Section 4 (P31 L1022-1025).

- **RC2:** Page 6 lines 222-227: Choosing the What-if scenario could be perceived as quite a responsibility. A responsibility that might be (partly) taken away with the introduction of probabilistic forecasts. Did you discuss this with the MFDOs and what are their and your thoughts on this? Consider elaborating on this in the paper.

  This was previously mentioned in Table 1, which has been adapted into text in Section 4 (P27 L901-903).

- **RC2:** Are all the warnings issued being archived (including alerts, issue time, updates, etc.)? Are actual flood occurrences being documented? And if so, are the archives being compared and analysed? Could you reflect on this, and do you think such analysis could be/has been helpful for identifying challenges in the current forecasting system and warning practices, as well as for analysing in the near future the impact (or lack thereof) when introducing the probabilistic forecasts and identifying persistent and potentially new challenges?

  The flood warnings are logged in a database, however not enough information is stored currently for post-event analyses. This was mentioned in Section 3 (P18 L621-625). We agree with the reviewer that this would indeed be very helpful in improving the current system and evaluating the impact of the transition to a new system. We discussed this and added a recommendation based on the discussion in Section 4 (P37 L1272-1279).

- **RC2:** Page 11 line 391/392: Could these differences perhaps also be a consequence of differences in catchment size/rainfall-runoff response time/land use and differences in flood management actions that follow the warnings and the time these measures take? Consider mentioning/reflecting on this (at this point) in the paper.

  This is indeed true and the historical differences are also caused by catchment response differences as per our interview discussions, and possibly by the amount of time it takes to prepare in anticipation for a flood (partly controlled by the catchment size too). This was mentioned in Section 3 (P18 L617-620).

- **RC2:** Page 11 line 400: Are the DOs being scored, and if so, how are they scored, and what are these scores used for? If possible, would be interesting to comment on below this citation, and perhaps consider to reflect on how such scoring may have an encouraging or discouraging impact on the uptake of probabilistic forecasts.

  This was a figure of speech and was clarified in Section 3 (P18 L621). It was additionally discussed in Section 4 (P30 L1009-1010), alongside discussion about FWDOs’ concerns of having more responsibility in interpreting the probabilistic forecast to make a decision.

- **RC2:** The paper concerns the upcoming transition from a 2-scenario forecast to a probabilistic forecast, but the Supplementary material seems to focus on the recently completed transition from a single forecast to the two scenario’s (following 2013/2014). Please clarify, e.g. in the author response, not necessarily in the manuscript.

The Supplementary material indeed displays examples of the current system (two scenario-based), as the future probabilistic system is still in the making. This was clarified in the paper in the Appendix B caption (P55).

- **RC2:** p1 l24 This sentence is rather broad and in my view not necessary. Consider leaving it out. Instead consider putting some of the key findings and recommendations (similarly to what is written in the Conclusions section)

  We have left this sentence in the abstract as it is important to highlight at this stage of the paper that a Glossary is available, as this is a paper for Geoscience Communication and should hence be able to communicate these findings for readers from a range of disciplines. We have however included a few more specific key findings to the Abstract (P1 L20-29).

- **RC2:** p3 l113 I would suggest including here an explanation on how the two scenarios are prepared. (I realise this is described later, but it left me curious from this point onward, especially because it matters for the context of the interviews to what extend these two scenarios are a step towards probabilistic forecasting or not). p3 l114-118 I am not sure if I now understand correctly how the two scenarios should be used. This might be due to me not being a native speaker, but if you could reformulate to further clarify, that would be appreciated.

  More and clearer information was provided about the two scenarios in the Introduction (P5 L194-203).

- **RC2:** p7 l257 please add who has the 'Expert knowledge'.

  This refers to the FWDOs' expert knowledge and the knowledge about potentially affected catchments contained in the 'Flood Intelligence Files'. This was rewritten in Section 3 (P14 L497-499 and 501-504).

- **RC2:** p7 l264 please also describe how/for what/when the 'reasonable worst case' should be used. p9 l345 please consider to add also the procedure for using the reasonable worst case again.

  The RWC should be used for incident planning, as clarified in Section 3 (P16 L559-566). However, in certain cases it may be used for warning, although technically against procedure, as mentioned in Section 3 (P18 L626-631).

- **RC2:** P10 l380 - 383 seem to me a bit too personal. Kindly double-check.

We have removed this quote as it was not of added value to the points made in the paper.

- **RC2:** p12 l453 In my view this is an important finding that can also be used in the upcoming transition (and gives reason for a positive prospect). I cannot recall whether you clearly refer back to this finding in the Discussion and Conclusion sections at the end of the paper, but if not, I recommend including it.

  We have discussed this in Section 4 (P25 L853-864) and mentioned it in the Conclusions (P37 L1296).

- **RC2:** p13 l463/464 Unclear, and appears as a stand-alone sentence. I suggest making this part of a discussion to be added, of Fig. 5, Table 1, and Appendix C. (See also my third general comment)

  We added further discussion in Section 4 (P32-36 L1087-1257) on how the interviewees' "resistance" to the transition to probabilistic forecast may hint at the lack of knowledge that the transition was happening, the wording of interview questions, and/or their experience with the previous transition to two scenarios. We also made recommendations based on these.

- **RC2:** p13 l469/470 I do not understand this sentence. If we achieve increased confidence levels before moving up lead time, why is the second part of the sentence, about the chaotic system, posing problems? Consider clarifying or leaving out the sentence.

  This sentence was removed.

- **RC2:** p13 l472/473 ..'uncertain' science.. Not sure I understand. Do you mean new discoveries being at first 'uncertain' (or not trusted), until the experiment has been reproduced with the same results (or tested in pilots, practice, etc.)? Or do you mean, more specifically, the science of quantifying uncertainty associated with predictions? Consider reformulating.

  We rephrased this to: "new and probabilistic science" and moved it to the Introduction (P1 L17).

- **RC2:** p15 recommendation 1: Before this campaign, should there first be known a bit more on how the change will be done, or not?

We agree to an extent but think that the EA shouldn't wait for the entire system to be set up before starting to tell people about the changes to come. As shown by some of the interviewees' responses, not knowing about a transition may cause personal resistance to the idea if not involved in shaping the transition. Making the transition public as it is happening will give key actors a chance to be involved for a more successful transition. This was clarified in Section 4's Recommendation 7 (P30 L993-1000) and expended on further (P32-36 L1087-1257).

- **RC2:** p14 l512/513 ..crucial to develop a methodology.. Not sure if a single methodology is the 'crucial' solution of the challenge of using probabilistic forecasts. It may be that case-dependent and user-community dependent ways have to be found, by scientists and users together, on how to effectively use confidence (uncertainty) information.

  We agree with the reviewer's comment, which is now reflected in Section 4's Recommendation 8 (P31 L1026-1029).

- **RC2:** p14 l518 I do not think this reflects the main idea of probabilistic forecasts, nor that the provision of scenarios causes more false alarms. I would argue the other way around, that having the scenarios, the probabilistic forecasts, gives the opportunity to the decision maker (and its beneficiaries) to balance the number of missed events and false alarms to their needs. Please reformulate. p14 l525 This seems a bit out of the blue and not clear to what extend you think this relates specifically to EA communication pathways and warning procedures.

  We have changed this paragraph to clarify its main point, that a transition to probabilistic flood forecasts should be reflected in an institution's wider flood management priorities. Based on the points raised in this paragraph an EA-specific recommendation was made (Section 4, P31-32 L1053-1059).

- **RC2:** p15 l577 is this recommendation specifically for EA, or for the flood forecasting and early warning research community. If the latter, consider moving this elsewhere.

  This recommendation was specific to the EA and clarified in Section 4 (P31 L1026-1029).

- **RC2:** p17 l623 because of the mentioned concern of the responsibility of decision making being pushed down to the DOs, I would not write 'lie mostly outside their role', rather just something like 'the main perceived challenges concern..'. In the sentence before, perhaps it would be more clear to write something like '..concerns about impacts of this transition on the communication and interaction between them.'

We agree with this point and will rephrase this sentence.

- **RC2:** p17 l624 consider replacing 'translating uncertain information to a binary decision' (because it is a challenge that they already perceive in the present situation) for the worry of the responsibility of decision making being pushed further to them.

  The entire Conclusions paragraph was rewritten.

- **RC3:** I also find that the manuscript tends to use language that, at times, can be a little more 'dramatic' than required. This is exemplified by the title's "front line perspectives" (a change in processes and procedures is not a war!) and the reference to "Armageddon" (which, by the way, is a settlement on top of a hill - the 'Ar' originates from the Hebrew 'har' which means mountain - and not prone to flooding and hence reference thereto is somewhat unfortunate - but I am digressing now). Additional examples: "the chaotic and far from certain world we live in", "urgently required", "high priority recommendations".

  We have toned down some of the language. However, where language has been used in quotes or there is precedent in the current policy in this area we have left it. For example, "front line" is language often used by the EA.

- **RC3:** The language used to describe the somewhat technical aspects of predictive uncertainty could be a little more precise. Some examples: It's not forecasts themselves that are uncertain. What's uncertain is the future water levels, streamflows, etc. - also even if an estimate of those future values is made through a forecast. When that residual uncertainty is quantified or expressed, we have available 'estimates of uncertainty', rather than 'uncertainty'. Uncertainty estimates and probabilistic forecasts are not the same thing. Hopefully the level of uncertainty can be expressed as a probability, but very often it cannot. I wouldn't want to use the terms interchangeably in a manuscript. In a manuscript that discussed 'uncertainty', you have to be a little careful with using the word 'certain' ('certain decisions', l609). In most of those cases, the word 'certain' can be either safely omitted, or replaced by 'various'.

  We have clarified throughout the paper with: the forecasts display the uncertainty in our estimates of the future water levels, streamflows, etc. (e.g. P5 L171-173). This was also explained in the Glossary under 'Uncertainty' and 'Probabilistic forecasts' (P50-51). We have also replaced the word 'certain' with synonyms.

- **SC1:** Firstly the importance of timings/lead time is confusing as the focus changes throughout the paper from the 2-6 hour window for issuing flood warnings to the 2-5 day window for more strategic planning decision making. The relative value, and expected use of probabilistic forecasts will be different at these two timescales. The quote on line 270 is key to this discussion. It would be helpful to have a clearer focus on what lead time is being discussed at different points in the paper. A specific example is line 234 talking about waiting for the forecast to be confident – I expect there is also a balance of confidence and lead time here

  We have clarified that the paper focuses on the window of 2 hours to 5 days ahead, as this is the timescale likely to be affected by this transition (Section 3, P8 L326-328).

- **SC1:** I know it is beyond the scope of the paper but there is limited consideration of how the change to probabilistic forecasts might affect external decision makers although it is raised as a concern by FWDOs. A useful extension to the work would be to see what information those receiving flood warnings actually want, to understand if it is a perceived or real concern about the lack of binary forecast information and the pushing of decision making further down the chain. This is also relevant to recommendation 1 – as well as communicating that there will be a change, should the EA also have some responsibility for preparing external decision makers on how this might change their practices?

  Although beyond the scope of this paper, we agree that this is indeed a very important point and that EA's strategic overview role includes preparing external decision-makers. We have included it in Section 4's Recommendation 7 (P30 L993-1000).

Editorial changes

- **RC2:** p1 l12 Consider ..inclusion of uncertainty information in..

  Rephrased (P1 L12): "By showing the uncertainty surrounding a prediction, probabilistic forecasts can give an earlier indication of potential upcoming floods, increasing the amount of time available to prepare."

- **RC2:** p1 l13 Consider ..potential upcoming floods.. instead of 'future' to avoid confusion with climate change. Also consider for other occurrences of 'future'.

  Done (P1 L13): see sentence above.

- **RC2:** p1 l18 Consider ..understand their perception on how this transition..

Rephrased (P1 L20): “to understand how they perceive this transition might impact on their decision-making.”

- **RC2:** p1 l38/39 Consider ..given the explicit provision of uncertainty information.. Single forecasts are as uncertain as probabilistic forecasts. The uncertainty is just not shown.

  Rephrased (P5 L171-175 and P6 L211-212): “By indicating how likely a flood is to occur, probabilistic forecasts communicate an estimate of the uncertainty surrounding a prediction (expressed as a probability), and can support risk-based decision-making through an increased probability of detection of floods (reducing missed events*), an earlier indication of potential future extreme events, such as floods, and their associated impacts” and “Probabilistic forecasts can be challenging to use for operational decision-making*, given the explicit uncertainty information they communicate.”

- **RC2:** p2 l42/43 ..designed to capture scenarios that may not always realise.. That does not sound quite right/the point of probabilistic forecasting. Consider just leaving that whole sentence out, or reformulate to something like "Warning on the basis of low probabilities of flood, for example, will reduce the chance of missing an event, but will also lead to more false alarms."

  Rephrased (P6 L215-216): “warning based on low probabilities of a flood, for example, will reduce the chance of missing an event, but might also lead to more false alarms.”

- **RC2:** p2 l44 Consider .. when a pre-defined threshold (e.g. river stage) is reached..

  Rephrased (P6 L216-217): “Decisions can be made following a set of rules, such as threshold exceedance”.

- **RC2:** p3 l88 Consider ..whilst local flood authorities..

  Removed as not crucial.

- **RC2:** p3 l120 ..potential risks of impacts.. Please reformulate.

  Rephrased (P5 L176-177): “by allowing to quantify the potential impacts of upcoming floods and their associated likelihood”.

- **RC2:** p4 l129 I do not think you can ’ensure’ the appropriate use. Consider to reformulate, e.g. ’support’.

  Changed to ‘support’ (P6 L231).

- **RC2:** p5 l171 ..advance..

  Done (P7 L277).

- **RC2:** p5 l186 ..communicated by several interviewees,..

  Done (P8 L295).

- **RC2:** p13 l463 consider ..sound extreme.. or alternative formulation.

  Sentence removed.

- **RC2:** p13 l490/491 consider ..decision makers operate, and where the forecast..

  Sentence removed.

- **RC2:** p13 l497 consider ..uncertainty information.. or ..information on uncertainty..

  Changed (P26 L874): “the design and communication of uncertainty information”.

- **RC2:** p15 l547 consider ..we made a list..

  We kept the present tense as these recommendations are relevant and actionable now.

- **RC2:** p15 l548 consider something like ..The recommendations concern actions we think the EA should take with high priority..

  Rephrased to the sentence provided by the reviewer (P25 L841-842).

- **RC2:** p14 l531 Consider adding a brief explanation on what is a 'post-factual society'.

  Explanation added (P25 L983): "(i.e. culture in which public opinion depends on appeals to emotions rather than objective facts)".

- **RC2:** p15 recommendation 2: consider ..to all players..

  Recommendation removed.

- **RC2:** p16 l582/583 given the reported differences in catchments, forecast performance, impacts, and warning response actions, etc., double-check this recommendation. Consider 'customised' rather than 'homogeneous'.

  Used the word 'customised' (P27 L918): "we recommend that the EA carry out a locally tailored customised transition".

- **RC2:** p16 l601 consider ..should be collected and used to update design and procedures..

  Changed (P32 L1082-1083): "end-user feedback should be collected from all key players and considered to update the new system's design and procedures"

- **RC2:** p16 l602 consider ..To handle situations..

  Removed.

- **RC2:** p16 l613 stand-alone sentence, consider moving somewhere else or elaborating.

  Removed.

- **RC2:** p17 l625 consider reformulating to something like ..High priority actions were recommended to the EA.. to support a successful..

  Rephrased (P37 L1293-1294): "thirteen recommendations were spelled out to support a successful transition for flood early warning in England".

- **RC2:** p23 Caption figure 4: consider ..Complex flood forecast interpretation landscape.. because the decision making landscape includes more elements, such as external pressure.

  Changed (now Fig. 3): “Complex flood forecast interpretation landscape in which EA Duty Officers operate”.

- **RC2:** p23 Caption figure 5: please add from what the opportunities and challenges arise (e.g. ..from the introduction of probabilistic flood forecasts)

  Figure removed as it did not add any additional value to the text.

- **RC2:** p24 Title table 1: consider ..A sample of supporting quotes.. line 2: ’improve long-term communication’ please clarify. add a full-stop at the end of the sentence. line 5: consider ..contain information on forecast uncertainty.. line 22: ..it is worth noting that..

  This was adapted into text (Section 4).

- **RC3:** A glossary is, I think, unnecessary, and I find the asterisks a little distracting.

  We disagree and think this is very helpful for readers outside of this field of expertise, who are interested about geoscience communication. We have kept the Glossary and improved it following reviewers’ comments.

- **RC3:** Minor, minor issue: In author contributions, why not simply reference first names? “Hannah, Louise and Susan posed the original question” is a lot easier to read than “H.L.C., L.An. and S.M. posed the original question”.

  This is the convention and we have kept this author contributions format.

- **SC1:** Line 19 – I would remove ‘alternative’, I’m not sure why these two areas are alternative.

  Sentence removed.

- **SC1:** Lines 130:134 – this is largely a repeat of lines 76:81.

The former Introduction and Context sections were merged into a single Introduction, removing repetitions.

- **SC1:** Line 224 – increase/ change of 200%?

  Clarified (P10 L374-375): "(e.g. a 200% increase in catchment rainfall totals over the next 6 hours)".

- **SC1:** Personally figure 5 (the wordcloud) doesn't add much to the paper for me.

  We have removed this figure from the paper.

"Are we talking just a bit of water out of bank? Or is it Armageddon?" Front line perspectives on transitioning to probabilistic fluvial flood forecasts in England

Louise Arnal[1,2], Liz Anspoks[3], Susan Manson[3], Jessica Neumann[1], Tim Norton[3], Elisabeth Stephens[1], Louise Wolfenden[3], Hannah Louise Cloke[1,4,5]

[1]University of Reading, UK
[2]European Centre for Medium-Range Weather Forecasts, UK
[3]Environment Agency, UK
[4]Uppsala University, Sweden
[5]Centre of Natural Hazards and Disaster Science, Sweden

Correspondence to: Louise Arnal (louise.arnall.s.arnal@p@usask.cagr.reading.ac.uk)

Abstract. By showing the uncertainty surrounding a prediction, probabilistic forecasts can give an earlier indication of potential upcoming floods, increasing the amount of time available to prepare. However, making a decision based on probabilistic information is challenging. As part of the UK-wide policy's move towards forecast-based flood risk management, the Environment Agency (EA), responsible for managing risks of flooding in England, is transitioning towards the use of probabilistic fluvial forecasts for flood early warning. While science and decision-making are both individually progressing, there still lacks an ideal framework for the incorporation of new and probabilistic science in decision-making practices, and, respectively, the uptake of decision-makers' perspectives in the design of scientific practice. To address this, interviews were carried out with EA decision-makers (i.e. Duty Officers), key players in the EA's flood warning decision-making process, to understand how they perceive this transition might impact on their decision-making. The interviews highlight the complex landscape in which EA Duty Officers operate and the breadth of factors that inform their decisions, additionally to the forecast. Although EA Duty Officers already account for uncertainty and communicate their confidence in the forecast they currently use, the interviews revealed a decision-making process which is still very binary and linear to an extent, which appears at odds with probabilistic forecasting. Based on the interview results, we make recommendations to support a successful transition to probabilistic forecasting for flood early warning in England. These recommendations include: the inclusion of Duty Officers in the new system's design process, the preparation of clear guidelines on how probabilistic forecast should be used for decision-making in practice, the EA communication with all players in the decision-making chain (internal and external) that this transition will become operational practice and the documentation of this transition to help other institutes yet to face a similar challenge.

~~The inclusion of uncertainty in flood forecasts is a recent, important yet challenging endeavour. In the chaotic and far from certain world we live in, probabilistic estimates of potential future floods are vital. By showing the uncertainty surrounding a prediction, probabilistic forecasts can give an earlier indication of potential future floods, increasing the amount of time we have to prepare. In practice, making a binary decision based on probabilistic information is challenging. The Environment Agency (EA), responsible for managing risks of flooding in England, is in the process of a transition to probabilistic fluvial flood forecasts. A series of interviews were carried out with EA decision-makers (i.e. duty officers) to understand how this transition might affect their decision-making activities. The interviews highlight the complex and evolving landscape (made of alternative 'hard scientific facts' and 'soft values') in which EA duty officers operate, where forecasts play an integral role in decision-making. While EA duty officers already account for uncertainty and communicate their confidence in the system they use, they view the transition to probabilistic flood forecasts as both an opportunity and a challenge in practice. Based on the interview results, recommendations are made to the EA to ensure a successful transition to probabilistic forecasts for flood early warning in England.~~

We believe that this paper is of wide interest for a range of sectors at the intersection between geoscience and society. A glossary of technical terms is highlighted by asterisks in the text and included in Appendix A.

1 Introduction

The ongoing shift~~One of the most recent and significant challenges in hydrology has been the inclusion of uncertainty information in flood forecasts. We live in a world where it is currently impossible to say with 100% certainty how the weather will evolve in the following days to months, or by how much exactly a river level is expected to change. This is due to the inaccurate measurement of hydro-meteorological observations*, errors in the mathematical models used to produce these forecasts (due to scientific and technical limitations) and, most importantly, nature's intrinsic chaos* . In this world, probabilistic estimates of potential future floods are vital. Probabilistic forecasts* give a range of likely possible future outcomes, contrary to deterministic forecasts*, which indicate a single future possibility . Probabilistic flood forecasts are generally produced by forcing* a hydrological model* with an ensemble* of future meteorological scenarios (. By giving an idea of the uncertainty surrounding a prediction, probabilistic forecasts can give an earlier indication of potential future extreme events, such as floods, increasing the amount of time decision-makers have to prepare .~~

~~In practice however, probabilistic forecasts can be challenging to use for operational decision-making*, given their uncertain nature . Having to translate a range of possible outcomes into a binary decision (such as sending out a flood warning) is intricate and requires careful interpretation, an understanding of probabilities, risk*, uncertainty* and of the systems modelled. Furthermore, probabilistic forecasts are designed to capture scenarios that may not always realise, which in turn could lead to false alarms*. Decision-making can be based on a set of rules, such as threshold exceedance . It is, for example, possible to take decisions (e.g. send a flood warning) when a pre-defined threshold is reached with a minimum forecast probability . However, the decision-making process is generally based on, and influenced, by several additional factors. These include the type of event considered (e.g. a localised small flood event vs a large scale extreme flood event), the costs of taking action vs not taking action, experience of past events, the decision-maker's trust in the forecast (which can be built up over time), their risk aversion, and the cultural context in which decisions are made ;.~~

~~The Environment Agency (EA)* is responsible for managing risks of flooding in England and their flood incident management strategy* is often shaped by major flood events . In the 1990s and early 2000s, the UK policy shifted from a 'flood defence' to a 'flood risk management' strategy, on the back of the 1998 and 2000 floods , which has led to more forecast-based decision-making. The summer 2007 UK floods boosted the development of the National Flood Forecasting System and the Flood Forecasting Centre (FFC*; a UK Met Office and EA partnership), with the aim to improve national flood warning services . The winter 2013/14 UK floods further demonstrated the value of the FFC and the use of ensemble surge forecasts* for flood preparedness* . It was also during the 2013/14 floods that the EA started using two fluvial (or river) flood scenarios* (a reasonable worst case* and a best estimate*, instead of a single prediction) for flood incident management. Following this, Defra (the UK government Department for Environment, Food & Rural Affairs)* published a National Flood Resilience Review (NFRR) in 2016 . This review aimed at understanding and increasing the UK's resilience to river and coastal flooding from extreme weather over the next ten years. The NFRR recommends a better integration of probabilistic weather forecasts into flood forecast products, for an improved characterisation of uncertainty and an enhanced communication of flood risk and likelihood to inform a range of flood management measures*.~~

~~While catastrophic events can foster the uptake of state-of-the-art science (e.g. probabilistic forecasts) for decision-making, achieving a complete and successful transition relies on many elements. For example, the use of ensemble surge forecasts in 2013/14 might not have been possible without the prior shift to a flood risk management mindset and the creation of the FFC. Moreover, we do not want to be in a situation where we require a catastrophic event in order to begin implementing the best science into risk management practice; it is vital to understand a country's and institution's cultural landscape to ensure that~~

science is not being under- or misused . In the case of probabilistic forecasts, making sure that they add value rather than uncertainty to operational decision-making is key . Interviews can be an effective method to capture an institution's complex cultural landscape . They can provide interviewers with an understanding of the world (in this case the institution world) from the perspective of the informants, shedding light on their unique perceptions and information only known to them .

As outlined by the NFRR, the EA is in the process of a transition to probabilistic fluvial flood forecasts, from the two flood scenarios they currently use operationally . To capture the EA's forecasting practice landscape and understand how this transition might affect their flood decision-making activities, a series of interviews were carried out in the summer 2018 with EA 'Monitoring and Forecasting Duty Officers' (MFDOs) and 'Flood Warning Duty Officers' (FWDOs). These two roles are at the heart of the EA's flood risk management decision-making chain. The outcomes of these interviews were used as a basis for this paper, with the aim to highlight the potential opportunities and challenges that this transition might translate to for the duty officers, ahead of it happening.

2 Context: the Environment Agency's flood incident management strategy

The Environment Agency (EA) is an executive non-departmental public body, sponsored by Defra. The EA has an operational responsibility to manage risks of flooding from rivers and the sea in England, by warning and informing the public and businesses about impending floods. Flood warnings are sent with a 2-hour minimum lead time*, however, different lead times have recently been introduced to take into account the type of flooding and catchment characteristics*; i.e. flash flooding vs slow responding catchment. Under the Flood and Water Management Act 2010 , the EA takes a lead role on river and coastal flooding, whilst lead local flood authorities take a lead role on local flood risk (which covers flooding from other sources, including surface water, groundwater and minor watercourses). The EA also has a strategic overview role for all sources of flooding and works with lead local flood authorities by providing guidance, knowledge and support in responding to surface water flooding. The following schematic (Fig. 1) displays the EA's institutional landscape, with a particular focus on the flood incident management (FIM) information flow to and from MFDOs and FWDOs.

Historically, the EA was structured as a national body, delivering its work across England in six operational regional boundaries (i.e. regional boundaries were political delineations and were roughly aligned with the regional development fund boundaries). On 1st April 2014, the EA changed its operating structure to adopt area boundaries (i.e. broadly based on catchment delineations, but some catchments span different areas, especially at the borders with Wales and Scotland). These were aligned in 2016 with the Natural England (non-departmental public body, sponsored by Defra, and responsible for ensuring the protection and improvement of England's natural environment) boundaries. The EA is now operating over 14 areas with 7 forecasting centres (hereafter referred to as 'centres'; see Fig. 2).

To help manage flood risk, the EA receive hydro-meteorological forecasts* produced by the Flood Forecasting Centre (FFC; see Fig. 1) on a daily basis (more or less frequently depending on the forecasting product* – see Sect. 4.1.1). The FFC is a partnership between the EA and the UK Met Office. It combines the hydrological and meteorological expertise from both institutes to provide hydro-meteorological forecasting products (for all natural forms of flooding, including river, surface water, coastal and groundwater flooding) to emergency responders: category 1 (e.g. police services, fire and rescue authorities, including the EA for England), category 2 (e.g. utilities, telecommunications, transport providers, Highways Agency), Natural Resources Wales (for Wales) and the Met Office (for England and Wales).

The EA's FIM is based on the principle: 'think big, act early, be visible' . This is part of a wider move from incident response to risk anticipation, with the aim to ensure that resources are put in place early and that the EA is prepared to scale-up or -down (i.e. preparations for measures implemented or not closer to the potential incident; e.g. expanded incident rotas with duty officers on standby, instigating requests for mutual aid to a different area, requests for equipment to support preventative and/or repair work, such as temporary barriers and pumps). As part of this strategy, the FFC forecasts are currently (and since the UK winter floods of 2013/14) used to produce two deterministic fluvial flood scenarios with a five-day lead time at the EA, a 'Best Estimate' and a 'Reasonable Worst Case'.

Several internal documents have been written to give guidance on how to use these scenarios to support decision-making for FIM activities, in line with the EA's principle. In summary, the Reasonable Worst Case gives an indication of what 'could' happen and should be used for preparation, information and response to flooding. The Best Estimate gives an indication of what 'should' happen and should be used as the basis for planning for warning. Together, the two scenarios provide the scale and size of the incident for planning and response preparations .

According to research done in the Thames river basin (UK), showed that probabilistic forecasts provide more informative results (enabling the potential risks of impacts to be quantified) than a scenario-based approach. The transition to the two scenarios can be seen as a stepping stone towards probabilistic fluvial flood forecasts. Ultimately, the EA would like to: 1) quantify uncertainty and communicate flood risk in a clear manner internally and externally, and 2) make decisions around incident preparation and escalation, operational activities and flood warnings effectively, intelligently and accurately. While the EA acknowledges that a potential benefit of probabilistic flood forecasts is the possibility to give earlier warnings, they question the extent to which probabilistic forecasts would reduce scientific and decision uncertainties in a FIM context .

While work has already been done by the EA to investigate the technical feasibility of a transition to probabilistic fluvial flood forecasts , this paper focuses on exploring the perceptions of the EA duty officers on the subject matter. This work is important as it will ensure the appropriate use of fluvial flood probabilistic forecasts for FIM decision-making activities, once operational. It should be noted that the EA already uses coastal flood probabilistic forecasts ; this work focuses on fluvial flooding. To this end, a series of interviews were carried out with EA 'Monitoring and Forecasting Duty Officers' (MFDOs) and 'Flood Warning Duty Officers' (FWDOs), as they are the two roles at the heart of the EA's internal forecast-led decision-making, building on the exchange between the MFDOs and the FFC (see Fig. 1; more information about their respective roles in Sect. 3.1 and 4.1).

in UK policy from 'flood defence' towards a forecast-based 'flood risk* management' approach to better anticipate floods (Dale et al., 2012; McEwen et al., 2012) has shaped a series of developments in the uptake of flood forecasting science in practice, often implemented in the wake of significant flood events. Following the summer 2007 UK floods, the development of the National Flood Forecasting System (NFFS) and the Flood Forecasting Centre (FFC*; a UK Met Office and Environment Agency (EA)* partnership; Defra, 2014) were prioritised, with the aim of improving national flood warning services (Pitt, 2008; Stephens and Cloke, 2014). The winter 2013/14 UK floods illustrated the value of these institutional changes to flood forecasting, as well as the value in using new forecasting techniques, such as ensemble* surge forecasts*, for flood preparedness* (Flowerdew et al., 2009; Stephens and Cloke, 2014). It was also during the 2013/14 floods that the EA moved from using a single prediction of upcoming floods (known as a deterministic forecast*) to using two fluvial (river) flood scenarios*; a 'Best Estimate'* and a 'Reasonable Worst Case'* (see more information below); for flood incident management in England (FFC, 2017). However, the recent winter 2019/2020 UK floods have shown that this approach could be further improved to better capture the uncertainty* in upcoming floods and communicate risk more effectively:

> *"The recent floods exposed a limitation in our forecasting approach by only running flood models with a Best Estimate and Reasonable Worst Case meteorological inputs. Whilst this approach is fine at providing a high level general meteorological input to flood forecast models small variances in rainfall profiles within and across catchments makes a big difference in river response and flood risk. Modelling the impacts of snow accumulation and melting was also a particular problem […] Being able to run meteorological ensembles through our flood forecasting models to determine the probability of different magnitudes of flood impacts within and across catchments would in my view given us a better understanding of river response and allowed for clearer communication of risk from forecasters to responders. […] There was a lot we did well but a lot we can do better" (Neil Ryan, lead modelling and forecasting duty officer at the EA Leeds Forecasting Centre, March 2020)*

In 2016, the UK National Flood Resilience Review (NFRR; HM Government, 2016; House of Commons - Environment, Food and Rural Affairs Committee, 2016) indeed recommended a better integration of probabilistic forecasts* of the weather into flood forecast products to improve the characterisation of uncertainty in future water levels, and to enhance the communication of flood risk and likelihood for informing a range of flood management measures* (as the quote above alludes to). Probabilistic flood forecasts express the likelihood of possible future high river flow scenarios, and can be produced by forcing* a hydrological model* with an ensemble of future meteorological scenarios (Cloke and Pappenberger, 2009). By indicating how likely a flood is to occur, probabilistic forecasts communicate an estimate of the uncertainty surrounding a prediction (expressed as a probability), and can support risk-based decision-making through an increased probability of detection of floods (reducing missed events*), an earlier indication of potential future extreme events, such as floods, and their associated impacts (Buizza, 2008; Verkade and Werner, 2011; Dale et al., 2012; Stephens and Cloke, 2014). Based on research for the Thames river basin (UK), New et al. (2007) showed that probabilistic forecasts provide more informative results (i.e. by allowing to quantify the potential impacts of upcoming floods and their associated likelihood) than a scenario-based approach, as is currently used operationally at the EA.

The EA, an executive non-departmental public body sponsored by Defra* (the UK government Department for Environment, Food & Rural Affairs), is responsible for the operational management of flood risks from rivers and the sea in England (under the Flood and Water Management Act 2010; Werner et al., 2009; Defra, 2010; 2014; Pilling et al., 2016). Their role is to warn and inform the public and businesses about impending coastal and fluvial floods. The EA also has a strategic overview role for all sources of flooding and works with lead local flood authorities (i.e. emergency responders category 1 (e.g. police services, fire and rescue authorities) and 2 (e.g. utilities, telecommunications, transport providers, Highways Agency)) by providing guidance, knowledge and support in responding to flooding. The EA ‘Monitoring and Forecasting Duty Officers’ (MFDOs) and ‘Flood Warning Duty Officers’ (FWDOs) are two roles at the heart of the EA’s internal forecast-led decision-making process and are responsible for coordinating local flood warning.

It is within the remit of their responsibilities for the EA to move away from incident response and implement flood risk management policy. As part of this wider move and since 2016, the EA’s flood incident management strategy* is based on the principle: “think big, act early, be visible” (EA, 2018a). Below the umbrella of this principle, the EA’s objectives are to quantify uncertainty, make decisions around incident preparation and escalation (to ensure that resources are put in place early and that the EA is prepared to scale-up or -down closer to the potential incident; e.g. expanding incident rotas with Duty Officers on standby, requesting equipment to support preventative and/or repair work, such as temporary barriers and pumps) and communicate flood risk clearly internally and externally (Tim Norton, personal communication). To this end, based on hydro-meteorological forecasts received from the FFC daily, the EA currently (and since the UK winter floods of 2013/14 as mentioned above) produce two deterministic fluvial flood scenarios with a five-day lead time*, a ‘Best Estimate’ and a ‘Reasonable Worst Case’. The EA’s operating practice provides guidance on how to use these scenarios to support decision-making for a range of flood incident management activities, in line with the EA’s principle. In summary, the ‘Reasonable Worst Case’ gives an indication of what ‘could’ happen (i.e. the upper range of forecast rainfall, river conditions and impacts that may occur) and should be used for preparation and informing others. The ‘Best Estimate’ gives an indication of what ‘should’ happen (i.e. the middle range of forecast rainfall, river conditions and impacts that may occur) and should be used as the basis for planning where and when to issue flood warnings (EA, 2018b). Together, the two scenarios provide the scale and size of the incident for planning and response preparations (FFC, 2017).

The two EA flood scenarios are an intermediate step between deterministic and probabilistic fluvial flood forecasting (n.b. probabilistic coastal flood forecasts are already operational and this paper focuses on fluvial flood forecasting), as outlined as essential by the NFRR. The new probabilistic flood forecasting system is currently being technically developed and several feasibility projects have been carried out to guide the FFC’s move towards probabilistic fluvial flood forecasts (Pitt, 2008; Orr and Twigger-Ross, 2009; Sene et al., 2007; 2009; 2010; Dale et al., 2013). However, as the EA will have to accommodate these probabilistic fluvial flood forecasts in practice, there is still a lack of clarity about how they should be used for flood incident management and by the EA Duty Officers’ for flood warning decision-making.

Probabilistic forecasts can be challenging to use for operational decision-making*, given the explicit uncertainty information they communicate (Nicholls, 1999; Cloke and Pappenberger, 2009; Demeritt et al., 2010; Nobert et al., 2010; Ramos et al., 2010; Stephens et al., 2012). Having to translate a range of possible outcomes into an operational decision (such as sending out a flood warning) is intricate and requires careful interpretation, and an understanding of probabilities, risk, uncertainty and of the systems modelled (Dessai and Hulme, 2004). Furthermore, warning based on low probabilities of a flood, for example, will reduce the chance of missing an event, but might also lead to more false alarms*. Decisions can be made following a set of rules, such as threshold exceedance (Dale et al., 2013). However, the decision-making process is complex and generally influenced by several additional factors. These include: the event type (e.g. a localised small flood event vs a large scale extreme flood event), the costs of taking action vs not taking action, the decision-maker's experience of past events, trust in the forecast (which can be built up over time), personal risk aversion, and the cultural context in which decisions are made (Cloke et al., 2009; Arnal et al., 2016; Neumann et al., 2018).

The aim of this paper is to capture the forecast-based decision-making landscape in which EA Duty Officers operate to understand how they perceive the potential impacts of this transition on their decision-making activities. To this end, a series of interviews were carried out in the summer 2018 with EA MFDOs and FWDOs. We hypothesise that the EA Duty Officers' decision-making is still very binary and that many elements of their decision-making process will have to change to make space for the transition to probabilistic fluvial flood forecasts.

After describing the interview and analysis methods (Sect. 2), this paper relates how EA MFDOs and FWDOs make forecast-based decisions in the current EA practice – with a focus on fluvial flooding and decision-making for up to the next 5 days, as these are the forecasts that will change (Sect. 3). Finally, based on the interview results and further literature findings, we discuss the Duty Officers' perceived opportunities and challenges associate with this transition and make a series of recommendations to support a successful transition to operational probabilistic fluvial flood forecasting at the EA.

23 Methods

23.1 Participants

The EA operates over 14 different areas (i.e. broadly based on catchment delineations) with 7 forecasting centres (hereafter referred to as 'centres'; see Fig. 1). Within these centres, The EAit has several 'Monitoring and Forecasting Duty Officer' (MFDO) and 'Flood Warning Duty Officer' (FWDO) MFDO and FWDO roles, fulfilled by a number of different people. These are voluntary roles, added to the staff's day-to-day job, for which they follow relevant training. MFDOs receive, process and communicate forecast information to FWDO's, who are responsible for interpreting the information and working out the potential impacts on the ground. The Dduty Oofficers' schedules are predetermined by a rota, and Dduty Oofficers are on call for a period of one week at a time. During times of increased flood risk, when more forecasting or warning activities are required, additional rostering takes place. Duty Oofficers receive a range of forecasts (nowcasting* products to monthly outlooks*) and are aware of potential situations from a month out. Five days ahead is when the activity really starts to build and is the focus of these interviews.

A total of six EA MFDOs and FWDOs from three different EA centres (one pair per centre) were interviewed to capture a range of perspectives in relation to theeis topic at heart, following best practice (Sivle et al., 2014; participant information sheet provided as supplementary material). Forecasting and decision-making varies between EA centres due to different management approaches and different types of geography and catchment response*. To protect anonymity, the three centres where interviews were carried out are shown in terms of the wider area they are responsible for: 1) the Yorkshire area (YOR) in the North (area 3), 2) the Thames area (THM) in the South East (area 11), and 3) the Solent and South Downs area (SSD) in the South East (area 14) (Fig. 12).

MFDOs and FWDOs were interviewed in pairs as they are used to working together and the information they use sits between these two roles. The thought was that by talking to the MFDOs alone we would lose the element of "and so what?", while talking to the FWDOs alone ~~we would lose all~~ the forecasting expertise ~~about forecasting~~would be lost. All MFDOs and FWDOs interviewed had several years of experience and so were able to describe the~~how~~ current practice and express personal expectations of how it might~~would~~ change with probabilistic forecasting~~a different type of forecast~~.

Participants were selected by EA study co-developer I1 to meet the above criteria. For the purpose of anonymity, the interviewees will thereafter be reported using codes. The three MFDOs interviewed will be referred to as MFDO1, MFDO2 and MFDO3, and the three FWDOs interviewed as FWDO1, FWDO2 and FWDO3 (interviewed pairs are ~~however~~ represented by the same number). As well as those from the MFDOs and FWDOs, quotes from two EA study co-developers are reported in this paper, I1 and I2, who helped the interviewer (Louise Arnal) by providing some context about the EA's organisational landscape, forecasting systems and MFDO and FWDO roles prior to the three interviews.

2~~3~~.2 Interviews

This paper is based on content gathered through interviews at the EA. Interviews can be an effective method to capture an institution's complex cultural landscape (Schoenberger, 1991; Pagano et al., 2004). They can provide interviewers with an understanding of the world (in this case the institution world) from the perspective of the informants, shedding light on their unique perceptions and information only known to them (Sivle et al., 2014).

~~By design, q~~Qualitative~~,~~ semi-structured interviews were carried out. These types of interviews ~~-~~are often used to understand interviewees' perspectives~~,~~ and allow~~ing~~ the exploration of a research question that does not necessitate quantifying information and creating generalisations from the interview transcripts. The strength of such studies (compared to other survey methods) is that they are more sensitive to historical and institutional complexity and can capture the influence of local context (Schoenberger, 1991; Pagano et al., 2004). Moreover, they are flexible, allowing the interviewer to remodel questions throughout an interview and from one interview to the next, to follow up on new information discovered (Sivle et al., 2014).

A ~~fixed~~ set of open-ended questions were prepared in advance to guide the discussion and allow for comparability across all three interviews. To prompt discussion, all three MFDO and FWDO pairs were asked the same opening question: "Could you please walk me through what you would do ahead of a potential flood event?" The following questions were also prepared in advance~~d~~, but their order was changed, or they were skipped depending on whether the interviewees had already answered them:

- "Could you tell me about the uncertainties in the information you said you used in this context?"
- "How do you deal with these uncertainties?"
- "Could you tell me about how you communicate these uncertainties to each other?"
- "How would your job be influenced by a transition to probabilistic forecasts?"

Each interview lasted between 30 minutes and 1 hour 30 minutes. All interviews were conducted and digitally recorded by the first author (Louise Arnal) in meeting rooms at the corresponding EA centres.

2~~3~~.3 Data analysis

All interviews were transcribed verbatim and transcripts were analysed qualitatively in order 1) to define the current practice (i.e. EA Duty Officers' roles and the information and systems they use) and 2) to explore, together with the EA Duty Officers, how they think this transition might affect their roles and the current practice~~with respect to three main research questions~~. These two points ~~research questions~~ provide the structure for ~~the results' section of~~ this paper; the results are communicated in Sect. 3 and 4 respectively ~~(Sect. 4)~~.

1) ~~What are the MFDOs' and FWDOs' roles and how do they interact with one another?~~
2) ~~Where are the forecasts currently situated amidst their decision-making process?~~

~~3) Considering how the duty officers communicate confidence with one another at present, what might be the potential impacts of a transition to probabilistic forecasts on their roles?~~

Although interpretations might have been communicated by several~~many~~ interviewees, no frequencies are provided as quantitative generalisations cannot be inferred from this small and purposive sample. Following best practice, the results contain a mix of interviewees' perspectives, supported by quotes (numbered for cross-reference), and further interpretation of the interview transcripts by the authors, identifiable throughout the text (Rowley, 2012; Davies et al., 2014).

34 The current EA forecast-led decision-making practice ~~Results~~

3.1 The EA's institutional landscape

The ~~following~~ schematic on ~~(~~Fig. 2~~1)~~ displays the EA's institutional landscape, with a particular focus on the flood incident management ~~(FIM)~~ information flow to and from MFDOs and FWDOs. To help manage flood risk, the EA receive hydro-meteorological forecasts produced by the Flood Forecasting Centre (FFC) daily (more or less frequently depending on the forecasting product* – see Sect. 3.2.1). The FFC is a partnership between the EA and the UK Met Office which combines the hydrological and meteorological expertise from both institutes to produce hydro-meteorological forecasting products for all natural forms of flooding (including river, surface water, coastal and groundwater flooding; note that in this paper the focus is on river flooding).

Within the EA, the FFC products are combined with the flood forecasting expertise of the Flood Forecasting team to then follow two separate routes. The flood forecast information is relayed higher up the chain to the Strategic Support and the National Response teams via the National Flood Forecasting Duty Manager to support national response. To support local response, the flood forecast information is downscaled to local flood outlooks by the MFDOs and passed on to the Area Response team, coordinated by Area Duty Managers and Area Base Controllers who are responsible for an area's incident preparation and response. As part of this team, the FWDOs and the Flood Incident Duty Officers then combine national information and area impact assessments to coordinate flood warning and operational decision-making on the ground, respectively. Pre-defined lead times are assigned to each specific planning and response activities; e.g. flood warnings are sent with a 2-hour minimum lead time, although different lead times have recently been introduced to account for flood event type and catchment characteristics* (i.e. flash flooding vs a slow responding catchment). FWDOs are also part of a Flood Advisory Service, an integrated service provided by the EA and the UK Met Office, via which the flood forecast is communicated with partners (e.g. emergency responders) to help them make informed decisions about their flood response. This service is delivered through emails, teleconferences and face to face meetings.

MFDOs and FWDOs are decision-makers* at the heart of the flood forecasting to local flood decision-making process, which relies vastly on the interaction between their two roles. Hereafter, we use the term "decision-makers" to refer to the MFDOs and FWDOs, unless stated otherwise.

34.21 From national hydro-meteorological forecasting to local flood warning decision-making~~Roles and interactions between EA duty officers~~

The sections below (Sect. 3.2.1 to 3.2.4)~~Below, we~~ describe the flow of information between~~summarise the~~ MFDOs~~'~~ and FWDOs~~'~~ ~~roles~~ in an incident response context (following the numbers on Fig. 2), ahead of a flood event (i.e. with 2 hours to 5 days of lead time, as this is the timescale likely to be affected by this transition). The content for these sections is based on ~~using~~ the interviewees' responses to the question: "Could you please walk me through what you would do ahead of a potential flood event?" It is worth noting that all interviewed pairs suggested the MFDO answer that question before the FWDO, indicating that the forecasting and decision-making process starts with the MFDO.

"My role's an MFDO so generally if there's a flood event coming I should know before the FWDO, in theory" [MFDO2] (Q1)

~~*"My role's an MFDO so generally if there's a flood event coming I should know before the FWDO, in theory" [MFDO2]*~~

43.21.1 The FFC national The hydro-meteorological forecasts

The FFC generates three types of products of relevance for river flooding (i.e. coastal and high tides reports are also produced but not discussed in this paper; Defra, 2014). These are produced with the help of and communicated with the EA.:

- **Flood Ooutlook products:** – annual, seasonal and monthly assessments of flood risk produced up to every two weeks (please note that these are not the focus of this paper; see paragraph below);
- **Flood Guidance Statement (FGS)*:** – a five-day forecast of flood risk for all sources of flooding, for England and Wales, at a county scale (i.e. area sub-divisions) and issued daily (with additional issues when significant or severe impacts forecasts; (see Appendix B, Fig. ~~Appendix B, Fig.~~ (a) for a pastn example);
- **Hydro-Meteorological Services*:** – detailed products communicating flood forecast data, ~~currently~~ comprising , among others, a Hydro-meteorological Guidance (i.e. a summary of the hydro-meteorological situation for the next five days and issued once daily; Appendix B, Fig. (b)), ~~Hydro-Meteorological Guidance,~~ Forecast Meteorological Data (i.e. rainfall summary for the next five days based on the 'Best Estimate' and issued twice daily; Appendix B, Fig. (c)), a Rainfall Scenario Map (i.e. 'Reasonable Worst Case' scenarios of rainfall amounts for areas across England and Wales; Appendix B, Fig. (d)), and Heavy Rainfall Alerts for the next hours to five days (i.e. produced manually for specific rainfall events and communicating the rainfall amounts and confidence; Appendix B, Fig. (e) and (f)~~see Appendix B, Fig. (b), (c) and (d), respectively, for examples).~~
-

Since 2007 (this vaguely corresponds with the summer 2007 UK floods), the lead time for which forecasts are shown and on which MFDOs and FWDOs can take action has increased from a few days to a few months ahead (i.e. based on the FFC outlook products). However, the outlook products are currently mainly used as supporting information, and the EA relies on the shorter-range forecasts (i.e. FFC five-day products) for their flood warning decision-making activities. This is consistent with findings from Neumann et al. (2018).

"So even from a month out now we're starting to become aware of potential situations [...], but [...] because [...] most of our products [...] are [...] based on that five-day forecast [...] that's when the activity really starts to build" [MFDO1] (Q2)

~~role of Monitoring and Forecasting Duty Officers~~3.2.2 Local flood forecasting by the MFDOs

The MFDOs' role is to process the FFC forecasts (see Sect. 3.2.1) before communicating the local flood forecast to the FWDOs.~~*"Ramping up to a flood event, the MFDO gathers that information, processes it and filters it, and passes that along to the area staff [FWDO]." [MFDO2]*~~

> *"Ramping up to a flood event, the MFDO gathers that information, processes it and filters it, and passes that along to the area staff [FWDO]." [MFDO2]* (Q3)

Based on the suite of FFC national and county scale flood risk information, the MFDOs decide whether they should run the locally tailored hydrological forecasting model, which sits in a separate system called the National Flood Forecasting System (NFFS; Appendix B, Fig. (g)), to produce catchment/local scale flood forecasts. This decision can for example be triggered by the colours shown on the FGS, which communicates flood risk as a combination of likelihood and impact (i.e. high flood risk values on the FGS are likely to prompt the MFDOs to run the hydrological model). The NFFS allows users to explore observed data (i.e. river levels and rainfall) and run hydrological and hydraulic models*. These models, forced with the FFC's deterministic weather forecast, provide a single trace of future (i.e. for the next five days) river level at specific locations. This initial forecast scenario is usually referred to as the 'Best Estimate' scenario. According to the FGS user guide, the 'Best Estimate' scenario shows what 'should' happen, it is "a forecaster's assessment of the middle range of rainfall, river or groundwater levels or coastal conditions and impacts that may occur" (FFC, 2017).

What 'could' happen (i.e. referred to as the 'Reasonable Worst Case' scenario) may not always be run by the MFDOs. This decision is usually based on the hydro-meteorological conditions and on the MFDOs' expert judgment.

> *"If there's uncertainty in the forecast like if there's showers […] especially when they're thundery and they can give you really high totals in a very short space of time that's when you start to run 'What If' scenarios" [MFDO1]* (Q4)

'What If' scenarios refer to the additional local river level forecast run by the MFDOs. This is usually done by manually modifying the FFC's deterministic weather forecast, using predefined factors applied over an entire catchment (e.g. a 200% increase in catchment rainfall totals over the next 6 hours). The MFDOs choose which 'What If' scenario to run based on the FFC Hydro-meteorological Guidance, the Rainfall Scenario Map and their own expert judgment.

> *"[The FFC] might give us a number of different scenarios and we tend to pick the worst one and then see what that does" [MFDO1]* (Q5)

Running this 'modified weather forecast' through the hydrological/hydraulic models, the MFDOs obtain a supplementary river level forecast scenario to the 'Best Estimate', called the 'Reasonable Worst Case' scenario (Appendix B, Fig. (g)). According to the FGS user guide, the 'Reasonable Worst Case' scenario shows what 'could' happen, it is "a forecaster's assessment of the upper range of rainfall, river or groundwater levels or coastal conditions and impacts that may occur" (FFC, 2017). The MFDOs estimate the likelihood of both scenarios (i.e. the 'Best Estimate' and the 'Reasonable Worst Case') based on the 'What If' scenario they have run and further expert judgment.

A critical part of the MFDOs' role is to filter the forecast information to make a coherent story (e.g. there may sometimes be differences between the national and local scale pictures) and put the information into context for the FWDOs. They do this using additional tools and information available to them and by applying expert judgement based on their knowledge of model performance* and catchment response*.

> *"Whilst we are very data reliant on the information coming through, there's also that experience that you know that certain watercourses are very slow responding and […] no matter how much money we spend on your forecast, it's always not very good, you always delay it by a day and drop the peak by a bit. […] Data is very important but that local experience is as important if not more so in certain circumstances" [MFDO2]* (Q6)

Additional tools and information available to the MFDOs for example include river level correlations* (i.e. they are calculated using set tables, based on a linear regression between peak levels upstream and downstream of a station). These complement the river level forecast and aid MFDOs in the decision-making process. However, discrepancies between the forecasts and correlations are possible and can call into question the forecast accuracy*.

> *"If the model says you're going to get flooding, the correlation says we're going to get flooding, we've had more rainfall than any previous event, you know that that decision's […] a clear one. If the model says flooding, the correlation says no you're fine, and we've had somewhere in the middle in terms of rainfall, that's when it gets difficult, because those borderline calls are really tricky to make" [I2]* (Q7)

The MFDOs' knowledge of the hydraulic/hydrological model performances for various types of events and catchments is also key in interpreting the river level forecast. This can be based on experience, performance measures*, the FFC meteorological products' attached confidence, target lead times (i.e. the theoretical maximum lead time there is to send out a flood warning for a catchment before it floods, pre-calculated for each catchment based on its size, the gauge location and flood risk in that catchment) and local feedback from real time river gauges*.

3.2.3 Interaction between MFDOs and FWDOs

~~"The FWDO shouldn't even really be thinking about anything until they've had a phone call from the MFDO […]. Some FWDOs do go a bit more proactive than that, I think particularly the ones with the forecasting backgrounds almost can't help themselves looking into it. And it depends on personality as well, some people hate the idea of being surprised by anything. But it does also depend on the MFDO." [FWDO2]~~

Weighing the various sources of information available to them, the MFDOs generally flag a situation to the FWDOs once they are confident* about the signal shown by the river level forecast. The exact content of the communication depends on each MFDO-FWDO pair, but usually contains information about the scale of the event and their confidence in the forecast (see Appendix B, Fig. (h) for an example).

> *"Which scenario is going through which threshold [and] how likely that is to happen" [MFDO1]. "Approximate […] scale of the event […] are we talking just a bit of water out of bank? Or is it Armageddon?" [MFDO2]* (Q8)

> *"I look at the river level forecasts and then what I want to know from the MFDO is, does this account for the rain we've had? So, do you think this is likely to change? Is the forecast I'm seeing on my screen a good river level forecast? Or do we think it's not picked something up properly?" [FWDO2]* (Q9)

The conversation can sometimes be bilateral, and the MFDOs might also ask questions to the FWDOs about local conditions.

> *"Can they [the FWDO] provide information […] in terms of local sensitivity […] and are works going on in that catchment? Is there a gauge out of play?" [MFDO2]* (Q10)

~~There is usually a constant exchange of information between MFDOs and FWDOs, even when no major event is on the horizon. However, more recently, the level of activity in preparation for a potential event has increased. Since 2007 (this corresponds vaguely with the summer 2007 floods), the lead time for which forecasts are shown and on which MFDOs and FWDOs can take action has increased from a few days to a few months ahead (based on the FFC's outlook products mentioned in Sect.~~

~~4.1.1). This is consistent with findings from Neumann et al. (2018), who report that the EA currently uses long-range* (i.e. seasonal) hydrological forecasts mainly as supporting information, while relying on the shorter-range forecasts* for action. *"So even from a month out now we're starting to become aware of potential situations […], but […] because […] most of our products […] are […] based on that five-day forecast […] that's when the activity really starts to build" [MFDO1]*~~

The communication between MFDOs and FWDOs varies across people and EA centres. Factors that might influence communication – in terms of its trigger, frequency and content – include the type of event, Duty Officers' geographical proximities (i.e. communication in person, by email or phone), a centre's practice, the D~~d~~uty O~~o~~fficers' personality, day-to-day job and level of experience. Some FWDOs are more proactive than others in obtaining the information needed to make a decision; while~~-~~ some might wait to be contacted by the MFDOs with a processed forecast, ~~and~~ others monitor the situation ~~on a~~ daily ~~basis~~. In some cases, the FWDO might contact the MFDO first to get more details about an area of concern to them. ~~*(see quote from FWDO2 above).*~~

> *"The FWDO shouldn't even really be thinking about anything until they've had a phone call from the MFDO […]. Some FWDOs do go a bit more proactive than that, I think particularly the ones with the forecasting backgrounds almost can't help themselves looking into it. And it depends on personality as well, some people hate the idea of being surprised by anything. But it does also depend on the MFDO." [FWDO2]* (Q11)

> *"[…] and […] then it's […] liaising with regional forecasting [the MFDOs] so they can give us any more detail or certainty or if we're concerned about an area they can watch it a bit more for us [the FWDOs]" [FWDO3]* (Q12)

~~In some cases, the FWDO might contact the MFDO first to get more details about an area of concern to them.~~

> ~~*"[…] and […] then it's […] liaising with regional forecasting [the MFDOs] so they can give us any more detail or certainty or if we're concerned about an area they can watch it a bit more for us [the FWDOs]" [FWDO3]*~~

The ~~D~~Duty O~~o~~fficers' level of experience can ~~also~~ influence the content and interpretation of their conversation. Duty Officers who have been working together for a longer time will have more ease to ~~Knowing each other helps~~ interpret and gauge the confidence from each other's language, while~~, which MFDO2 refers to as 'nuanced communication'. W~~ working with new D~~d~~uty O~~o~~fficers can sometimes lead to misinterpretations~~ and you might have to justify your position further and prompt them to obtain the information you need.~~

> *"Knowing each other is really important because if I know it's [MFDO2] on duty [they've] probably put that interpretation on already. If I get someone who's reading off the screen, I put the interpretation on and if we misjudge that and we both put it on we could end up getting it too low" [FWDO2]* (Q13)

As can be seen with quote Q8 (i.e. the title of this paper), the forecast communication process is currently binary to an extent. However, as hinted by quote Q9,

> ~~"I've known [FWDO1] for quite a while so when I'm on duty with [them] […] I can sense […] what sort of questions [they] want to ask, where [they're] coming from. I think with less experienced duty officers it's often more tricky to do that. So […] the verbal communication that you go into with [FWDO1] for example might be a bit brief probably because I know that [they've] understood the message and interpreted the message well, whereas a new duty officer you might be spelling out […] your position more, spending more time explaining why the uncertainty is such and how that may impact on the ground" [MFDO1]~~

"Knowing each other is really important because if I know it's [MFDO2] on duty [they've] probably put that interpretation on already. If I get someone who's reading off the screen, I put the interpretation on and if we misjudge that and we both put it on we could end up getting it too low" [FWDO2]confidence and uncertainty in the information appear to be communicated between the MFDOs and FWDOs, usually using the two flood forecast scenarios. Understanding how the uncertainty will impact the FWDOs' decision-making is key.

"I don't think we can withhold uncertainty. One, the key role for MFDO is providing the forecast. So it's getting the forecast as accurate as you can and then communicating it in the clearest way possible. So that's often about interpreting the uncertainty and communicating it. So we often use the 'Reasonable Worst Case' and the 'Best Estimate' to do that" [MFDO1] (Q14)

"Uncertainty is present in everything that we do and every bit of communication, […] I don't think I've ever been able to say something with 100% confidence, ever." [MFDO2] (Q15)

"Uncertainty from the forecasting point of view is always prevalent but understanding how it will impact the […] area's reaction is kind of the key thing" [MFDO2] (Q16)

Other factors that influence communication include the context of the event, duty officers' geographical proximities and a centre's practice. In some areas, the FWDOs will make the final call of warning the public or not, while in other areas, the MFDOs will tell the FWDOs when they need to issue a warning. In addition, MFDOs and FWDOs do not always sit in the same building or town. MFDOs work from forecasting centres, while FWDOs are based in Area offices or Area incident rooms, which influences their (mode of) communication (in person vs via phone or emails).

"If these people [the FWDOs] were sitting geographically with these other people [the MFDOs], I think you'd get a better service" [I1]Local knowledge and personal experience

"Whilst we are very data reliant on the information coming through, there's also that experience that you know that certain watercourses are very slow responding and […] no matter how much money we spend on your forecast, it's always not very good, you always delay it by a day and drop the peak by a bit. […] Data is very important but that local experience is as important if not more so in certain circumstances" [MFDO2]

Local knowledge and personal experience are key ingredients for judgement, an important component of the decision-making process. This means duty officers can react appropriately to an event and add confidence to the forecast. As MFDO2 put it, "experience is the unwritten part of the value that each role has".

Local knowledge is so important to decision-making that the interviewees believe it cannot be replaced by training, written material or fully automated systems.

"Some areas have very set triggers for a severe flood warning whereas other areas may just take it on a feel. […] And each area has done it for a good reason, it's the local reasons for doing that but it isn't nationally consistent" [MFDO2]

"We have in the past looked at automated warnings […], we can't automate them […], there's a lot of personal interpretation and judgement [that] goes into it, and if a computer just hits a level and issues a warning, it's going to go wrong" [FWDO2]

This also manifests itself in perceptions about how successfully duty officers can transfer to other centres or areas to help during an important flood event.

"One of the things we're trying to do at the moment is to get mutual aid sorted out so that if a flood event happens in [some of the Northern areas] and their MFDOs […] or the FWDOs are very […] stretched […] we can go […] there, use their tools, their systems and do the same job. But whenever we've tried it the local knowledge is the key thing. Like knowing that this river responds particularly quickly and that we need to deal with it first before we move on to other

ones that's the sort of thing that even if you're picking it up whilst you're working in a different centre it's affecting your ability to deliver the role at the time" [MFDO1]

Duty officers have access to tangible information about past flood events that can be useful for placing model information into context. The 'Flood Intelligence Files' compile information (e.g. highest events on record, what rainfall led to them, what the catchment state was at the time and any known impacts) for every gauge the EA is providing forecasts for.

How information is interpreted, risk appetite and past experience, can all affect decisions taken. There is the danger of following instincts too much and becoming biased towards issuing too many (i.e. risk-averse) or not enough warnings (i.e. risk-hungry), while in some cases decisions might never be forecast-led.

"Since the Boxing Day floods I think the next level of flooding after that there was some discrepancies amongst the area responses […] they were a bit […] jumpy […] to not be caught out again which is understandable" [MFDO2]

"these kind of decisions about do we need to draw up a roster, do we need to be in the office overnight, a lot of that has probably been done on gut feel, probably this FWDO being the advisor. […] Do we need to do whatever based on judgement, experience, feel for it. […] I wouldn't expect these people to actually be looking at any forecast and saying, based on this I will do" [I1]

3.2.4 Local flood warning decision-making by the FWDOs

The FWDOs' role is to combine the MFDOs' processed local flood forecast with local information to decide whether to issue a flood alert or warning.

> *"The role of the FWDO is to make sense of all that forecasting information and try and work out potentially what the impacts could be of that on the ground and then make decisions as to whether or not [they] issue flood alerts, flood warnings or severe flood warnings." [FWDO1]* (Q17)

"The role of the FWDO is to make sense of all that forecasting information and try and work out potentially what the impacts could be of that on the ground and then make decisions as to whether or not [they] issue flood alerts, flood warnings or severe flood warnings." [FWDO1]

The information available to FWDOs includes:

- **The local flood forecast and its interpretation:** produced by the MFDOs (see Sect. 3.2.2 and 3.2.3);
- **Factors within the catchment that could influence river levels:** e.g. blockage from a fallen down tree. This is ad-hoc information and comes from a variety of sources, including: information gathered by community contacts (e.g. flood wardens* and flood action groups*), by EA staff and Duty Officers, hydrometric data/CCTV images, details of consented works (i.e. work going on in a channel);
- **The situation on nowcasting meteorological products:** e.g. rainfall radar;
- **Information about the catchment(s) that might be affected:** contained in the 'Flood Intelligence Files', available for every gauge of the NFFS. They compile catchment information such as: highest events on record, what rainfall led to them, what the catchment state was at the time and any known impacts;
- **Information about communities that might be affected:** e.g. have they been affected by many floods in the past.

The FWDOs combine and assess these various sources of information (i.e. in terms of their accuracy and uncertainty; according to *FWDO2*, a critical part of the FWDOs' role is the *"interpretation of the uncertainties"* into their impacts on the ground), together with their expert knowledge about catchment response, to make a judgment call on whether to issue a flood alert/warning. In some areas however, the MFDOs will tell the FWDOs when they need to issue a warning.

"Ramping up to a flood event, the MFDO gathers that information, processes it and filters it, and passes that along to the area staff [FWDO]." [MFDO2]

Local knowledge is so important to decision-making that the interviewees believe it cannot be replaced by training, written material or fully automated systems.

"Some areas have very set triggers for a severe flood warning whereas other areas may just take it on a feel. [...] And each area has done it for a good reason, it's the local reasons for doing that but it isn't nationally consistent" [MFDO2]

"We have in the past looked at automated warnings [...], we can't automate them [...], there's a lot of personal interpretation and judgement [that] goes into it, and if a computer just hits a level and issues a warning, it's going to go wrong" [FWDO2]

This also manifests itself in perceptions about how successfully duty officers can transfer to other centres or areas to help during an important flood event.

"One of the things we're trying to do at the moment is to get mutual aid sorted out so that if a flood event happens in [some of the Northern areas] and their MFDOs [...] or the FWDOs are very [...] stretched [...] we can go [...] there, use their tools, their systems and do the same job. But whenever we've tried it the local knowledge is the key thing. Like knowing that this river responds particularly quickly and that we need to deal with it first before we move on to other ones that's the sort of thing that even if you're picking it up whilst you're working in a different centre it's affecting your ability to deliver the role at the time" [MFDO1]

What information do they use?

The MFDOs regularly receive FFC (Flood Forecasting Centre) national and county scale (i.e. area sub-divisions) flood risk forecasts and produce catchment/local scale flood forecasts, which they communicate with the FWDOs (see Fig. 3). The FFC generates three types of products:

Outlook products – annual, seasonal and monthly assessments of flood risk;

Flood Guidance Statement (FGS)* – a five-day forecast of flood risk for all sources of flooding, for England and Wales, at a county scale (see Appendix B, Fig. (a) for an example);

Hydro-Meteorological Services* – detailed products communicating flood forecast data, currently comprising Hydro-Meteorological Guidance, Forecast Meteorological Data and Heavy Rainfall Alerts (see Appendix B, Fig. (b), (c) and (d), respectively, for examples).

How do they use this information?

Based on this suite of information, the MFDOs decide whether they want to run the hydrological forecasting model, which sits in a separate system called the National Flood Forecasting System (NFFS; see Appendix B, Fig. (e) for an example). The decision can be triggered by the colours shown on the FGS (which communicates flood risk as a combination of likelihood and impact; e.g. high flood risk values on the FGS are more likely to lead to the MFDOs running the hydrological model). The NFFS allows users to explore the observed data (i.e. river levels and rainfall) and run hydrological and hydraulic models*. These models, forced with the FFC's deterministic weather forecast, provide a single trace of past and future (i.e. for the next five days) river level for specific areas. This initial forecast scenario is usually referred to as the 'Best Estimate' scenario, showing what 'should' happen. What 'could' happen (i.e. the 'Reasonable Worst Case' scenario) may not always be run.

"If there's uncertainty in the forecast like if there's showers [...] especially when they're thundery and they can give you really high totals in a very short space of time that's when you start to run 'What If' scenarios" [MFDO1]

'What If' scenarios (i.e. 'Reasonable Worst Case' scenarios) are additional forecasts run by the MFDOs by manually modifying the FFC's deterministic weather forecast (usually through the use of predefined factors applied over an entire catchment; e.g. 200% of catchment rainfall totals in the next 6 hours). They then run this 'modified weather forecast' through the hydrological/hydraulic models to obtain a new river level forecast scenario, often referred to as the 'Reasonable Worst Case' scenario. The MFDOs choose which What If scenario to run based on the FFC Hydrometeorological Guidance and their own expert knowledge, to estimate the likelihood of both scenarios (the 'Best Estimate' and the 'Reasonable Worst Case').

"[The FFC] might give us a number of different scenarios and we tend to pick the worst one and then see what that does" [MFDO1]

~~A critical part of the MFDOs' role is to interpret the different forecasting products, which might sometimes be inconsistent (e.g. differences between the national and local scale pictures). The MFDOs usually do this by applying expert judgement based on knowledge of model performance and catchment response* to make a coherent story and put the information into context for the FWDOs. The FWDOs assess these various sources of information (e.g. in terms of their accuracy) to make a decision, knowing that they do not necessarily have all the information to make a judgement call.~~

~~*"I look at the river level forecasts and then what I want to know from the MFDO is, does this account for the rain we've had? So, do you think this is likely to change? Is the forecast I'm seeing on my screen a good river level forecast? Or do we think it's not picked something up properly?"*~~ [FWDO2]

According to ~~an~~ EA internal guidelines~~document~~ on using the two flood scenarios in practice, the 'Best Estimate' should be used as a basis to issue flood alerts and~~or~~ warnings, and the 'Reasonable Worst Case' should be used for incident planning activities (e.g. resources needed for response). However, both scenarios are currently used for incident planning ~~activities (e.g. resources needed for response)~~ and communication with responders and communities, while flood alerts and warnings are mostly issued based on nowcasting products. This discrepancy could be due to the challenges associated with forecast accuracy* and lead time, specifically for ~~surface water flooding* and~~ rapid-response catchments*. EA guidelines~~This document~~ ~~does~~ however encourage the use of the two scenarios for planning and flood warning activities whenever possible, in combination with expert judgement.

> *"The scenarios are planning scenarios and at some point […] we move into operational now type forecasting. So normally we'd issue a flood warning with anywhere between 30 minutes to […] six hours lead time, whereas these scenarios are generally two to five days ahead. So you wouldn't normally […] come up with a simple statement that will issue flood warnings based on the best estimate […] and at some point we transition into something that's more now that we use for operational decision making" [I1]* (Q18)

~~*"The scenarios are planning scenarios and at some point […] we move into operational now type forecasting. So normally we'd issue a flood warning with anywhere between 30 minutes to […] six hours lead time, whereas these scenarios are generally two to five days ahead. So you wouldn't normally […] come up with a simple statement that will issue flood warnings based on the best estimate […] and at some point we transition into something that's more now that we use for operational decision making" [I1]*~~

~~The MFDOs decide when to pass the information on to the FWDOs, generally waiting for the forecast to be confident* before flagging a situation. The exact content of the communication depends on each pair, but usually contains information about the scale of the event and their confidence in the forecast.~~

~~*"Which scenario is going through which threshold [and] how likely that is to happen" [MFDO1]. "Approximate […] scale of the event […] are we talking just a bit of water out of bank? Or is it Armageddon?" [MFDO2]*~~

~~The conversation can sometimes be bilateral, and the MFDOs might ask questions to the FWDOs.~~

~~*"Can they provide information […] in terms of local sensitivity […] and are works going on in that catchment? Is there a gauge out of play?" [MFDO2]*~~

~~4.1.2 The role of Flood Warning Duty Officers~~

"The role of the FWDO is to make sense of all that forecasting information and try and work out potentially what the impacts could be of that on the ground and then make decisions as to whether or not [they] issue flood alerts, flood warnings or severe flood warnings." [FWDO1]

What information do they use?

The FWDOs' role is to combine several different types of information to decide whether to issue a flood alert or warning (see Fig. 3). The information available to them includes:

- **The processed hydro-meteorological forecast and interpretation from the MFDOs**
- **Factors within the catchment** that could influence river levels (e.g. blockage from a tree fallen down). This is ad-hoc information and comes from a variety of sources, including: information gathered from community contacts (flood wardens*, flood action groups*, etc.), from EA staff and duty officers, hydrometric data/CCTV images, details of consented works (i.e. work going on in a channel);
- **The situation on nowcasting meteorological products** (e.g. rainfall radar);
- **Information about the communities that might be affected** (e.g. have they been affected by many floods in the past);
- **Expert knowledge about catchment response.**
- **How do they use this information?**

The FWDOs assess these various sources of information (e.g. in terms of their accuracy) to make a decision, knowing that they do not necessarily have all the information to make a judgement call.

"I look at the river level forecasts and then what I want to know from the MFDO is, does this account for the rain we've had? So, do you think this is likely to change? Is the forecast I'm seeing on my screen a good river level forecast? Or do we think it's not picked something up properly?" [FWDO2]

According to an internal document on using the two flood scenarios in practice, the *Best Estimate* should be used as a basis to issue flood alerts or warnings. However, both scenarios are currently used for incident planning activities (e.g. resources needed for response) and communication with responders and communities, while flood alerts and warnings are mostly issued based on nowcasting products. This discrepancy could be due to the challenges associated with forecast accuracy* and lead time, specifically for surface water flooding* and rapid-response catchments*. This document does however encourage the use of the two scenarios for planning and flood warning activities whenever possible, in combination with expert judgement.

"The scenarios are planning scenarios and at some point [...] we move into operational now type forecasting. So normally we'd issue a flood warning with anywhere between 30 minutes to [...] six hours lead time, whereas these scenarios are generally two to five days ahead. So you wouldn't normally [...] come up with a simple statement that will issue flood warnings based on the best estimate [...] and at some point we transition into something that's more now that we use for operational decision making" [I1]

Warning procedures can vary across Duty Officers and EA centres. FWDOs' risk appetite (i.e. issuing too many or not enough warnings - risk-averse vs risk-hungry; which may be triggered by past events) can influence the decisions taken.

"Since the Boxing Day floods I think the next level of flooding after that there was some discrepancies amongst the area responses [...] they were a bit [...] jumpy [...] to not be caught out again which is understandable" [MFDO2] (Q19)

Some areas and EA centres might be more forecast-led while others are more reliant on a nowcasting type approach. Discrepancies amongst responses are partially due to historical differences across areas and EA centres, which could in turn be a consequence of differences in catchment characteristics (e.g. catchment size, rainfall-runoff response time, land use) and differences in typical response times (i.e. time for emergency responders to respond to a flood warning in a given area; also partly dependent on catchment characteristics).

> *"There are definite differences between areas and [...] between individual staff, so [town X] are far more likely to issue flood alerts [...] purely on rainfall than [town Y] is, [town Y] will generally wait for a river level to rise and that develops I suppose out of slight historical differences and personalities involved" [FWDO2]* (Q20)

> *"Some other areas will issue messages based on forecast whereas, we were always told to base it on what's happening, so we kind of wait to see if the rain comes in and then if anything happens issue. And we get marked on messages that we send out, so one of the things is the timeliness and if you've issued one, did it actually flood afterwards? So if you're obviously issuing on a forecast, then you're probably going to get scored low because it doesn't always happen, so it's difficult" [FWDO3]* (Q21)

Please note that Duty Officers do not formerly get scored based on decisions taken, quote Q21 is a figure of speech. The flood warnings issued are nevertheless captured in the Flood Warning Validation Data Base, where a score is given to each warning based on whether flooding occurred, was missed, or the warning was sent out too late, etc. This database however does not capture catchment conditions or forecasts produced at the time the warning was issued (Susan Manson, personal communication).

There are additionally exceptions to the warning procedures for certain types of events and depending on the time of day a flood is expected to occur. For given types of events, such as convective rainfall events*, for which the Duty Officers know models are still limited, they might decide to issue a warning based on the 'Reasonable Worst Case', although it is *"technically against procedure" [MFDO2]*. *FWDO3* also mentions the possibility of issuing flood alerts based on the forecast (see quote Q21) when the impact is expected to occur overnight or if the forecast displays *"rarely high confidence"* of rainfall and *"if it's a more prolonged event"* and *"the catchment's already wet"*.

Other factors that may cause the FWDOs to deviate from standard warning procedures may be political. There is for example usually a political element to the response immediately following a very major flood event, as the EA puts a greater focus on demonstrating to communities and the government that they are being proactive in warning, informing, etc. There is also the need for the EA to align its message with actions of lead local flood authorities and responders and to think about public response.

> *"There are lots of external pressures as well, particularly as FWDO you can come under pressure from all different types of sources to make decisions and perhaps not based on the evidence that you've got for political reasons, [...] reputational reasons, organisation, in terms of being seen to be active, seen to [...] act early" [FWDO1]* (Q22)

> *"It's managing expectations internally in terms of operational response and how this is going to potentially play out which [...] can still be quite hard to do but it's even harder to do it externally with [the] mood of the public or even some of our professional partners, so local authorities are also obviously geared up to respond to flooding" [FWDO1]* (Q23)

The EA's principle, 'think big, act early, be visible', might also influence the Duty Officers' decision-making (EA, 2018a). In what ways does the EA's statutory warning responsibilities and principle influence decision-making? Does 'act early' put the forecast in first place while 'think big' and 'be visible' move it to a secondary position?

"Our mantra to incident response is think big, act early so sometimes […] there is a danger that you're over responding. Somewhere you're issuing alerts and warnings when actually the risk is low. So I think the role of the FWDO is to assimilate all that information, forecasting information and using it to help inform the instant response but also manage expectations" [FWDO1] (Q24)

Messages to the public are worded with care to communicate the appropriate level of risk and prompt appropriate response and also contain some information about confidence and uncertainty (see Appendix B, Fig. (i) and (j) for past examples of an EA flood warnings and alerts map and an EA fluvial flood alert message, both produced for and available to the public). As stated by internal EA guidelines, the language used should change according to each scenario. This can be seen as a step towards communicating probabilities.

"If messages around a 'Reasonable Worst Case' use, could or […] is possible; if it's a 'Best Estimate' use, we expect, it's probable" [I1] (Q25)

"To help them [Duty Officers] get used to the language and the way they're working around scenarios and probabilistic forecasting" [I1] (Q26)

Public messages are usually free-text messages and will therefore vary across FWDOs.

"The message starts off with this flood warning has been issued for this place then it runs on after a while into detail which is where you can communicate those shades of grey" [FWDO2] (Q27)

To conclude this section on the current EA practice, it is evident that, while forecasting supports incident response by providing a critical piece of information, Duty Officers have to make trade-offs, taking different sources of information into consideration for their decision-making process.

"Forecasting's really important. It is, it should be really central to what we do […] but actually it's a small cog in the middle of a much bigger wheel." [I1] (Q28)

"We always implore people to try and look at different sources of information" [I2] (Q29)

Additional sources of information and factors include river level correlations, model performance, local knowledge, personal experience, internal procedures and politics (see Fig. 3). However, the forecast helps determine the timing of warning and response activities. Because the forecast is a piece within a much bigger system, will the transition to probabilistic forecasting have very minor impacts on the Duty Officers? Or on the contrary, could it unsettle this very complex machine?~~***4.1.3 Communication between MFDOs and FWDOs***~~

~~***"The FWDO shouldn't even really be thinking about anything until they've had a phone call from the MFDO […]. Some FWDOs do go a bit more proactive than that, I think particularly the ones with the forecasting backgrounds almost can't help themselves looking into it. And it depends on personality as well, some people hate the idea of being surprised by anything. But it does also depend on the MFDO." [FWDO2]***~~

~~*There is usually a constant exchange of information between MFDOs and FWDOs, even when no major event is on the horizon. However, more recently, the level of activity in preparation for a potential event has increased. Since 2007 (this corresponds vaguely with the summer 2007 floods), the lead time for which forecasts are shown and on which*~~

MFDOs and FWDOs can take action has increased from a few days to a few months ahead (based on the FFC's outlook products mentioned in Sect. 4.1.1). This is consistent with findings from Neumann et al. (2018), who report that the EA currently uses long-range (i.e. seasonal) hydrological forecasts mainly as supporting information, while relying on the shorter-range forecasts* for action.*

"So even from a month out now we're starting to become aware of potential situations […], but […] because […] most of our products […] are […] based on that five-day forecast […] that's when the activity really starts to build" [MFDO1]

The communication between MFDOs and FWDOs varies across people and EA centres. Factors that might influence communication – in terms of its trigger, frequency and content – include the duty officers' personality, day-to-day job and level of experience. Some FWDOs are more proactive than others in obtaining the information needed to make a decision; some might wait to be contacted by the MFDOs with a processed forecast, and others monitor the situation on a daily basis (see quote from FWDO2 above). In some cases, the FWDO might contact the MFDO first to get more details about an area of concern to them.

"[…] and […] then it's […] liaising with regional forecasting [the MFDOs] so they can give us any more detail or certainty or if we're concerned about an area they can watch it a bit more for us [the FWDOs]" [FWDO3]

Duty officers' level of experience can also influence the content and interpretation of the conversation. Knowing each other helps interpret and gauge the confidence from each other's language, which MFDO2 refers to as 'nuanced communication'. Working with new duty officers can lead to misinterpretations and you might have to justify your position further and prompt them to obtain the information you need.

"I've known [FWDO1] for quite a while so when I'm on duty with [them] […] I can sense […] what sort of questions [they] want to ask, where [they're] coming from. I think with less experienced duty officers it's often more tricky to do that. So […] the verbal communication that you go into with [FWDO1] for example might be a bit brief probably because I know that [they've] understood the message and interpreted the message well, whereas a new duty officer you might be spelling out […] your position more, spending more time explaining why the uncertainty is such and how that may impact on the ground" [MFDO1]

"Knowing each other is really important because if I know it's [MFDO2] on duty [they've] probably put that interpretation on already. If I get someone who's reading off the screen, I put the interpretation on and if we misjudge that and we both put it on we could end up getting it too low" [FWDO2]

Other factors that influence communication include the context of the event, duty officers' geographical proximities and a centre's practice. In some areas, the FWDOs will make the final call of warning the public or not, while in other areas, the MFDOs will tell the FWDOs when they need to issue a warning. In addition, MFDOs and FWDOs do not always sit in the same building or town. MFDOs work from forecasting centres, while FWDOs are based in Area offices or Area incident rooms, which influences their (mode of) communication (in person vs via phone or emails).

"If these people [the FWDOs] were sitting geographically with these other people [the MFDOs], I think you'd get a better service" [I1]

4.2 The forecast, a small cog in a much bigger wheel

"Forecasting's really important. It is, it should be really central to what we do […] but actually it's a small cog in the middle of a much bigger wheel." [I1]

Forecasting supports incident response by providing a critical piece of information. However, duty officers have to consider a range of other sources of information and factors when making risk-based decisions.

"We always implore people to try and look at different sources of information" [I2]

These additional sources of information include river level correlations, model performance*, local knowledge (i.e. knowledge of how a certain catchment behaves), personal experience, and internal and external considerations (see Fig. 4). This section gives a more detailed overview of these factors and their relevance for decision-making.*

4.2.1 River level correlations and model performance

"The MFDO will be looking at how much rain is falling compared to what was forecast. You can check the river levels on the telemetry sites*, so you can see how fast they're responding compared to the model and you can start to gauge how that catchment's responding compared to what you thought it would do" [MFDO1]

MFDOs might use several products to gain an understanding of model and forecast performance while the event unravels. More basic forecasting methods, like river level correlation tables, complement forecast information and aid the decision-making process. These correlations are based on a linear regression between peak levels upstream and downstream of a station. However, discrepancies between the forecasts and correlations can call into question the forecast accuracy.

"If the model says you're going to get flooding, the correlation says we're going to get flooding, we've had more rainfall than any previous event, you know that that decision's […] a clear one. If the model says flooding, the correlation says no you're fine, and we've had somewhere in the middle in terms of rainfall, that's when it gets difficult, because those borderline calls are really tricky to make" [I2]

The MFDOs' knowledge of the hydraulic/hydrological model performances, for certain types of events and catchments, is also key in interpreting the forecast. This is based on performance measures, local feedback from real-time river gauges*, experience and target lead times (i.e. the theoretical maximum lead time you have to send out a flood warning for a catchment before it floods, based on catchment size, gauge location and flood risk in that catchment). For certain types of events, such as convective rainfall events*, for which the duty officers know models are still limited, they might decide to issue a warning based on the 'Reasonable Worst Case', although it is "technically against procedure" [MFDO2].*

The FFC meteorological products also communicate some sort of confidence, which the MFDOs can use to complement the hydrological models' performance information.

4.2.2 Local knowledge and personal experience

"Whilst we are very data reliant on the information coming through, there's also that experience that you know that certain watercourses are very slow responding and […] no matter how much money we spend on your forecast, it's always not very good, you always delay it by a day and drop the peak by a bit. […] Data is very important but that local experience is as important if not more so in certain circumstances" [MFDO2]

Local knowledge and personal experience are key ingredients for judgement, an important component of the decision-making process. This means duty officers can react appropriately to an event and add confidence to the forecast. As MFDO2 put it, "experience is the unwritten part of the value that each role has".

Local knowledge is so important to decision-making that the interviewees believe it cannot be replaced by training, written material or fully automated systems.

"Some areas have very set triggers for a severe flood warning whereas other areas may just take it on a feel. [...] And each area has done it for a good reason, it's the local reasons for doing that but it isn't nationally consistent" [MFDO2]

"We have in the past looked at automated warnings [...], we can't automate them [...], there's a lot of personal interpretation and judgement [that] goes into it, and if a computer just hits a level and issues a warning, it's going to go wrong" [FWDO2]

This also manifests itself in perceptions about how successfully duty officers can transfer to other centres or areas to help during an important flood event.

"One of the things we're trying to do at the moment is to get mutual aid sorted out so that if a flood event happens in [some of the Northern areas] and their MFDOs [...] or the FWDOs are very [...] stretched [...] we can go [...] there, use their tools, their systems and do the same job. But whenever we've tried it the local knowledge is the key thing. Like knowing that this river responds particularly quickly and that we need to deal with it first before we move on to other ones that's the sort of thing that even if you're picking it up whilst you're working in a different centre it's affecting your ability to deliver the role at the time" [MFDO1]

Duty officers have access to tangible information about past flood events that can be useful for placing model information into context. The 'Flood Intelligence Files' compile information (e.g. highest events on record, what rainfall led to them, what the catchment state was at the time and any known impacts) for every gauge the EA is providing forecasts for.

How information is interpreted, risk appetite and past experience, can all affect decisions taken. There is the danger of following instincts too much and becoming biased towards issuing too many (i.e. risk-averse) or not enough warnings (i.e. risk-hungry), while in some cases decisions might never be forecast-led.

"Since the Boxing Day floods I think the next level of flooding after that there was some discrepancies amongst the area responses [...] they were a bit [...] jumpy [...] to not be caught out again which is understandable" [MFDO2]

"these kind of decisions about do we need to draw up a roster, do we need to be in the office overnight, a lot of that has probably been done on gut feel, probably this FWDO being the advisor. [...] Do we need to do whatever based on judgement, experience, feel for it. [...] I wouldn't expect these people to actually be looking at any forecast and saying, based on this I will do" [I1]

4.2.3 Internal and external considerations

"There are lots of external pressures as well, particularly as FWDO you can come under pressure from all different types of sources to make decisions and perhaps not based on the evidence that you've got for political reasons, [...] reputational reasons, organisation, in terms of being seen to be active, seen to [...] act early" [FWDO1]

Decisions are not only dictated by the science, local knowledge or personal experience and differences, but might have to respond to internal and external considerations, especially during major events.

At an internal level, some areas and duty officers might be more forecast-led while others are more reliant on a nowcasting type approach. Discrepancies amongst the area responses are partially due to historical differences across the different areas and EA centres.

"There are definite differences between areas and [...] between individual staff, so [town X] are far more likely to issue flood alerts [...] purely on rainfall than [town Y] is, [town Y] will generally wait for a river level to rise and that develops I suppose out of slight historical differences and personalities involved" [FWDO2]

"Some other areas will issue messages based on forecast whereas, we were always told to base it on what's happening, so we kind of wait to see if the rain comes in and then if anything happens issue. And we get marked on messages that we send out, so one of the things is the timeliness and if you've issued one, did it actually flood afterwards? So if you're obviously issuing on a forecast, then you're probably going to get scored low because it doesn't always happen, so it's difficult" [FWDO3]

There are exceptions to these procedures and FWDO3 mentions the possibility of issuing flood alerts based on the forecast when the impact is expected to occur overnight or if the forecast displays "rarely high confidence" of rainfall and "if it's a more prolonged event" and "you know the catchment's already wet".

The EA's principle, 'think big, act early, be visible', is an example of an internal consideration, which might influence the duty officers' decision-making (EA, 2018). In what ways does the EA's statutory warning responsibilities and principle influence decision-making? Does 'act early' put the forecast in first place while 'think big' and 'be visible' move it to a secondary position?

"Our mantra to incident response is think big, act early so sometimes [...] there is a danger that you're over responding. Somewhere you're issuing alerts and warnings when actually the risk is low. So I think the role of the FWDO is to assimilate all that information, forecasting information and using it to help inform the instant response but also manage expectations" [FWDO1]

There is usually a political element (external consideration) to the response immediately following a very major flood, as the EA puts a greater focus on demonstrating to communities and the government that they are being proactive in warning, informing, etc. There is also the need for the EA to align its message with actions of lead local flood authorities and responders and to think about public response.

"It's managing expectations internally in terms of operational response and how this is going to potentially play out which [...] can still be quite hard to do but it's even harder to do it externally with [the] mood of the public or even some of our professional partners, so local authorities are also obviously geared up to respond to flooding" [FWDO1]

To conclude this section, it is evident that the duty officers have to take different sources of information, besides the forecast, into consideration to make a decision. However, the forecast helps determine the timing of warning and response activities. Because the forecast plays a seemingly small part in a much bigger system, could that mean that the transition to a different type of forecast will have very minor impacts on the duty officers? Or on the contrary, could it unsettle this very complex machine?

4.3 What could a transition to probabilistic forecasting mean in practice?

4.3.1 Current practice: communicating confidence for decision-making at the EA

"Uncertainty is present in everything that we do and every bit of communication, […] I don't **think I've ever been able to say something with 100% confidence, ever." [MFDO2]**

We have previously touched on the factors and uncertainties duty officers have to work with, including uncertainties in: the weather (and how it cascades down to hydrological response), model performance, the different spatial scales of response (local vs national), the situation on the ground (e.g. soil conditions prior to an event and river blockages), EA staff decisions and actions, and the public's reaction to warnings.

Duty officers currently adapt the language they use to communicate these uncertainties internally and externally, based on their confidence level. According to internal EA guidelines, the language used should change according to the scenario used so that duty officers *"get used to the [..] way they're working around scenarios and probabilistic forecasting" [I1]*.

"If messages around a 'Reasonable Worst Case' use, could or […] is possible; if it's a 'Best Estimate' use, we expect, it's probable" [I1]

Between the MFDOs and the FWDOs, confidence and uncertainty appears to always be (based on these interviews) communicated, usually using the two flood forecast scenarios.

"I don't think we can withhold uncertainty. One, the key role for MFDO is providing the forecast. So it's getting the forecast as accurate as you can and then communicating it in the clearest way possible. So that's often about interpreting the uncertainty and communicating it. So we often use the 'Reasonable Worst Case' and the 'Best Estimate' to do that" [MFDO1]

Messages to the public are also worded with care to communicate the appropriate level of risk and prompt appropriate response and also contain some information about confidence and uncertainty. These messages are usually free-text messages and will therefore vary from across FWDOs.

"The message starts off with this flood warning has been issued for this place then it runs on after a while into detail which is where you can communicate those shades of grey" [FWDO2]

However, not all uncertainties are critical, and local knowledge and experience are key for the *"interpretation of the uncertainties" [FWDO2]* and their impact on the ground.

"Uncertainty from the forecasting point of view is always prevalent but understanding how it will impact the […] area's reaction is kind of the key thing" [MFDO2]

There is currently space for the communication of confidence at the EA and externally. This is a step towards probabilistic forecasting. But how big of a step is it? And how big of a step is still needed to reach that full transition to probabilistic flood forecasts?

4.3 Duty Officers' perceptions on what the future practice might look likeWhat could a transition to probabilistic forecasting mean in practice?

The transition to probabilistic forecasts is a significant evolution, which will undeniably bring some changes at the EA, and generates mixed feelings amongst the Duty Officers.

"Whether it creates as many problems as it solves, maybe" [I2] (Q30)

"Probabilistic forecasting is kind of a fresh start for everyone" [FWDO2] (Q31)

This section presents the interviewed Duty Officers' perspectives (as quotes) on what the future practice might look like for EA Duty Officers. In light of these findings and relevant literature findings, we make a list of recommendations to support the uptake of probabilistic forecasts at the EA. These recommendations concern actions we think the EA should take with high priority. The service, role owners and those responsible for ensuring a quality service delivery should ensure that these recommendations are pursued, alongside technical work around the transition. Please note that these recommendations are not ranked in priority order for the EA, as some of these will be quicker and easier to implement and to demonstrate progress on.

4.1 The FFC national hydro-meteorological forecasts

At the time of the interviews, very little was known to Duty Officers about the new probabilistic forecasting system (which research and implementation project started in November 2008; Sene et al., 2009; 2010). However, at least one interviewed MFDO was involved in the future system's technical implementation.

While the new system's design was not formerly known by all yet, some interviewees think that the probabilistic forecast could help materialise the uncertainty otherwise sometimes hidden with the two scenarios.

"I think in a good way [...] it will [...] reveal the uncertainty that's hidden by apparent simplicity" [I1] (Q32)

Many interviewees however seem concerned that the probabilistic forecast could add another layer of uncertainty to their already uncertain decision-making process (see Sect. 3.2).

"Uncertainties are very tricky to deal with, whether probabilistic forecasting and a switch to that is going to help?" [MFDO2] (Q33)

"That would be my concern that it's even more information and more uncertainty and it's kind of like, well what do you do with this information? And which bit do you communicate to who?" [FWDO3] (Q34)

From these interviews, it is apparent that in the current practice (see Sect. 3.2) Duty Officers see uncertainty as an inherent component of their decision-making process (see quotes Q14-16) and appreciate that forecasts convey uncertain information, not unlike other types of information they use, which they currently communicate using the two flood scenarios. Decision-makers "view uncertainty as an unavoidable factor […,] all information about the future is uncertain [and] they must make decisions under uncertainty every day" (Morss et al. 2005). This is in line with the positive perception captured in quote Q32 about probabilistic forecasts revealing otherwise hidden uncertainty. In fact, numerous studies have shown that decision-makers want to see that uncertainty, which they do not necessarily perceive as a barrier to use (Morss et al., 2005; McCarty et al., 2007; Bruen et al., 2010; Neumann et al., 2018). Ramos et al. (2013) have additionally showed that providing uncertainty attached to a forecast leads to more optimal and consistent decisions across decision-makers; when decision-makers "are not provided with estimates of forecast uncertainty they attempt to take uncertainty into account on their own" (as hinted by quote Q13 about the current practice), which may lead to important errors and/or risk-averse decisions (Joslyn and Savelli, 2010; Joslyn et al., 2011; Ramos et al., 2013; Michaels, 2014).

However, while they appreciate that the information conveyed by forecasts is uncertain, many Duty Officers expressed worries about the consequences this 'visible uncertainty' may have on their decision-making process as they perceive this transition as an increase in information (see quotes Q33 and Q34). Mu et al. (2018) looked at decisions taken by participants based on the UK Met Office weather risk matrix, with varying information content and format, and concluded that "while increasing the information with content of warnings is usually beneficial and increases the trust in the warning system, it must be done with caution since better decisions (judged by higher profits) are not always made with an increase of information." This was also put forward by Michaels (2014).

These trade-offs highlight the need for a careful design of the probabilistic forecasting system. Indeed, a great amount of research has explored the impacts of graphical representation of uncertainty in hazard forecasts on decision-making, and showed that the design and communication of uncertainty information can impact the nature of actions taken and should be tackled with care (Bruen et al., 2010; Joslyn and Savelli, 2010; Stephens et al., 2012; Pappenberger et al., 2013; Sivle et al., 2014; Mulder et al., 2017). In this context, opening a dialogue between forecasters, developers and end-users and allowing for all parties to be involved in the co-design of forecast products is vital (Morss et al., 2005; Smith et al., 2018; Fundel et al., 2019).

Recommendation 1: While Duty Officers acknowledge the value of probabilistic for communicating otherwise hidden uncertainty, they are worried about the impact it may have on their decision-making process. We therefore recommend the expansion of existing EA communication structures to allow the co-design of the new probabilistic forecast products between FFC forecasters and Duty Officers. This will ensure that Duty Officers have a say in the new system's uncertainty visualisation and communication in FFC documents, and may help tackle some of their worries.

The idea expressed in quote Q34, that probabilistic forecast means "*even more information and more uncertainty*" highlights a common misconception about probabilistic forecasting. Indeed, probabilistic forecasts do not add more uncertainty, but they offer a formal estimate of the uncertainty inherent to the information conveyed (e.g. river levels). This highlights forecast users' need for accurate information (as seen in the current practice; Sect. 3.2), which may seem to be at odds with probabilistic forecasting (McCarthy et al.; 2007). It further hints that there is still an important barrier between scientists/scientific notions and forecast users, which the geoscience community should aim to tackle. As pointed out by Morss et al. (2005), "the way scientists referred to and discussed uncertainty sometimes confused practitioners".

Recommendation 2: The misconception that probabilistic forecasts add "more uncertainty" calls for the adequate training of EA Duty Officers on probabilistic forecasting. This training could be delivered by forecasters from the FFC or by institutes the EA is already working with (e.g. JBA Consulting, the University of Reading, the University of Leeds). In this context, using serious games may help deliver the right messages in an engaging setting (see the HEPEX[1] and the Red Cross Climate Centre[2] resources and the IMPREX online game[3] for inspiration).

4.2 Local flood forecasting by the MFDOs

From these interviews, it is apparent that this transition is not perceived as particularly challenging by and for the MFDOs, despite the changes it might incur.

"I think the MFDO role won't change, it will still be to communicate a forecast but the […] wording of the forecast may change slightly" [MFDO1] (Q35)

"I think from our point of view it will just mean a bit more interpretation of forecasts and then […] just a slightly different way of passing it on […]. But I don't think it will change the process" [MFDO3] (Q36)

[1] hepex.irstea.fr/resources/hepex-games
[2] www.climatecentre.org/resources-games/games
[3] https://www.imprex.arctik.tech/

The interviewed MFDOs mentioned several potential opportunities they perceive this transition will bring. Some interviewees for example mentioned that the two scenarios, and the 'What If' scenarios used to produce them, were sometimes complicated to play with and required a lot of expert judgment, making them inconsistent nation-wide. A few MFDOs thought probabilistic forecasts might lead to more consistency across the EA centres.

> *"The new flood forecasting system is being developed at the moment so it's going to replace the NFFS. [The] benefits to that I suppose […] are that if we can look to be more consistent across the country in even simple things like what displays look like […] we're more interoperable if we need to" [MFDO1]* (Q37)

According to an interviewee, probabilistic forecasts could help with new staff training by increasing their understanding of catchment response.

> *"I can see some benefits to it, especially when you've got less experienced staff […], you're almost […] showing them the breadth of what a catchment could do given a range of responses" [MFDO2]* (Q38)

As showed by quote Q37, this transition is perceived as an opportunity for more consistency across EA centres. However, given the heterogeneity of the EA at a national level and the areas' diversity in terms of history and catchment response (as highlighted in the current practice Sect. 3), we do not expect probabilistic forecasts to be welcomed similarly in all the EA centres. This is transparent in the variety of perceptions captured by quotes in this Sect. 4.

Recommendation 3: Considering the existing differences in the current practice across EA centres, we recommend that the EA ensure a simultaneous transition in all its centres.

As mentioned by Handmer and Proudley (2007), decision-making based on probabilistic forecasts can be challenging because of situation-specific factors, which vary greatly across events, EA centres and catchments as shown in the current practice Sect. 3 and as suggested by quote Q38. In this context, Nobert et al. (2010) advocate training for ensemble prediction systems users to be locally tailored to the local experience of different audiences.

Recommendation 4: To account for the heterogeneity of local conditions, existing dynamics and institutional practices across EA centres, we recommend that the EA carry out a locally tailored customised transition within each centre. Building on recommendation 1, we recommend the co-design of the probabilistic forecasting system with a panel of Duty Officers representative of all EA areas. Moreover, training and the Duty Officers' operating procedures should adequately reflect these local differences.

~~**Expand existing EA communication structures to allow the co-design of the new products between forecast producers and users . Everyone using the forecasting products and systems at the EA should have the chance to have a say in how the system will look and function through a mutual design strategy. If the new system does not reflect the complex landscape in which duty officers operate (a mix of 'hard scientific facts' and 'soft values'), probabilistic forecasts might end up being under- or misused.**~~

4.3 Interaction between MFDOs and FWDOs

It is worth noting that none of the interviewees mentioned worries concerning potential impacts of this future transition on the communication and interaction between their two roles.

> *"Between us [Duty Officers], it's probably OK because we've got that understanding of the roles" [FWDO3]* (Q39)

This transition is perceived as an opportunity by MFDOs for more confidence and credibility when communicating with FWDOs.

"If you've got a huge spread then you know that there's a very wide range of impact potentially, but if […] everything's within a couple of centimetres of each other, it gives you a lot more confidence in saying, no I think we're going, we're not going to see a threshold crossing. So […] it will help decision making I think" [MFDO3] (Q40)

In a study exploring the use of ensemble hydrological forecasts by decision-makers throughout Europe, Ramos et al. (2013) found that most decision-makers used the uncertainty information from the ensemble forecast to confirm the deterministic forecast. They observed that if the ensemble forecast showed a similar signal to the deterministic forecast, it made them more confident (as highlighted by quote Q40).~~From these interviews and previous EA studies, it is apparent that forecasts are one element in the complex decision-making landscape within which EA duty officers operate (Orr and Twigger-Ross, 2009; Dale et al., 2014). This landscape includes alternative 'hard scientific facts' (e.g. correlations, model performance and local knowledge to an extent), and 'soft values' (dependent on culture and context, personal experience and internal and external considerations) (Morss et al., 2005; Cloke et al., 2009; Arnal et al., 2016; Neumann et al., 2018). Morss et al. (2005) found that "although flood management practitioners might appreciate more certain hydro-meteorological information, scientific uncertainty is often swamped by other factors [e.g. community perception, time, money and resource constraints] and thus is not a high priority." When uncertainties are evident and decision stakes are high, as is the case for the uncertainty communicated by probabilistic forecasts for flood incident management, traditional decision-making pathways could become ineffective and soft values might become more important than hard scientific facts (Funtowicz and Ravetz, 1993). In this specific study for example, an uncertain probabilistic forecast could lead to some duty officers reverting to the 'Best Estimate' and the river level correlations to make a decision, ignoring low probabilities of extreme events which could have ultimately led to an earlier flood warning.~~

If the two forecasts' signals differed it made them more "confused". This happens to some extent in the current EA practice, where discrepancies between the two flood scenarios and the river level correlations can call into question the forecast accuracy (see quote Q7). We can imagine that this could still happen in the future practice, if the probabilistic forecast shows a wide range of possible outcomes or a different signal to for example the 'Best Estimate' (if still in use).

However, the various information sources and tools that constitute the Duty Officers' current practice are vital in their decision-making process, as shown in Sect. 3. Indeed, as showed by Pidgeon and Fischhoff (2011), decision-makers may benefit "from different perspectives that help them clarify the implications of a decision on what they value".

Recommendation 5: To clarify how the probabilistic forecast should be used in combination with the tools and information sources Duty officers are already using in the current practice, we recommend updating the Duty Officers' operating procedures to contain specific guidelines about: the various sources of information officially available to Duty Officers for decision-making, how to interpret a probabilistic forecast, the forecast confidence at which given decisions and actions should be made and the language that should be used. The updated guidelines should also describe a course of action to be followed by Duty Officers when the probabilistic forecast shows a contrasting signal to the deterministic forecast or other information sources.

Duty Officers seem optimistic as to the impact this transition may have on their interaction. However, as mentioned by Michaels (2014), with "deterministic models it was easier to consider that a linear approach to forecast transmission was adequate", as was observed to some extent in the current practice as MFDOs generally flag a situation to the FWDOs once they are confident about the signal shown by the river level forecast (Sect. 3.2.3). We can imagine that the Duty Officers' interaction might become less linear with probabilistic forecast and may as a result require more comprehensive discussions than it sometimes does in the current practice (Sect. 3.2.3).

Recommendation 6: To lay foundations for adequate probabilistic forecast transmission from MFDOs to FWDOs, which we expect to be less linear than with deterministic forecasting, we recommend combined MFDOs-FWDOs training.

4.4 Local flood warning decision-making by the FWDOs

This transition generated mixed perceptions with regards to the FWDOs role. Some interviewees believe that probabilistic forecasts will not solve the fundamental need of flood warning decision-making to be "binary" and see this transition as a potential cause for misunderstandings both internally and externally.

"All the comms research we hear about generally says [...] the public message has to be as simple as possible, so that is working the opposite way to any proposal for probabilistic forecasting" [FWDO2] (Q41)

"A lot of local authorities standing their staff up, putting them on standby for a weekend is quite a big budget thing [...]. So [...] if we say, it is going to flood, they can justify the spend on it [...]. If we pass it on as shades of grey, a lot of them, they'll appreciate the information but some of them would actually resent having the decision forced on them because they will struggle to then justify doing something or they'll be blamed, either way, blamed for spending money if it doesn't happen and blamed for not spending enough if it does happen." [FWDO2] (Q42)

"You're still going to have this overriding issue with fast responding catchment where one scenario says we might need to issue a flood warning but 99 of them say no. Someone has to make a decision" [MFDO1] (Q43)

"I think still for a lot of people the question they [...] want answered is am I going to flood?" [I2] (Q44)

Some interviewees also expressed the worry that probabilistic forecasts might push more of the interpretation further down the decision-making line and on to the FWDOs.

"Having probabilistic forecasting just moves the burden of making a decision further down the tree" [MFDO2] (Q45)

"I think my role is going to be the one where it has to stop and it can't be probabilistic because it [...] does come to a yes or no, issue it, don't issue it. So to some extent, probabilistic forecasting does feel like everyone else just pushing things down the line saying you make the decision, [...], we have to make the decision because we're the last ones on the line" [FWDO2] (Q46)

A few interviews however perceive this transition as an opportunity for early warning and long-term planning.

"I think in an incident I'm happy that that's [...] a useful range of things to know, [...] you probably warn for the lowest one and plan for the highest one and we can interpret between them" [FWDO2] (Q47)

"We're talking about some of these decisions that have got a long lead time, we're going to move people around the country, we're going to move equipment. It takes a long time to do that" [I1] (Q48)

It was also clear from the interviews that the transition needs to be gradual to give Duty Officers time to build confidence in the new system.

"It is something to bear in mind with that if probabilistic forecasting put too much pressure and stress on decision making on the people in these roles, the system probably would just collapse, people would walk away" [FWDO2] (Q49)

The term "binary" decision which transpires through quotes Q41-44 and in the current practice quote Q8 may be deceiving. The FWDOs can make a range of different decisions (from incident planning to flood warning; see Sect. 3.2.4), and a decision is never "bad" nor "good", but should be the "best" that can be made at a point in time with the information available. In the face of a socio-political context that is demanding ever more precise information and with the rise of a post-factual society (i.e. culture in which public opinion depends on appeals to emotions rather than objective facts), the general trust in science might be a limiting factor to the uptake of probabilistic forecasts (Soares and Dessai, 2015; Golding et al., 2017; Knudsen and de Bolsée, 2019). Very often, the ability of an institution to pick up new information and methods is not only down to them, but could be influenced by the wider socio-political context and other key actors in the decision-making web (e.g. the government, local authorities, regulations and guidelines), additionally to the populations at risk and the way they respond to flood warnings (Dessai and Hulme, 2004; Morss et al., 2005; Parker et al., 2009). Michaels (2014) states that "conveying the uncertainties surrounding scientific knowledge and admitting the limitations of that knowledge helps gain and retain decision makers' and the public's trust". In the current practice, forecast confidence is already communicated to an extent to the public (see Sect. 3.2.4). This is a step towards probabilistic forecasting. But how big of a step is still needed to reach that full transition to probabilistic flood forecasts?

Recommendation 7: To address a socio-political context demanding ever more precise information, we recommend that the EA, as the lead authority for flood warning in England, communicates (via engagement campaigns, videos, email newsletters, social media updates and webinars, etc.) with external players (i.e. emergency responders, the public and professional partners) ahead of this transition to ensure that they are aware that probabilistic forecasting will become operational practice and to communicate the benefits of probabilistic over deterministic forecasting. This includes rethinking the language that will be used in warning messages going out to public and, as part of the EA's strategic overview role, preparing external decision-makers on how this might change their practices.

It is also important to note that "moving to probabilistic forecasting from deterministic forecasting may trigger an institutional shift in who is responsible for decision making under uncertainty" (Michaels, 2014). Because making a decision based on probabilistic information is more nuanced than using deterministic information, the outcome will determine who will be "blamed" and this ownership of the uncertainty judgment might have implications on the forecasters-users relationships (Michaels, 2014). With regards to the implementation of the European Commission's European Flood Awareness System (EFAS), sending flood alerts to European National flood forecasting agencies, it was noted that EFAS users were concerned about being held responsible for "wrong" EFAS alerts (Demeritt et al., 2010). This echoes our findings regarding some of the interviewed Duty Officers' fears regarding this transition potentially pushing more of the interpretation on to the FWDOs (see quotes Q45 and Q46). This worry seems present in the current practice to an extent, as an interviewed FWDO expressed the difficulties of forecast-based decision-making and their concern of being "scored low" as a result (see quote Q21). Furthermore, those not involved in the probabilistic forecast production may not be comfortable with the responsibility of interpreting the uncertainty they convey (Faulkner et al., 2007; Michaels, 2014).

In this context, decision-making methods can provide a framework to support users in making a decision based on probabilistic forecasts, ensuring that decisions are made "objectively, with confidence and an understanding of uncertainty" (Dale et al., 2012). Examples of decision-making methods from the literature (see Duan et al. (2019) for more examples) include: 1) the series of decision-support methods developed by Dale and Wicks (2013), where the efforts associated with using each specific method is proportional to the costs and benefits of the decision at stake. The basic method associates a probability threshold to a specific flood incident management action based on expert judgement and local knowledge. The detailed method is based on a pre-defined water level-impact relationship used to determine, in real time, whether the average forecasted flood impact (if no action is taken) is greater than the flood incident management action cost (Dale et al. 2012); 2) a method for data-scarce locations, which links the latest forecast with an action based on the magnitude of past flood events and the decision-makers' willingness to "act in vain" (Coughlan de Perez et al., 2016); 3) the current EA method for decision-making based on ensemble surge forecasts, where extreme probabilities are communicated with responders who understand the low probability but need to mobilise out to 5 days ahead, and escalating or scaling down response closer to the event as the uncertainty narrows down (Gold and Connolly, 2018).

Recommendation 8: Given the FWDOs' fears of having to interpret the probabilistic forecast and potentially being blamed for decisions made, we recommend the co-design of a tailored risk-based decision-making framework between the FFC and the EA Duty Officers. This will promote a co-ownership of the methods so that Duty Officers are more comfortable in interpreting and using the probabilistic forecast.

~~It is also important to note that "moving to probabilistic forecasting from deterministic forecasting may trigger an institutional shift in who is responsible for decision making under uncertainty" . Because making a decision based on probabilistic information is more nuanced than using deterministic information, the outcome will determine who will be 'blamed' and this ownership of the uncertainty judgment might have implications on the forecasters-users relationships . This relates to some of the interviewed duty officers' fears of a transition to probabilistic forecasts at the EA, as it might move "the burden of making a decision further down the tree" (Sect. 4.3.2). In this context, a framework to engage with all key actors of the decision-making web ahead of and during a transition to probabilistic forecasts appears crucial. advocated the use of integrated platforms to allow a continuous exchange between scientists and decision-makers in real-time. Similar studies on the provision of climate services have identified the lack of user engagement as a great limiting factor of the uptake of climate information in practice . It is evident that a transition to probabilistic forecasts is not only a scientific endeavour and feasibility studies should include other disciplines, such as social science.~~"Institutional mandates understandably dictate what staff members emphasize" (Michaels, 2014). As shown in the EA current practice, decisions are sometimes led by internal procedures and politics (see Sect. 3.2.4). The cultural landscape in which decision-makers operate not only has an impact on the decision-making outcome, but may also have an impact on an institution's uptake of probabilistic flood forecasts in practice (Nobert et al., 2010; Ishikawa et al., 2011; McEwen et al., 2012; Demeritt et al., 2013; Michaels, 2014). Institutions like the EA have specific flood management priorities: seeking to avoid false alarms, or on the contrary, seeking to avoid missed flood events, and the minimum/maximum lead time at which they have to issue flood warnings. There is no doubt that probabilistic forecasts will offer a very different perspective on these factors. Bischiniotis et al. (2019) for example showed that the optimal lead time to trigger action depends on both the actions' operational implementation time and the probabilistic flood forecast quality. While the EA currently operates with pre-defined lead times for each specific planning and response activity (see Sect. 1), probabilistic forecasts could in theory provide earlier indications of potential upcoming floods, giving the EA more time to prepare ahead of a flood event. A few interviewed Duty Officers indeed perceive this transition as an opportunity for early warning and long-term planning (see quotes Q47 and Q48).

Recommendation 9: To ensure an EA-wide successful transition in practice, we recommend that the EA adapt their wider flood management priorities. For example, the EA will have to be prepared to move towards lead times that reflect the probabilistic forecast predictability. To this end, tailored studies should be carried out during the system's co-design and implementation to identify new planning and warning lead times (reflecting the probabilistic forecast predictability – and therefore the event and catchment type -, actions' operational

implementation time, and the EA's acceptable flood incident management action vs impact cost ratio). This should be done with ample time for testing by the EA Duty Officers.~~**Communicate (via engagement campaigns, videos, email newsletters, social media updates and webinars, etc.) with all key players in the decision-making chain (as well as external players such as the emergency responders and the public) to ensure that they are all aware that the transition to probabilistic forecasts will become operational practice.**~~

Morss et al. (2005) found that "although flood management practitioners might appreciate more certain hydro-meteorological information, scientific uncertainty is often swamped by other factors [e.g. community perception, time, money and resource constraints] and thus is not a high priority." When uncertainties are evident and decision stakes are high, as is the case for the uncertainty communicated by probabilistic forecasts for flood incident management, traditional decision-making pathways could become ineffective and soft values (dependent on culture, context and personal experience; see Sect. 3) might become more important than hard scientific facts (e.g. river level correlations, model performance and local knowledge to an extent; see Sect. 3) (Funtowicz and Ravetz, 1993). Given the complex decision-making landscape within which EA Duty Officers operate (see Sect. 3), this could translate to low probabilities of extreme events being ignored, which could have ultimately led to appropriate and earlier flood warnings.

Furthermore, facing constantly evolving soft values, some decision-makers may find familiarity with the scientific methods they use reassuring, reducing their personal willingness to adopt new scientific methods (Morss et al., 2005; Ishikawa et al., 2011). The interviewees' personal willingness was captured during these interviews, hinted by the range of quotes presented in this Sect. 4.

To ensure that users gradually adapt to a new system, there should be a reasonable period of overlap between two systems (Funtowicz and Ravetz, 1993). Additionally, as mentioned by Thielen et al. (2006; 2009) who documented the implementation of EFAS, the success of a new system should be measured via end-user feedback. used to update design and procedures throughout the system's operational implementation.

Recommendation 10: To ensure a successful transition during which users can gradually adapt to the new system, we recommend a reasonable period of overlap between the two scenarios and the probabilistic forecasting system. During that time of overlap, end-user feedback should be collected from all key players and considered to update the new system's design and procedures.~~**4.3.2 The duty officers' perceived opportunities and challenges**~~

4.5 Additional recommendations

As mentioned in Sect. 4.1, while some interviewed Duty Officers knew about the transition to probabilistic forecasting and were involved in the technical design of the new forecasting system, a few interviewees had just learnt about the transition a few days prior to the interviews. This may help explain the diversity of perceptions presented in this Sect. 4 and some of the perceived challenges. ~~"Whether it creates as many problems as it solves, maybe" [I2]~~

~~The transition to probabilistic forecasts is a significant evolution, which generates mixed feelings amongst the duty officers. It is undeniable that this transition will bring changes at the EA; as *FWDO2* put it, *"probabilistic forecasting is kind of a fresh start for everyone"*. This section presents the interviewees' perspectives on the changes that will ensue from this transition, in terms of perceived opportunities (left wordcloud on Fig. 5), challenges (right wordcloud on Fig. 5) and neutral changes. Table 1 outlines these perspectives, split into six main topics and supported by quotes reported in Appendix C. Some of quotes reported in Appendix C might sound very extreme, which could be partly due to the way the questions that prompted them were phrased. However, it could also reflect personal resistance and should be explored further.~~

5 Discussion and recommendations

5.1 Considerations for a successful transition to probabilistic forecasts

Probabilistic forecasts have a great potential to capture extreme events , and their benefits (compared to deterministic forecasts) for flood warning are evident . However, despite the increasing lead times at which we can confidently predict floods, the uncertainty inherent in the chaotic natural system being modelled grows with increasing lead times, posing new problems. As science and decision-making are both individually progressing, adapting to their respective internal and external changes, there still lacks an ideal framework for the incorporation of new and 'uncertain' science in decision-making practices, and, respectively, the uptake of decision-makers' perspectives in the design of scientific practice. Here, results from this study and relevant literature are joined to put forward elements that should be considered for a successful transition to probabilistic forecasts for flood warning in England.

From these interviews and previous EA studies, it is apparent that forecasts are one element in the complex decision-making landscape within which EA duty officers operate). This landscape includes alternative 'hard scientific facts' (e.g. correlations, model performance and local knowledge to an extent), and 'soft values' (dependent on culture and context, personal experience and internal and external considerations) (; Cloke et al., 2009; ;. found that "although flood management practitioners might appreciate more certain hydro-meteorological information, scientific uncertainty is often swamped by other factors [e.g. community perception, time, money and resource constraints] and thus is not a high priority." When uncertainties are evident and decision stakes are high, as is the case for the uncertainty communicated by probabilistic forecasts for flood incident management, traditional decision-making pathways could become ineffective and soft values might become more important than hard scientific facts (. In this specific study for example, an uncertain probabilistic forecast could lead to some duty officers reverting to the 'Best Estimate' and the river level correlations to make a decision, ignoring low probabilities of extreme events which could have ultimately led to an earlier flood warning.

Facing constantly evolving soft values, some decision-makers may find familiarity with the scientific methods they use reassuring, reducing their personal willingness to adopt new scientific methods (Morss et al., 2005; Ishikawa et al., 2011). This personal willingness was captured in the range of responses (perceived challenges and opportunities) obtained during the interviews. An institute's operating practice should reflect the complex landscape in which decision-makers operate, where the forecast plays an integral role in decision-making. To this end, the co-design of forecasting systems by both forecasters and users is necessary.

To do that, clear communication between forecasters and users is needed. However, language is perhaps one of the biggest barriers between scientists and decision-makers. It has been observed that "the way scientists referred to and discussed uncertainty sometimes confused practitioners" (Morss et al., 2005). Similarly, there is a lot of research done on the impacts of graphical representation of uncertainty in hazard forecasts on decision-making. These have shown that great care has to be taken when designing and communicating uncertain information, as it can impact the nature of the actions taken (Bruen et al., 2010; Joslyn and Savelli, 2010; Stephens et al., 2012; Pappenberger et al., 2013; Sivle et al., 2014.

There is the common misconception amongst the scientific community that decision-makers want 100% certain information (Demeritt et al., 2013; Michaels, 2014). In reality, as shown in this paper, decision-makers appreciate that scientific information is uncertain, not unlike other types of information they use. Decision-makers want to see that uncertainty, which they do not necessarily perceive as a barrier to use (Morss et al., 2005; Bruen et al., 2010; Neumann et al., 2018). One reason for this misconception might be the different ways scientists and decision-makers approach forecast uncertainty. Scientists see (the reduction of) forecast uncertainty as an end goal and "often deal with uncertainty by attempting to reduce, quantify, analyze, and/or assess it". Decision-makers "view uncertainty as an unavoidable factor […,] all information about the future is uncertain [and] they must make decisions under uncertainty every day, in a complex, evolving social, institutional, and political environment" (Morss et al. 2005).

In this complex evolving landscape, decision-makers deal with forecast uncertainty similarly to other uncertainties they might face: under time and resources constraints. They assess the total uncertainty there is (the forecast uncertainty might sometimes be negligible compared to all the other factors at stake) in terms of its potential effect on the decision-making process and outcome (Morss et al., 2005). As mentioned by a few EA duty officers, uncertainty is prevalent in everything that they do, and the key is understanding what the impact of these uncertainties will be on the ground. It is crucial to develop a methodology for decision-makers to be able to use (forecast) uncertainty information optimally. A solution that does not require any additional time- and resource-consuming complex analyses, given the high stakes and strict deadlines decision-makers have to work with. Smith et al. (2018) argue that if there was a "greater involvement of decision-makers in the design and execution of uncertainty analyses", "more purposeful evaluation and communication of uncertainty would certainly result". This remains an open challenge to be tackled.

By design, probabilistic forecasts might contain some realisations that capture scenarios which do not always realise. This may lead to false alarms. Institutions can have specific risk perceptions and flood management priorities: seeking to avoid false alarms, or on the contrary, seeking to avoid missed flood events*, and the minimum/maximum lead time at which they (have to) issue flood warnings. This cultural landscape within which decision-makers operate may have an impact on the decision-making outcome (as discussed in Sect. 4.2.3) and an institution's uptake of probabilistic flood forecasts in practice (Nobert et al., 2010; Ishikawa et al., 2011; McEwen et al., 2012; Demeritt et al., 2013; Michaels, 2014). A transition to probabilistic flood forecasts should be reflected in an institution's wider flood management priorities. This could be done, for example, by changing their internal communication pathways or their warning procedures (e.g. lead times at which they operate).

Very often however, the ability of an institution to pick up new information and methods is not only down to them, but could be influenced by the wider socio-political context and other key actors in the decision-making web (e.g. the government, local authorities, regulations and guidelines), additionally to the populations at risk and the way they respond to flood warnings (Dessai and Hulme, 2004; Morss et al., 2005; Parker et al., 2009). This is reflected in the interviewed EA duty officers' perceived challenges regarding 'Language & communication' and 'Binary decision-making' (Sect. 4.3.2). In the face of a socio-political context that is demanding ever more precise information and with the rise of a post-factual society, the general trust in science might be a limiting factor to the uptake of new science and institutions should trust their capacity to use uncertain probabilistic information (Soares and Dessai, 2015; Golding et al., 2017; Knudsen and de Bolsée, 2019).

It is also important to note that "moving to probabilistic forecasting from deterministic forecasting may trigger an institutional shift in who is responsible for decision making under uncertainty" (Michaels, 2014). Because making a decision based on probabilistic information is more nuanced than using deterministic information, the outcome will determine who will be 'blamed' and this ownership of the uncertainty judgment might have implications on the forecasters-users relationships (Michaels, 2014). This relates to some of the interviewed duty officers' fears of a transition to probabilistic forecasts at the EA, as it might move "the burden of making a decision further down the tree" (Sect. 4.3.2). In this context, a framework to engage with all key actors of the decision-making web ahead of and during a transition to probabilistic forecasts appears crucial. Ramos et al. (2010) advocated the use of integrated platforms to allow a continuous exchange between scientists and decision-makers in real-time. Similar studies on the provision of climate services have identified the lack of user engagement as a great limiting factor of the uptake of climate information in practice (Golding et al. 2017). It is evident that a transition to probabilistic forecasts is not only a scientific endeavour and feasibility studies should include other disciplines, such as social-science.

5.2 Recommendations to the EA

In light of the findings of this study, and other relevant studies, we make a list of recommendations to support the uptake of probabilistic forecasts at the EA. These ten recommendations are high priority actions for the EA as an institution. The service, role owners and those responsible for ensuring a quality service delivery should ensure that these recommendations are pursued, alongside technical work around the transition. Please note that these recommendations are not ranked in priority order for the EA, as some of these will be quicker and easier to implement and to demonstrate progress on.

Communicate (via engagement campaigns, videos, email newsletters, social media updates and webinars, etc.) with all key players in the decision-making chain (as well as external players such as the emergency responders and the public) to ensure that they are all aware that the transition to probabilistic forecasts will become operational practice.

Give appropriate and custom designed internal training to all key players (Nobert et al., 2010). Duty officers must receive training on how to make decisions based on probabilistic forecasts (for example in the form of decision-making activities and serious games - see the HEPEX[4] and the Red Cross Climate Centre[5] resources for inspiration).

Expand existing EA communication structures to allow the co-design of the new products between forecast producers and users (Morss et al., 2005; Smith et al., 2018). Everyone using the forecasting products and systems at the EA should have the chance to have a say in how the system will look and function through a mutual design strategy. If the new system does not reflect the complex landscape in which duty officers operate (a mix of 'hard scientific facts' and 'soft values'), probabilistic forecasts might end up being under- or misused.

Reach out to the community of practice in hydrological probabilistic forecasting, such as HEPEX[6] (community of international experts in the field of probabilistic hydrological forecasting and decision-making) and connect with institutes which have already gone through such a transition to gain insights and share best practice, as some elements might be transferrable (Nobert et al., 2010; Dale et al., 2014). This could be done through organised workshops, webinars and the establishment of an advisory group.

The way probabilistic information will be translated into meaningful content and communicated to the emergency responders and the public requires careful thought and design . To this end, an interdisciplinary approach between forecasters and social-scientists would be greatly valuable as social-science can offer insights into the human response to warning messages. A tailored and inter-disciplinary study of the forecasting products using probabilistic information and used in the decision-making process is urgently required.

a) The EA's heterogeneity at the national level should be accounted for and addressed. Given the heterogeneity of the EA at a national level and the areas' diversity in terms of history and catchment response, we do not expect probabilistic forecasts to be welcomed similarly in all the EA centres. Efforts will therefore have to be made by the EA to achieve a simultaneous and homogeneous transition in all its centres.

b) Furthermore, the design of the new forecasting system should be homogenised at the national level (to allow for staff movement during major flood events), while accounting for the heterogeneity of local conditions, existing dynamics and institutional practices. This could be achieved through the co-design of the forecasting system with local duty officers (see recommendation 3).

Be prepared to move towards lead times that reflect the probabilistic forecast predictability. The optimal lead time to trigger action depends on both the probabilistic flood forecast quality and the actions' operational implementation time (Bischiniotis

[4] hepex.irstea.fr/resources/hepex-games
[5] www.climatecentre.org/resources-games/games
[6] hepex.irstea.fr

et al., 2019). While the EA operates with pre-defined lead times for each specific activity (e.g. it takes x hours/days to move equipment from A to B, or to deploy temporary defences), probabilistic forecasts could in theory provide earlier indications of potential future floods, giving the EA more time to prepare ahead of a flood event. To utilise probabilistic forecasts to their full potential, tailored studies should be performed during the EA system's co-design to adjust lead times (for planning and warning) on the probabilistic products and event types, with ample time for testing by the EA duty officers.

Under no circumstances should the old system be switched off as soon as the probabilistic system is operational. There should be a reasonable period of overlap between the two systems in order to give everyone some time to gradually adapt (Funtowicz and Ravetz, 1993). During that time of overlap, end-user feedback should be collected (Thielen et al., 2006). To avoid situations where the probabilistic forecast and the two scenarios show contrasting results, the new operating procedures need to specify that the probabilistic forecasts should be looked at first.

Update the duty officers' operating procedures. Clear guidelines should be provided to the duty officers on how to make a decision based on the new probabilistic products. These guidelines should include information such as: the various sources of information available to them for making a decision, how to interpret a probabilistic forecast, the forecast confidence at which certain decisions and actions should be made and the language that should be used.

Document this transition (in writing or through documentary-style interviews, etc.) to help other institutes and future transitions at the EA (Pielke, 1997). While this paper investigates how things might change, post-transition evaluation should seek to answer the question: "How did we do?"

Many of these recommendations are however general and could be applicable to other institutes and types of information. Golding et al. (2017) identified the lack of user engagement as a great limiting factor of the uptake of climate information in practice. Ramos et al. (2010) additionally advocated the use of integrated platforms to allow a continuous exchange between scientists and decision-makers in real-time.

> **Recommendation 11: In light of the Duty Officers' perceived challenges, building on recommendation 7, we recommend that the EA foster user engagement by putting in place a framework to communicate progress with all key players in the decision-making web (both internal and external) ahead of and during the EA's transition to probabilistic forecasts.**

Other factors that may help explain the diversity of perceptions reported by the quotes presented in this Sect. 4 are: the wording of questions that prompted them, personal resistance, and/or the interviewees' experience with the 2013/2014 transition from a single flood forecast to the two scenarios. These points were however not explored further during the interviewees and may be quite relevant for the prospects of the upcoming change from two scenarios to probabilistic forecasting. This merits additional investigation.

As stated in the introduction (Sect. 1), Document this transition (in writing or through documentary-style interviews, etc.) to help other institutes and future transitions at the EA . While this paper investigates how things might change, post-transition evaluation should seek to answer the question: "How did we do?"transitioning to operational hydrological probabilistic forecast is still a prevailing challenge in the field. Reaching out to the community of practice and institutes which have undergone this transition may help to gain insights and share best practice, as some elements might be transferrable (Nobert et al., 2010; Dale et al., 2012).

Recommendation 12: To gain external insights on how to achieve a successful transition in practice, we recommend that the EA reach out to the community of practice in hydrological probabilistic forecasting, such as HEPEX (community of international experts in the field of probabilistic hydrological forecasting and decision-making) and connect with institutes which have already gone through such a transition, such as EFAS. This could for example be done through the establishment of an advisory group and organised workshops.

Similarly, insights from this transition could be of great value to the EA for future transitions, to other institutes facing or yet to face a similar situation, and to the wider geoscience community to contribute to the advancement of the field of operational science (Pielke, 1997).

Post-event analyses can help improve a forecasting system, by identifying challenges in the current system and warning practices, and during the post-transition phase, by evaluating the impact of the introduction of a new system (Thielen et al., 2006). However, in the EA's current practice, while warnings sent out by the EA FWDOs are logged in a database, they are not currently used for post-event analysis (see Q21 and the associated text below it). This could have formed valuable insights for the current transition to probabilistic forecasts at the EA.

Recommendation 13: To help future transitions at the EA and other institutes, we recommend that the EA document (in writing or through documentary-style interviews, etc.) and evaluate this transition (and the new forecasting system; via post-event analyses).

5~~6~~ Conclusions

The Environment Agency (EA) is currently ~~in the process of a~~ transitioning from two flood scenarios to ~~to~~ probabilistic fluvial flood forecasting ~~s, from the two flood scenarios they currently use operationally~~ for operational -flood ~~warning and~~ incident management ~~activities~~ in England. ~~State-of-the-art p~~Probabilistic forecasts enable a better and earlier ~~can~~ detection of potential future floods and their associated impacts, ~~give an earlier indication of potential future extreme events, such as floods,~~ increasing the amount of time we have to~~decision-makers have to~~ prepare. However, there is currently- a lack of clarity about how probabilistic forecasts should be used for flood incident management and how this transition will affect decision-makers' roles at the EA. To address this issue, ~~A series of~~ interviews were carried out with EA 'Monitoring and Forecasting ~~Duty Officers~~Duty Officers' (MFDOs) and 'Flood Warning ~~Duty Officers~~Duty Officers' (FWDOs), two roles at the heart of the EA's flood warning~~risk management~~ decision-making chain. These interviews aimed to capture the Duty Officers' current decision-making process and their perceptions on how this transition to probabilistic forecasting might impact their ~~The aim was to understand how an operational transition to probabilistic flood forecasts might affect their~~ decision-making activities. Based on these interviews and literature findings, thirteen recommendations were spelled out to support a successful transition for flood early warning in England. The interviews highlight the complex landscape in which EA duty officers operate and the breadth of factors that inform their decisions, additionally to the forecast. Within this landscape, the interviews revealed that, while EA Duty Officers already account for uncertainty and communicate their confidence in the forecast they currently use, their decision-making process is still very binary and the forecast transmission from MFDOs to FWDOs linear to an extent. This appears at odds with probabilistic forecasting and hints that several elements of the EA Duty Officers' forecast-based decision-making process will have to change. Key recommendations include (in no specific order):~~Overall, none of the interviewed duty officers mentioned concerns about impacts of this transition on their two roles' interaction. Perceived challenges lie mostly outside of their roles and relate to: communication with emergency responders and the public, translating uncertain information into a binary decision and the speed of the transition. Ten high priority recommendations were made to the EA to ensure a successful transition. They include: i) communicating with all key players in the decision-making chain (as~~

~~well as emergency responders and the public) to ensure that they are all aware that this transition will become operational practice, ii) facilitating the co-design of the new products by forecasters and users and collecting end-user feedback during a reasonable period of overlap between the two systems, iii) employing an inter-disciplinary approach to translate probabilistic information into meaningful content for communication with emergency responders and the public, and iv) being prepared to adapt the EA's overarching warning and incident planning strategy to reflect this transition. It is vital for these recommendations to be followed to ensure that state-of-the-art science is used to its fullest potential for risk management practice and is not being under- or misused.~~

- Enabling the co-design of the probabilistic forecasting system and a risk-based decision-making framework between forecasters and EA Duty Officers.
- Updating the Duty Officers' operating procedures with specific guidelines on how the probabilistic forecasts should be used in practice in combination with other tools they currently use.
- Communicating with internal and external players (i.e. emergency responders, the public and professional partners) that probabilistic forecasting will become operational practice and clarifying the benefits of probabilistic over deterministic forecasting.
- Adapting the EA wider flood management priorities (e.g. warning lead times).

~~It is vital for these recommendations to be followed to ensure that state-of-the-art science is used to its fullest potential for risk management practice and is not being under- or misused.~~

Author contributions. H.L.C., L.An. and S.M. posed the original question. L.An., S.M., T.N. and L.W. brought L.Ar. up to speed about the EA and their decision-making practices. T.N. identified the interviewees. L.Ar., H.L.C., T.N. and E.S. designed the interviews. L.Ar. carried out the interviews and analysed the interview transcripts. L.Ar., J.N. and H.L.C. wrote the paper. H.L.C., S.M., J.N. and T.N. commented on the manuscript. T.N. and S.M. provided L.Ar. with EA documents and forecast product examples.

Competing interests. The authors declare that they have no conflict of interest.

Disclaimer. The information and findings in this paper are based on interviewees with six EA ~~duty officers~~Duty Officers. They should not be taken as representing the views or practice of the EA as a whole.

Acknowledgements. This work was funded by the EU Horizon 2020 IMPREX project (www.imprex.eu) (641811) and the joint Flood and Coastal Erosion Risk Management Research and Development Programme. We thank all the interviewees who dedicated some time to this work. We would also like to thank ~~thank~~ Stuart Hyslop at the EA for the background he provided in preparation for the interviews, and for his support in the organisation of the interviews. Lastly, we would like to acknowledge the invaluable help provided by Neil Ryan at the EA in sourcing the right materials for Appendix B.

References

Arnal, L., Ramos, M.-H., Coughlan de Perez, E., Cloke, H. L., Stephens, E., Wetterhall, F., van Andel, S. J., and Pappenberger, F.: Willingness-to-Pay for a Probabilistic Flood Forecast: A Risk-Based Decision-Making Game, Hydrol. Earth Syst. Sci., 20, 3109–28, https://doi.org/10.5194/hess-20-3109-2016, 2016.

Bischiniotis, K., van den Hurk, B., Coughlan de Perez, E., Veldkamp, T., Guimarães Nobre, G., and Aerts, J.: Assessing Time, Cost and Quality Trade-Offs in Forecast-Based Action for Floods, Int. J. Disast. Risk Re., 40, 101252, https://doi.org/10.1016/j.ijdrr.2019.101252, 2019.

Bruen, M., Krahe, P., Zappa, M., Olsson, J., Vehvilainen, B., Kok, K., and Daamen, K.: Visualizing Flood Forecasting Uncertainty: Some Current European EPS Platforms-COST731 Working Group 3, Atmos. Sci. Lett., 11, 92–99, https://doi.org/10.1002/asl.258, 2010.

Buizza, R.: The Value of Probabilistic Prediction, Atmos. Sci. Lett., 9, 36–42, https://doi.org/10.1002/asl.170, 2008.

Cloke, H. L., and Pappenberger, F.: Ensemble Flood Forecasting: A Review, J. Hydrol., 375, 613–26, https://doi.org/10.1016/j.jhydrol.2009.06.005, 2009.

Cloke, H. L., Thielen, J., Pappenberger, F., Nobert, S., Bálint, G., Edlund, C., Koistinen, A., de Saint-Aubin, C., Sprokkereef, E., Viel, C., Salamon, P., and Buizza, R.: Progress in the Implementation of Hydrological Ensemble Prediction Systems (HEPS) in Europe for Operational Flood Forecasting, ECMWF Newsletter No. 121, Autumn, Reading, UK, 20-24, 10.21957/bn6mx5nxfq, 2009.

Dale, M., Ji, Y., Wicks, J., Mylne, K., Pappenberger, F., and Cloke, H. L.: Applying Probabilistic Flood Forecasting in Flood Incident Management, Environment Agency Technical Report, Project No. SC090032, Bristol, UK, 97 pp., 2013.

Dale, M., and Wicks, J.: Decision-making with probabilistic flood forecasts, Illustrative guide for using decision-support methods, Project No. SC090032, Bristol, UK, 63 pp., 2013.

Dale, M., Wicks, J., Mylne, K., Pappenberger, F., Laeger, S., and Taylor, S.: Probabilistic Flood Forecasting and Decision-Making: An Innovative Risk-Based Approach, Nat. Hazards, 70, 159–72, https://doi.org/10.1007/s11069-012-0483-z, 20124.

Davies, A., Hoggart, K., and Lees, L.: Researching Human Geography, 1st edition, Routledge, London, 384 pp., 2014.

Demeritt, D., Nobert, S., Cloke, H. L., and Pappenberger, F.: The European Flood Alert System and the Communication, Perception, and Use of Ensemble Predictions for Operational Flood Risk Management, Hydrol. Process., 27, 147–57, https://doi.org/10.1002/hyp.9419, 2013.

Demeritt, D., Nobert, S., Cloke, H. L., and Pappenberger, F.: Challenges in Communicating and Using Ensembles in Operational Flood Forecasting, Meteorol. Appl., 17, 209–22, https://doi.org/10.1002/met.194, 2010.

Defra (Department for Environment Food and Rural Affairs): Flood and Water Management Act 2010, UK Public General Acts, 1–84, 2010.

Defra (Department for Environment Food and Rural Affairs): The National Flood Emergency Framework for England, 1-105, 2014

Dessai, S., and Hulme, M.: Climate Policy Does Climate Adaptation Policy Need Probabilities? Does Climate Adaptation Policy Need Probabilities?, Clim. Policy, 4, 107–28, https://doi.org/10.1080/14693062.2004.9685515, 2004.

Duan, Q., Pappenberger, F., Wood, A., Cloke, H. L., and Schaake, J.: Handbook of Hydrometeorological Ensemble Forecasting, Springer, Berlin, Heidelberg, 1521pp., https://doi.org/10.1007/978-3-642-39925-1, 2019.

EA (Environment Agency): Creating a Better Place - Our Ambition to 2020, 2018a.

EA (Environment Agency): Using forecast scenarios for flood incident planning, internal report, unpublished, 2018b.

Faulkner, H., Parker, D., Green, C., and Beven, K.: Developing a translational discourse to communicate uncertainty in flood risk between science and the practitioner, AMBIO: a Journal of the Human Environment, 36, 8, 692-704, https://doi.org/10.1579/0044-7447(2007)36[692:DATDTC]2.0.CO;2, 2007.

FFC (Flood Forecasting Centre): Flood Guidance Statement User Guide, 2017.

Flowerdew, J., Horsburgh, K., and Mylne, K.: Ensemble Forecasting of Storm Surges, Mar. Geod., 32, 91–99, https://doi.org/10.1080/01490410902869151, 2009.

Fundel, V. J., Fleischhut, N., Herzog, S. M., Göber, M., and Hagedorn, R.: Promoting the use of probabilistic weather forecasts through a dialogue between scientists, developers and end-users, Q. J. Roy. Meteor. Soc., 145, 210-231, https://doi.org/10.1002/qj.3482, 2019.

Funtowicz, S. O., and Ravetz, J. R.: Science for the Post-Normal Age, Futures, 25, 739–55, https://doi.org/10.1016/0016-

3287(93)90022-L, 1993.

Gold, I., and Connolly, S.: Forecasting coastal overtopping: What's the worst that can happen?, 3rd International Conference on Protection against Overtopping, 6-8 June, UK, 2018.

Golding, N., Hewitt, C., Zhang, P., Bett, P., Fang, X., Hu, H., and Nobert, S.: Improving User Engagement and Uptake of Climate Services in China, Climate Services, 5, 39–45, https://doi.org/10.1016/j.cliser.2017.03.004, 2017.

Handmer, J., and Proudley, B.: Communicating uncertainty via probabilities: The case of weather forecasts, Environmental Hazards, 7, 2, 79-87, https://doi.org/10.1016/j.envhaz.2007.05.002, 2007.

HM Government: National Flood Resilience Review, 2016.

House of Common - Environment Food and Rural Affairs Committee: Future Flood Prevention - Second Report of Session 2016-17, 2016.

Joslyn, S., and Savelli, S.: Communicating Forecast Uncertainty: Public Perception of Weather Forecast Uncertainty, Meteorol. Appl., 17, 180–95, https://doi.org/10.1002/met.190, 2010.

Joslyn, S., Savelli, S., and Nadav-Greenberg, L.: Reducing probabilistic weather forecasts to the worst-case scenario: Anchoring effects, J. Exp. Psychol.: Applied, 17, 4, 342–353, https://doi.org/10.1037/a0025901, 2011.

Lorenz, E. N.: The Predictability of a Flow Which Possesses Many Scales of Motion, Tellus, 21, 289–307, https://doi.org/10.3402/tellusa.v21i3.10086, 1969.McCarthy, S., Tunstall, S., Parker, D., Faulkner, H., and Howe, J.: Risk communication in emergency response to a simulated extreme flood, Environmental Hazards, 7, 3, 179-192, https://doi.org/10.1016/j.envhaz.2007.06.003, 2007.

McEwen, L. J., Krause, F., Jones, O., and Garde Hansen, J.: Sustainable Flood Memories, Informal Knowledge and the Development of Community Resilience to Future Flood Risk, WIT Trans. Ecol. Envir., 159, 253–64, https://doi.org/10.2495/FRIAR120211, 2012.

Michaels, S.: Probabilistic Forecasting and the Reshaping of Flood Risk Management, Journal of Natural Resources Policy Research, 7, 41–51, https://doi.org/10.1080/19390459.2014.970800, 2014.

Morss, R. E., Wilhelmi, O. V., Downton, M. W., and Gruntfest, E.: Flood Risk, Uncertainty, and Scientific Information for Decision Making: Lessons from an Interdisciplinary Project, B. Am. Meteorol. Soc., 86, 1593–1602, https://doi.org/10.1175/BAMS-86-11-1593, 2005.

Mu, D., Kaplan, T. R., and Dankers, R.: Decision making with risk-based weather warnings, Int. J. Disast. Risk Re., 30, 59-73, https://doi.org/10.1016/j.ijdrr.2018.03.030, 2018.

Mulder, K. J., Lickiss, M., Harvey, N., Black, A., Charlton-Perez, A., Dacre, H., and McCloy, R.: Visualizing Volcanic Ash Forecasts: Scientist and Stakeholder Decisions Using Different Graphical Representations and Conflicting Forecasts, Weather Clim. Soc., 9, 333–48, https://doi.org/10.1175/WCAS-D-16-0062.1, 2017.

Neumann, J. L., Arnal, L., Emerton, R. E., Griffith, H., Hyslop, S., Theofanidi, S., and Cloke, H. L.: Can seasonal hydrological forecasts inform local decisions and actions? A decision-making activity, Geosci. Commun., 1, 35-57, https://doi.org/10.5194/gc-1-35-2018, 2018.

New, M., Lopez, A., Dessai, S., and Wilby, R.: Challenges in Using Probabilistic Climate Change Information for Impact Assessments: An Example from the Water Sector, Philos. T. Roy. Soc. A, 365, 2117–31, https://doi.org/10.1098/rsta.2007.2080, 2007.

Neville, N.: Cognitive Illusions, Heuristics, and Climate Prediction, B. Am. Meteorol. Soc., 80, 1385–97, https://doi.org/10.1175/1520-0477(1999)080<1385:CIHACP>2.0.CO;2, 1999.

Nobert, S., Demeritt, D., and Cloke, H. L.: Informing Operational Flood Management with Ensemble Predictions: Lessons from Sweden, J. Flood Risk Manag., 3, 72–79, https://doi.org/10.1111/j.1753-318X.2009.01056.x, 2010.

Orr, P., and Twigger-Ross, C.: Communicating Risk and Uncertainty in Flood Warnings: A Review of Defra/Environment Agency FCERM Literature, Environment Agency Science Report, Project No. SC070060/SR2, Bristol, UK, 60 pp., 2009.

Pagano, T. C., Hartmann, H. C., and Sorooshian, S.: Seasonal Forecasts and Water Management in Arizona: A Case Study of the 1997–98 El Niño Event, 29th Annual Water Resources Planning and Management Conference, 21, 1–11, https://doi.org/10.1061/40430(1999)227, 2004.

Pappenberger, F., Stephens, E., Thielen, J., Salamon, P., Demeritt, D., van Andel, S. J., Wetterhall, F., and Alfieri, L.: Visualizing Probabilistic Flood Forecast Information: Expert Preferences and Perceptions of Best Practice in Uncertainty Communication, Hydrol. Process., 27, 132–46, https://doi.org/10.1002/hyp.9253, 2013.

~~Pappenberger, F., Cloke, H. L., Parker, D. J., Wetterhall, F., Richardson, D. S., and Thielen, J.: The Monetary Benefit of Early Flood Warnings in Europe, Environmental Science & Policy, 51, 278–91, https://doi.org/10.1016/j.envsci.2015.04.016, 2015.~~

Parker, D. J., Priest, S. J., and Tapsell, S. M.: Understanding and Enhancing the Public's Behavioural Response to Flood Warning Information, Meteorol. Appl., 114, 103–14, https://doi.org/10.1002/met.119, 2009.

Pidgeon, N., and Fischhoff, B.: The role of social and decision sciences in communicating uncertain climate risks, Nat. Clim. Change, 1, 1, 35-41, https://doi.org/10.1038/NCLIMATE1080, 2011.

Pielke, R. A. Jr.: Asking the Right Questions: Atmospheric Sciences Research and Societal Needs, B. Am. Meteorol. Soc., 78, 255–255, https://doi.org/10.1175/1520-0477(1997)078<0255:ATRQAS>2.0.CO;2, 1997.

Pilling, C., Dodds, V., Cranston, M., Price, D., Harrison, T., and How, A.: Chapter 9 - Flood Forecasting — A National Overview for Great Britain, Flood Forecasting - A Global Perspective, edited by: Adams, T. E., III, and Pagano, T. C., Academic Press, 201–47, https://doi.org/10.1016/B978-0-12-801884-2.00009-8, 2016.

Pitt, M.: Learning Lessons from the 2007 Floods, The Pitt Review, London: Cabinet Office, 1–205, 2008.

Ramos, M.-H., Mathevet, T., Thielen, J., and Pappenberger, F.: Communicating Uncertainty in Hydro-Meteorological Forecasts: Mission Impossible?, Meteorol. Appl., 17, 223–35, https://doi.org/10.1002/met.202, 2010.

Ramos, M.-H., Van Andel, S. J., and Pappenberger, F.: Do probabilistic forecasts lead to better decisions?, Hydrol. Earth Syst. Sci., 17, 2219-2232, https://doi.org/10.5194/hess-17-2219-2013, 2013.

Rowley, J.: Conducting research interviews, Management Research Review, 35, 3/4, 260-271, https://doi.org/10.1108/01409171211210154, 2012.

Schoenberger, E.: The Corporate Interview as a Research Method in Economic Geography, The Professional Geographer, 43, 180–89, https://doi.org/10.1111/j.0033-0124.1991.00180.x, 1991.

Sene, K., Huband, M., Chen, Y., and Darch, G.: Probabilistic Flood Forecasting Scoping Study, R&D Technical Report, Joint Defra/EA Flood and Coastal Erosion Risk Risk Management R&D Programme, Project No. FD2901/TR, London, UK, 216 pp., 2007.

Sene, K., Weerts, A., Beven, K., Moore, R. J., Whitlow, C., and Young P.: Risk-Based Probabilistic Fluvial Flood Forecasting for Integrated Catchment Models - Phase 1 Report, Environment Agency Science Report, Project No. SC080030/SR1, Bristol, UK, 179 pp., 2009.

Sene, K., Weerts, A., Beven, K., Moore, R. J., and Whitlow, C.: Risk-based Probabilistic Fluvial Flood Forecasting for Integrated Catchment Models - Phase 3 Implementation Plan, Environment Agency Science Report, Project No. SR SC080030, Bristol, UK, 35pp., unpublished, 2010.

Sivle, A. D., Kolstø, S. D., Hansen, P. J. K., and Kristiansen, J.: How Do Laypeople Evaluate the Degree of Certainty in a Weather Report? A Case Study of the Use of the Web Service Yr.No., Weather Clim. Soc., 6, 399–412, https://doi.org/10.1175/WCAS-D-12-00054.1, 2014.

Smith, K. A., Wilby, R. L., Broderick, C., Prudhomme, C., Matthews, T., Harrigan, S., and Murphy, C.: Navigating Cascades of Uncertainty — As Easy as ABC? Not Quite…., Journal of Extreme Events, 5, 1850007, https://doi.org/10.1142/S2345737618500070, 2018.

Stephens, E., and Cloke, H. L.: Improving Flood Forecasts for Better Flood Preparedness in the UK (and Beyond), Geogr. J., 180, 310–16, https://doi.org/10.1111/geoj.12103, 2014.

Stephens, E. M., Edwards, T. L., and Demeritt, D.: Communicating Probabilistic Information from Climate Model Ensembles-Lessons from Numerical Weather Prediction, WIREs Clim. Change, 3, 409–26, https://doi.org/10.1002/wcc.187, 2012.

Thielen, J., Bartholmes, J., Ramos, M.-H., and de Roo, A.: The European Flood Alert System – Part 1: Concept and development, Hydrol. Earth Syst. Sci., 13, 125-140, https://doi.org/10.5194/hess-13-125-2009, 2009.

Thielen, J., Bartholmes, J., and Ramos, M.-H.: The Benefit of Probabilistic Flood Forecasting on European Scale – Results of the European Flood Alert System for 2005/2006, European Commission, Ispra, Italy, 99 pp., 2006.

Verkade, J. S. and Werner, M. G. F.: Estimating the benefits of single value and probability forecasting for flood warning, Hydrol. Earth Syst. Sci., 15, 3751-3765, https://doi.org/10.5194/hess-15-3751-2011, 2011.

Werner, M., Cranston, M., Harrison, T., Whitfield, D., and Schellekens, J.: Recent Developments in Operational Flood Forecasting in England, Wales and Scotland, Meteorol. Appl., 16, 13–22, https://doi.org/10.1002/met.124, 2009.

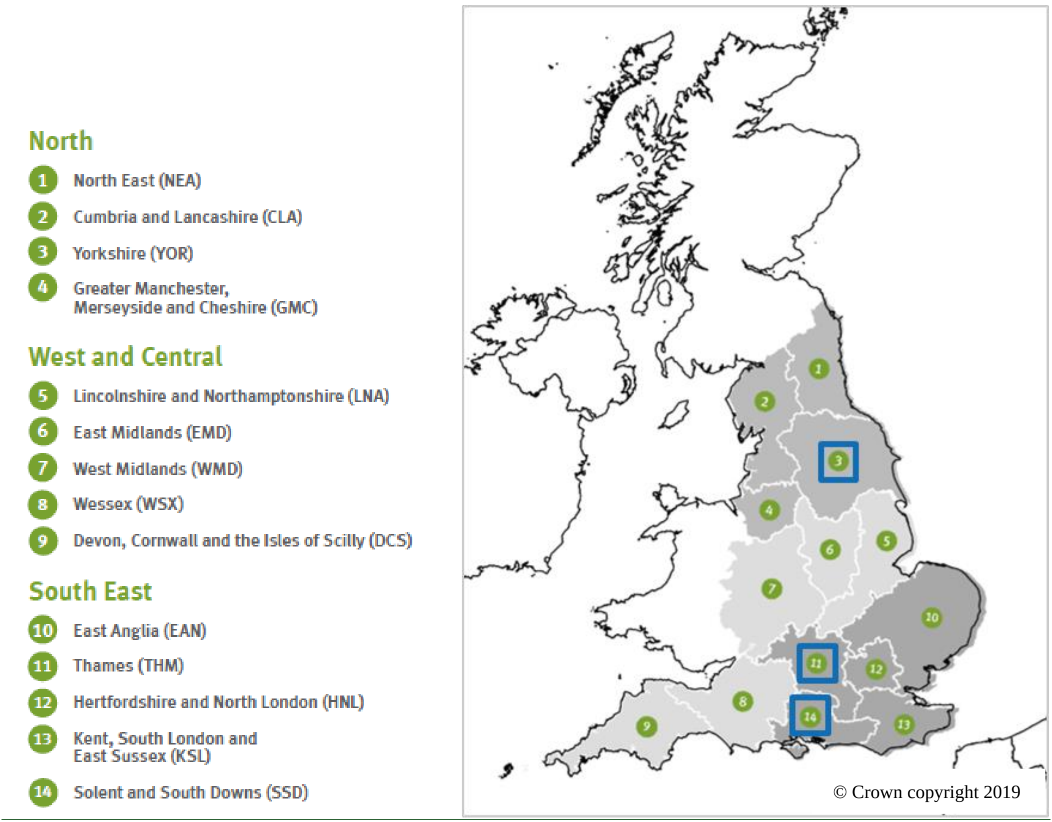
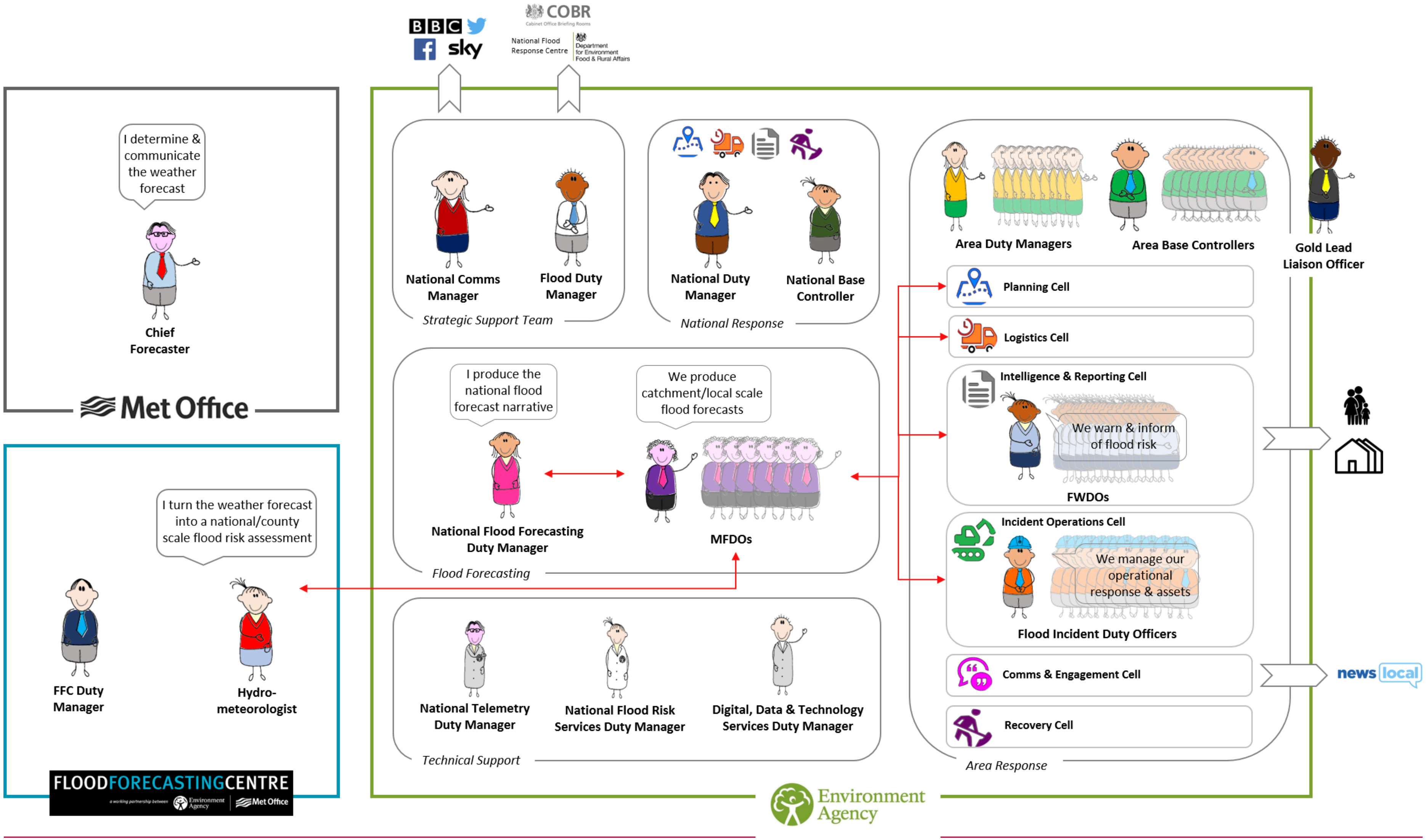


Figure 12: Map showing the geographical areas of the EA's operations (green numbered areas), highlighting the three areas which the centres where interviews were carried out are responsible for (blue boxes) (source: EA). The works published in this journal are distributed under the Creative Commons Attribution 4.0 License. This licence does not affect the Crown copyright work, which is re-usable under the Open Government Licence (OGL). The Creative Commons Attribution 4.0 License and the OGL are interoperable and do not conflict with, reduce or limit each other.



BBC
sky
COBR
National Flood Response Centre
Department for Environment Food & Rural Affairs
I determine & communicate the weather forecast
Chief Forecaster
Met Office
I turn the weather forecast into a national/county scale flood risk assessment
FFC Duty Manager
Hydro-meteorologist
FLOODFORECASTINGCENTRE
National Comms Manager
Flood Duty Manager
Strategic Support Team
National Duty Manager
National Base Controller
National Response
I produce the national flood forecast narrative
We produce catchment/local scale flood forecasts
National Flood Forecasting Duty Manager
MFDOs
Flood Forecasting
National Telemetry Duty Manager
National Flood Risk Services Duty Manager
Digital, Data & Technology Services Duty Manager
Technical Support
Area Duty Managers
Area Base Controllers
Gold Lead Liaison Officer
Planning Cell
Logistics Cell
Intelligence & Reporting Cell
We warn & inform of flood risk
FWDOs
Incident Operations Cell
We manage our operational response & assets
Flood Incident Duty Officers
Comms & Engagement Cell
Recovery Cell
Area Response
news local
Environment Agency

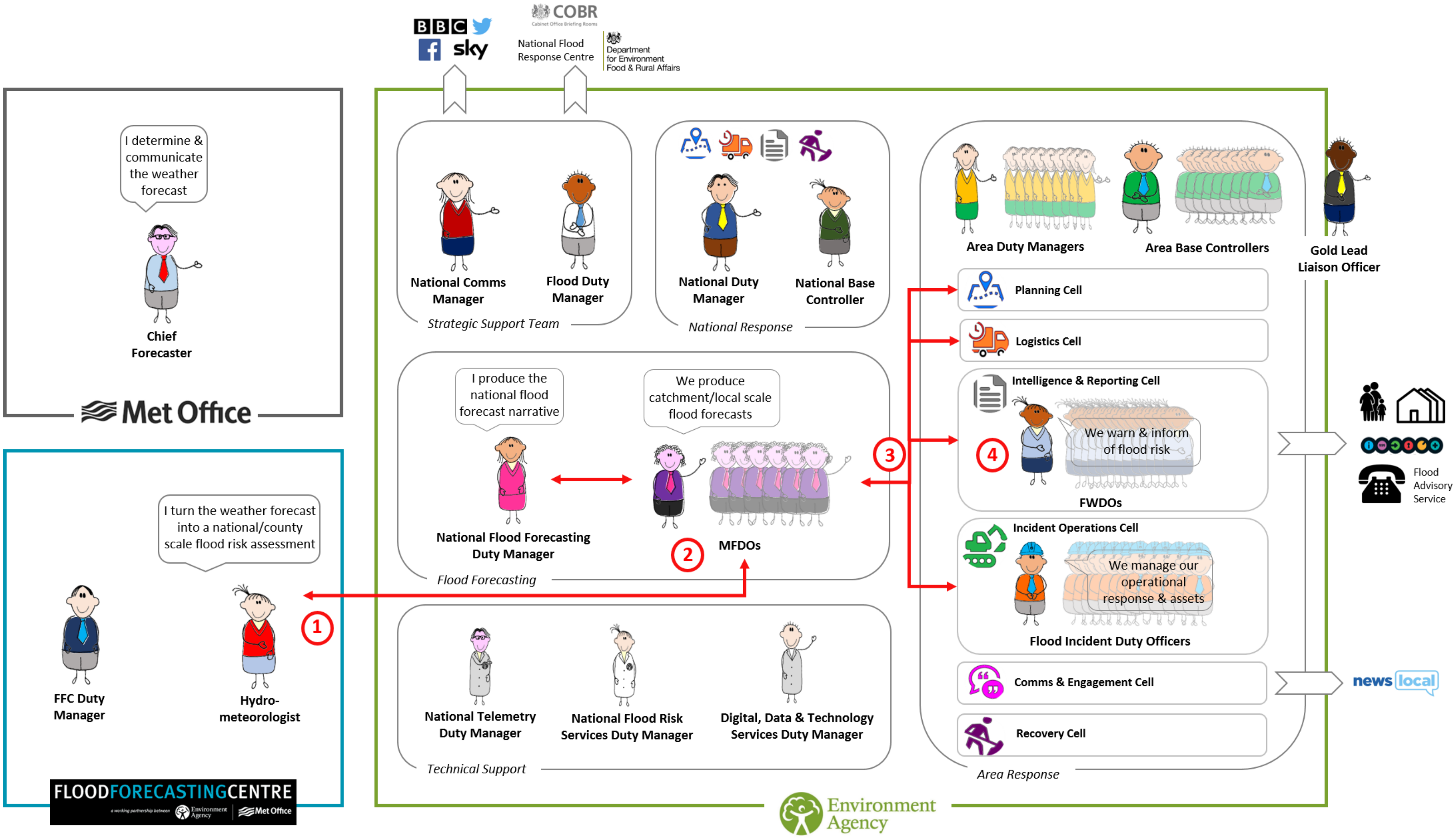


Figure 21: Schematic of the EA's institutional landscape and the flood incident managementFIM information flow between MFDOs, FWDOs and first-degree contact points (red arrows) (source: EA). The numbers highlight the structure of Sect. 3.2

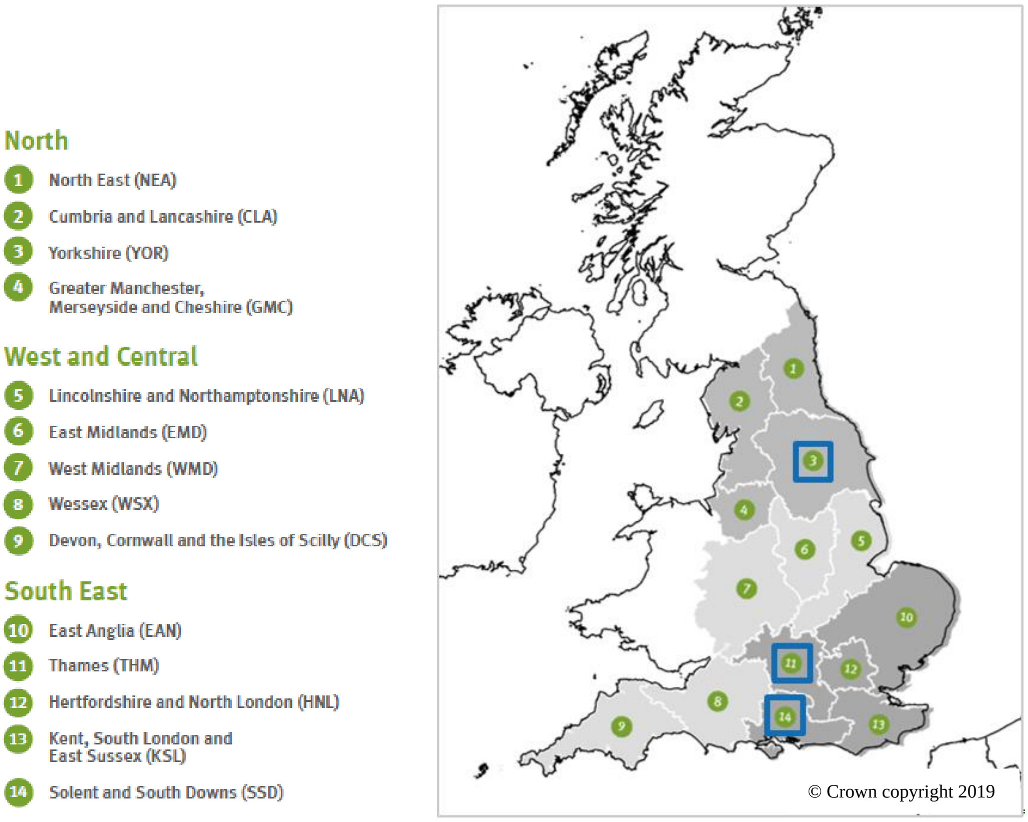


Figure 2: Map showing the geographical areas of the EA's operations (green numbered areas), highlighting the three areas which the centres where interviews were carried out are responsible for (blue boxes) (source: EA). The works published in this journal are distributed under the Creative Commons Attribution 4.0 License. This licence does not affect the Crown copyright work, which is re-usable under the Open Government Licence (OGL). The Creative Commons Attribution 4.0 License and the OGL are interoperable and do not conflict with, reduce or limit each other.

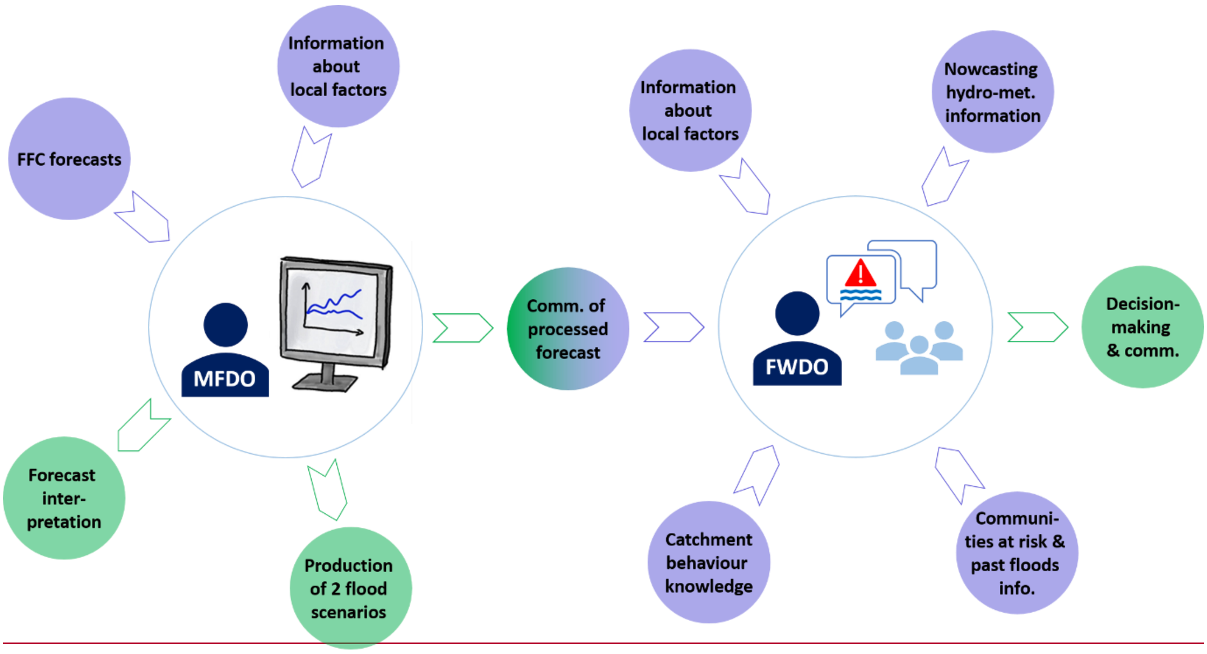


Figure 3: Roles and interactions between EA duty officers. Blue arrows and circles are for incoming information and green arrows and circles relate to outputs from either of the duty officers.

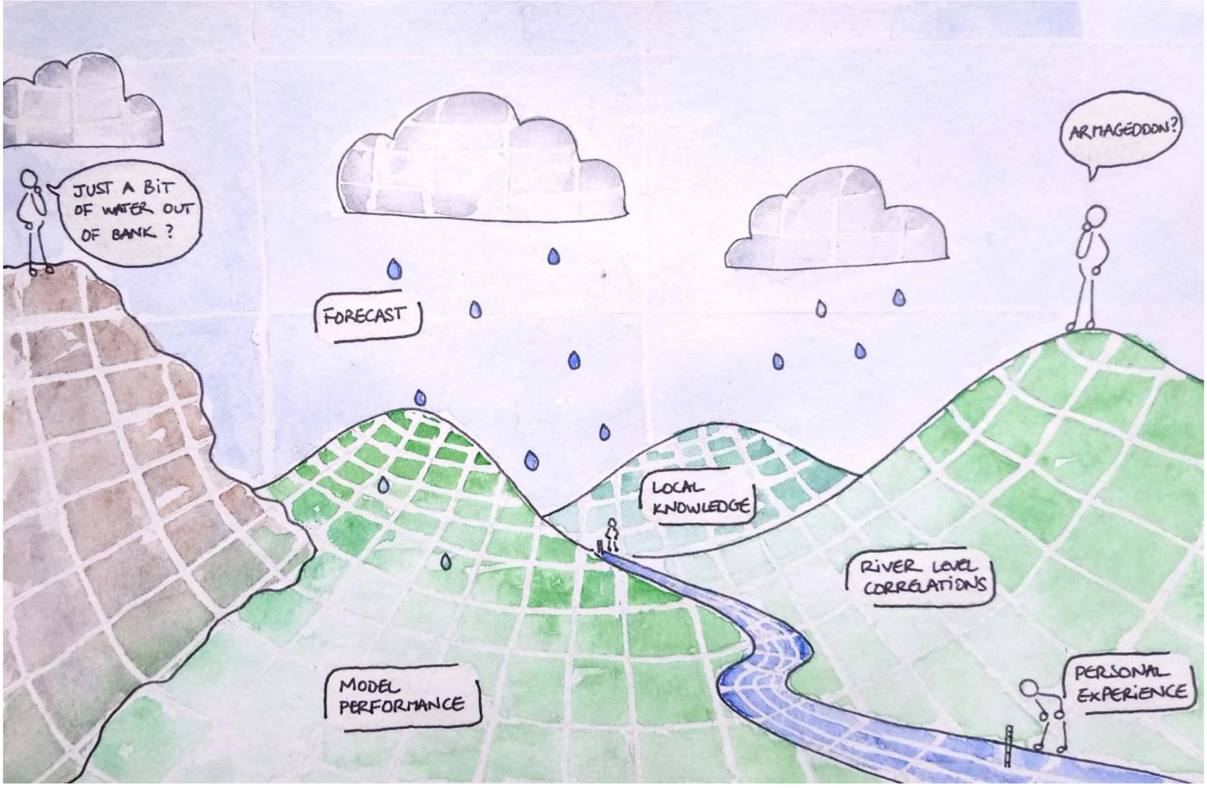


Figure 4:3 Complex flood forecast interpretationdecision-making landscape in which EA duty officersDuty Officers operate.

~~**Figure 5: Wordclouds of perceived opportunities (left) and challenges (right), based on the interview transcripts.**~~

Table 1: Interviewees' perceived opportunities, challenges and neutral changes associated with a transition to probabilistic forecasts. Perspectives are split into six main topics (rows). Supporting quotes can be found in Appendix C.

Language and communication	Most interviewees agreed that this will probably be the biggest change. Some said they thought it might improve long-term communication and increase the MFDOs' credibility and confidence (quote O1) This was also found by Thielen et al. (2006). Others believe that there is a potential for misunderstanding and that a lot more work is still needed on this topic (quotes C1 and C2).
Uncertainty	Probabilistic forecasts contain uncertainty which they openly display. Some interviewees thought that this would materialise the forecast uncertainty, otherwise sometimes hidden with the two scenarios (quote O2). This is in line with the EA's 2009 science report (Sene et al., 2009). Many interviewees however questioned whether probabilistic forecasts would really help tackle the uncertainty they deal with while on duty (quotes N1 and C3).
The forecasting system	Some interviewees mentioned that the two scenarios, and the What If scenarios used to produce them, were sometimes challenging to play with and required a lot of expert judgment, thus making them inconsistent nation-wide. There were hints that a few MFDOs thought probabilistic forecasts might lead to more consistency across the EA centres (quote O3). It was however clear from the interviews that things will need to change slowly to give duty officers time to build confidence in the new system (quote C4).
Decision-making	A few interviewees mentioned the fact that probabilistic forecasts will not solve the fundamental need of decision-making to be binary and saw this as a challenge (quotes C5 and C6). Others saw this as an opportunity for early warning and long-term planning (quotes O4 and O5)
Duty officers' roles	This transition was seen neither as an opportunity nor as a challenge by and for the MFDOs. They simply stated how things might change for them (quotes N2 and N3). A few of the FWDOs however thought that this might push more of the interpretation on to them (quotes C7 and C8). It is worth noting is that none of the interviewees mentioned worries concerning potential impacts of this future transition on the communication and interaction between duty officers. The worries seem to mostly lie outside of their interaction (quote O6).
New staff training	An interviewee mentioned that probabilistic forecasts could help with new staff training, by increasing their understanding of catchment response (quote O7).

Appendix A. Glossary of terms.

Best Estimate	A forecaster's assessment of the most likely rainfall, river and groundwater levels, and coastal conditions, and their impacts.
Catchment characteristics and response	Catchment characteristics are the features that describe a river basin (i.e. the area of land drained by a river), such as its location, size, vegetation cover, soil type and topography. They partially define the catchment response, the catchment's reaction when subjected to a rainfall event (e.g. how fast the water level increases after a rainfall event).
~~**Chaos**~~	~~The property of a complex system, like the weather, whose behaviour is so unpredictable that it appears random. This is due to the system's sensitivity to small changes in conditions.~~
Confident	A forecaster's expert judgement of how certain they are that the forecast is right, combining various sources of information (e.g. model performance information). Please note that in the literature, the term "confident" may also refer to the uncertainty range of a prediction, where a "confident" forecast is an ensemble forecast with a small uncertainty range.
Convective rainfall events	The sun heats the ground, warming up the air above it. This causes the air to rise. As the air rises it cools and condenses, forming water droplets that organise into clouds and lead to rainfall. Convective rainfall events can lead to thunderstorms.
Decision-makers	Persons whose professional role requires them to make important actionable decisions based on one or multiple sources of information.
Department for Environment, Food and Rural Affairs (Defra)	UK government department responsible for safeguarding the UK's natural environment and supported by 33 agencies and public bodies, including the Environment Agency (EA). www.gov.uk/government/organisations/department-for-environment-food-rural-affairs
Deterministic forecasts	Refers to a forecast which gives a single possible outcome of the future rainfall, river and groundwater levels and coastal conditions.
Ensemble	Instead of running a single deterministic forecast, computer models can run a forecast several times, using slightly different inputs to account for uncertainties in the forecasting process. The complete set of forecasts is called an 'ensemble', and each individual forecast within it are 'ensemble members'. Each ensemble member represents a different possible

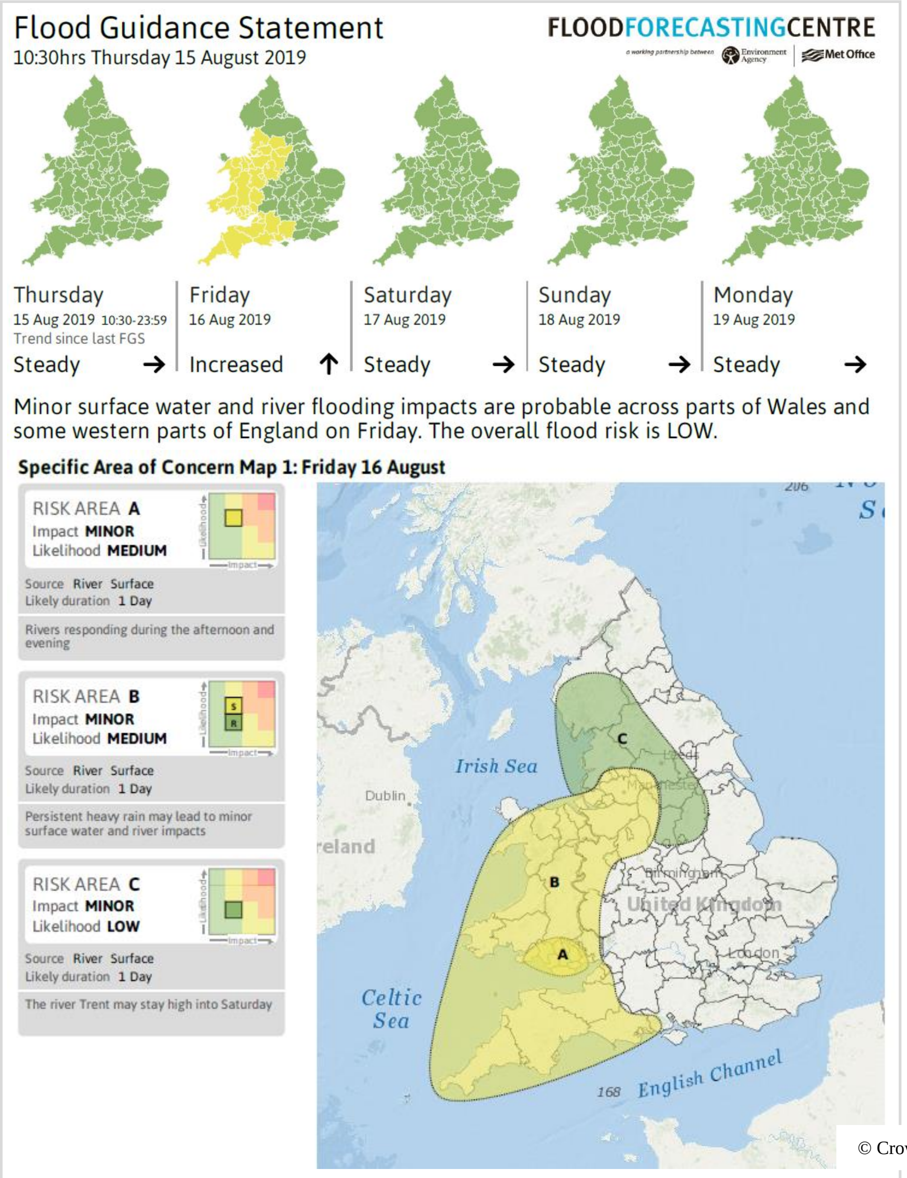
	scenario of future rainfall, river and groundwater levels and coastal conditions. Each scenario is equally likely to occur.
Environment Agency (EA)	An executive non-departmental public body sponsored by Defra. The EA has an operational responsibility to manage risks of flooding from rivers and the sea in England, by warning and informing the public and businesses about impending floods. www.gov.uk/government/organisations/environment-agency
False alarms	A warning given ahead of an event (e.g. flood) that does not ultimately occur.
Flood action groups	Cores of local people who act as representative voices for their wider community. They work alongside agencies and authorities and meet on a regular basis with the aim of reducing their community's flood risk and improving its resilience to flooding.
Flood Forecasting Centre (FFC)	A partnership between the Environment Agency and the UK Met Office. It provides a UK-wide 24/7 hydro-meteorological service to emergency responders to better prepare for flooding (river, surface water, tidal/coastal and groundwater). www.ffc-environment-agency.metoffice.gov.uk
Flood Guidance Statement (FGS)	A daily flood risk forecast for the UK, produced by the FFC (in collaboration with the EA and Natural Resources Wales) to assist with strategic, tactical and operational planning decisions. It gives a flood risk assessment shown by county and unitary authority across England and Wales over the next five days for all types of natural flooding (coastal/tidal, river, groundwater and surface water). The FGS is issued by the FFC every day at 10:30am and at other times, day or night, if the flood risk assessment changes. www.ffc-environment-agency.metoffice.gov.uk/services/FGS_User_Guide.pdf
Flood incident management strategy	An institute's priorities for preparing for and responding to flood events.
Flood management measures	Solutions to reduce the impacts that floods pose to humans and the environment. They can be natural (e.g. planting vegetation to retain extra water in the ground) or engineered (e.g. flood barriers).
Flood preparedness	Measures taken to prepare for and reduce the effects of a flood event.
Flood scenarios	Possible future development of a flood event and its associated likelihood.
Flood wardens	Volunteers from local communities who have the responsibility to monitor watercourses in the area they cover and contact local authorities with up to date information.
Forcing	The action of inputting information into a computer model to produce a forecast.
Forecast accuracy	The level of agreement between the forecast and the truth (i.e. what is observed in reality).
Forecasting product	A comprehensive and tailored overview (i.e. in the form of text, graphics and/or tables, etc.) of the forecast.
Hydraulic models	Mathematical models of the movement of water in a system (e.g. a river).
Hydrological model	Simplified model of a real-world system that describes the water cycle.
Hydro-meteorological observations and forecasts	Hydro-meteorology is a branch of meteorology and hydrology that studies the transfer of water and energy between the land surface and the lower atmosphere. Hydro-meteorological observations include observations of meteorological (e.g. temperature and rainfall) and hydrological variables (e.g. river and groundwater levels). Hydro-meteorological forecasts are forecasts that predict the evolution of meteorological and hydrological variables in time.

Hydro-Meteorological Services	Hydro-meteorological forecasting* products* produced by the FFC and issued daily (Hydro-Meteorological Guidance), twice daily (Forecast Meteorological Data) or whenever required (Heavy Rainfall Alerts).
Lead time	The length of time between when the forecast is made and the occurrence of the event (e.g. flood) being predicted.
Long-range forecasts	Forecasts which cover a period of time from a month to more than a season.
Missed ~~flood~~ events	An event, for example a flood, for which no warning was given ahead of it happening.
Model performance	The level of agreement between the model's outputs and their observations in reality. The difference between a model output and its respective observation is the error. The lower the error, the greater the model performance.
Nowcasting	Extrapolating from the latest observations (e.g. radar rainfall) to forecast the evolution of, for example the weather, in the next couple of hours.
Operational decision-making	Decision-making based on real-time information to resolve imminent situations.
Outlooks	Refers to ~~a~~ forecasting products* based on long-range forecasts* (i.e. monthly to seasonal).
Performance measures	Metrics that characterise the quality of a forecast or a model compared to observations.
Probabilistic forecasts	While a deterministic model gives a single possible outcome for an event, a probabilistic model gives a probability distribution as a solution, indicating the likelihood of each scenario to occur. By design, probabilistic forecasts display the uncertainty in our estimates of future water levels, for example. ~~Probabilistic and ensemble forecasts are sometimes used interchangeably (~~S~~s~~ee 'Ensemble' for information on how these forecasts can be produced~~)~~.
Rapid-response catchments	Catchments and rivers that respond quickly to rainfall events.
~~**Real-time river gauges**~~	~~Instruments that measure a river's characteristics (e.g. flow or water level) and communicate these data in real-time remotely.~~
Reasonable Worst Case	A forecaster's assessment of the potential upper range of rainfall, river and groundwater levels, and coastal conditions, and their impacts.
Risk	A combination of likelihood and impact of an event.
River level correlations	Mathematical characterisation of the river level at one point of the river with respect to another point on the river. This can be used to estimate the river level at a point on the river if the river level upstream is known.
~~**Short-range forecasts**~~	~~Forecasts which cover a period of time from a couple of a hours to a couple of weeks.~~
~~**Surface water flooding**~~	~~Flooding caused when the volume of rainwater falling does not drain away through the river network and other drainage systems, or infiltrate into the ground, but lies on or flows over the ground.~~
Surge forecasts	Forecasts of the rise of water along coastlines.
~~**Telemetry sites**~~	~~Sites where instruments collect measurements automatically and transmit it remotely (see 'Real-time river gauges')~~
Uncertainty	Having limited knowledge or understanding of our environment, it is impossible to characterise and predict its evolution with 100% certainty. ~~All forecasts are uncertain, and that uncertainty amplifies with lead time*.~~ Ensemble* or probabilistic forecasting* can be

	used to represent the forecast uncertainty in our estimates of future water levels, among others.

Appendix B. Visual examples of operational products used by EA MFDOs and FWDOs: (a) Flood Guidance Statement, (b) Hydro-Meteorological Guidance, (c) Forecast Meteorological Data, (d) Heavy Rainfall Alert, and (e) National Flood Forecasting System (source: EA). The works published in this journal are distributed under the Creative Commons Attribution 4.0 License. This licence does not affect the Crown copyright work, which is re-usable under the Open Government Licence (OGL). The Creative Commons Attribution 4.0 License and the OGL are interoperable and do not conflict with, reduce or limit each other.

(a)



Flood Guidance Statement
10:30hrs Thursday 15 August 2019
FLOODFORECASTINGCENTRE
Environment Agency
Met Office
Thursday
15 Aug 2019 10:30-23:59
Trend since last FGS
Steady
Friday
16 Aug 2019
Increased
Saturday
17 Aug 2019
Steady
Sunday
18 Aug 2019
Steady
Monday
19 Aug 2019
Steady
Minor surface water and river flooding impacts are probable across parts of Wales and some western parts of England on Friday. The overall flood risk is LOW.
Specific Area of Concern Map 1: Friday 16 August
RISK AREA A
Impact MINOR
Likelihood MEDIUM
Source River Surface
Likely duration 1 Day
Rivers responding during the afternoon and evening
RISK AREA B
Impact MINOR
Likelihood MEDIUM
Source River Surface
Likely duration 1 Day
Persistent heavy rain may lead to minor surface water and river impacts
RISK AREA C
Impact MINOR
Likelihood LOW
Source River Surface
Likely duration 1 Day
The river Trent may stay high into Saturday
Irish Sea
Dublin
Celtic Sea
English Channel
A
B
C

(b)

Daily Hazard Assessment

Issued 14:02 on Wednesday, 14 August 2019

The Daily Hazard Assessment is intended to provide an 'at a glance' top level overview only. The links provided to the relevant Partner Organisations should then be used to obtain further

Hazards Five Day Summary – FLOOD: YELLOW, THUNDERSTORM: YELLOW

FLOOD: Significant surface water and river flooding impacts are possible but not expected across central England on Wednesday and into Thursday morning. The overall flood risk is LOW.

THUNDERSTORM: Heavy showers and thunderstorms may cause flooding and transport disruption for parts of central and eastern England on Wednesday afternoon.

Hazards Five Day Summary Maps

Wednesday 14-Aug 1400 – 2359	Thursday 15-Aug 0000 – 2359	Friday 16-Aug 0000 – 2359	Saturday 17-Aug 0000 – 2359	Sunday 18-Aug 0000 - 2359

(c)

Forecast Meteorological Data
EA South East Region

FLOODFORECASTINGCENTRE

a working partnership between Environment Agency | Met Office

Issued by the Flood Forecasting Centre on 15/08/19 at 05:11 GMT (06:11 local time)
Unique Reference No. 5766 Version 1 Morning Issue

Precipitation Forecast Days 1 and 2

		Thursday 15/08/19					Friday 16/08/19			
		00-06 (GMT)	06-12	12-18	18-24	Day 1 Total (06-24)	00-06	06-12	12-24	Day 2 Total (00-24)
WT(N)	Ave (mm)		0	0	0	0	0	1	18	19
	Max (mm)		1	0	0	1	0	2	22	23
WT(S)	Ave (mm)		0	0	0	0	0	0	13	13
	Max (mm)		1	0	0	1	0	2	23	24
NET	Ave (mm)		0	0	0	0	0	1	11	12
	Max (mm)		1	0	0	1	0	2	16	16
HIOW	Ave (mm)		0	0	0	0	0	0	17	17
	Max (mm)		0	0	0	0	0	1	24	25
Sussex	Ave (mm)		0	0	0	0	0	0	11	11
	Max (mm)		1	0	0	1	0	1	18	18
KSL	Ave (mm)		0	0	0	0	0	0	8	8
	Max (mm)		1	0	0	1	0	1	12	12

WT(N)	West Thames (North)	WT(S)	West Thames (South)
NET	North East Thames	HIOW	Hampshire & IOW
KSL	Kent and South London		

Notes: All precipitation values are given as rainfall equivalents
Ave: Best estimate of mean rainfall depth over the Area during the period.
Max: Best estimate of maximum rainfall depth at any one location in this time period, this is not an extreme value.
Model Output: A number in brackets shows the original model output value. The number below this, is the FFC's Hydrometeorologists modification.

Daily Summary Days 1 – 5

		Thursday 15/08/19	Friday 16/08/19	Saturday 17/08/19	Sunday 18/08/19	Monday 19/08/19
Precipitation	Ave(mm)	See table above		1	1	0
	Max(mm)			3	4	2

		Thursday 15/08/19	Friday 16/08/19	Saturday 17/08/19	Sunday 18/08/19	Monday 19/08/19
Temperature	Min(degC)	10	8	12	11	11
	Max(degC)	22	20	23		

(d)

Heavy Rainfall Alert
EA South East Region (Summer)

FLOODFORECASTINGCENTRE
a working partnership between Environment Agency | Met Office

Issued by the Flood Forecasting Centre on 19/07/19 at 16:51 GMT (17:51 local time)
Unique Alert Reference No. 2817_SOUTHEAST_795 Version 1

ORIGINAL

Start of meteorological event: 0800 GMT on 20/07/19

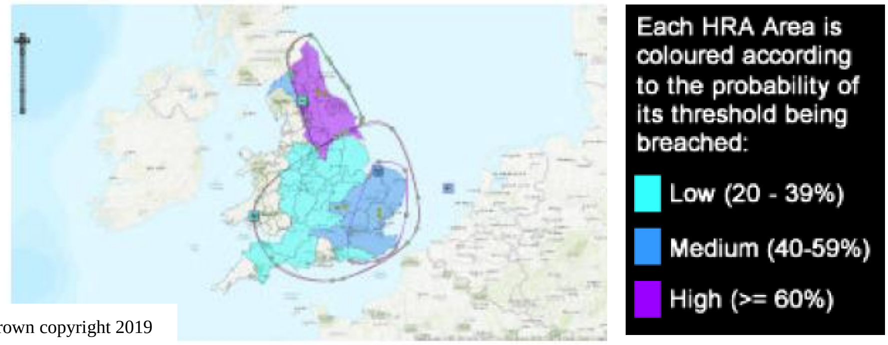
End of meteorological event: 2100 GMT on 20/07/19

Summary of Alert Criteria Met

Alert Criteria	HRA Areas covered	Confidence
10 mm (or more) in 1 hours (or less)	West Thames (North)	L
	West Thames (South), North East Thames, Kent and South London	M
30 mm (or more) in 6 hours (or less)	Sussex, Kent and South London	L
30 mm (or more) in 12 hours (or less)	West Thames (South), North East Thames	L

Notes:

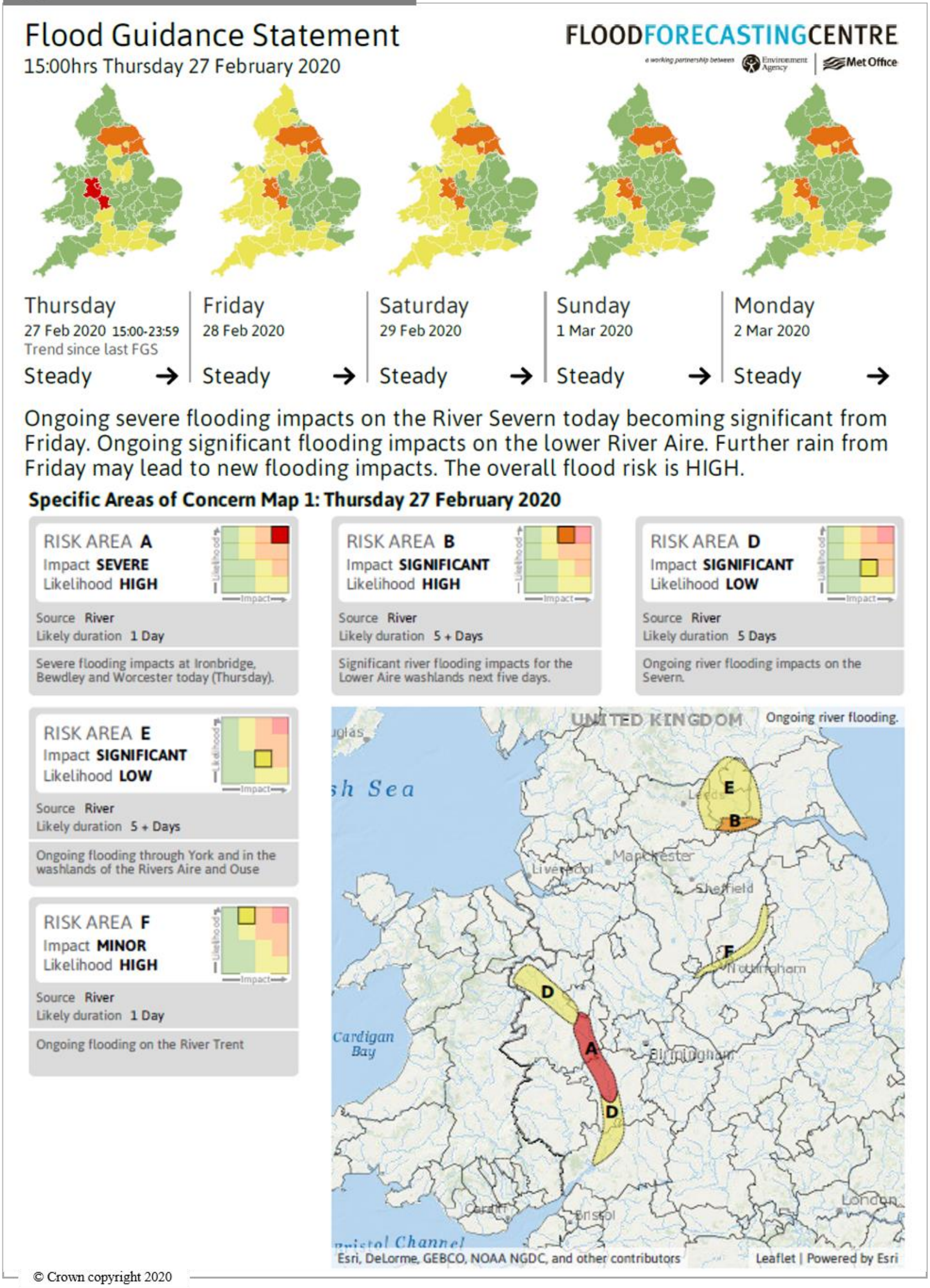
- ***Confidence:*** *The probability of this threshold being achieved anywhere in the specific HRA Area within the time periods outlined by the Heavy Rainfall Alert. H = more than 60%; M = 40 – 60%; and L = 20 – 40%*
- *Issue of a Heavy Rainfall Alert means the probability of rainfall thresholds being met or exceeded during the meteorological event is within the bands indicated by the confidence levels above.*
- *All Alert criteria should be defined in this table. If it is predicted that some criteria will not be exceeded, these boxes should be greyed out*



© Crown copyright 2019

Appendix B. Visual examples of current operational forecast products and fluvial flood forecast messages and products used and produced by EA MFDOs and FWDOs for various dates in the past: (a) Flood Guidance Statement, (b) Hydro-meteorological Guidance, (c) Forecast Meteorological Data, (d) Rainfall Scenario Map, (e) and (f) Heavy Rainfall Alert, (g) 'Best Estimate' and 'Reasonable Worst Case' rainfall and water level scenarios on the NFFS, (h) written description of the two forecast scenarios from an MFDO, (i) EA flood alerts and warnings to the public, and (j) fluvial flood alert message to the public. Sources: Fig. (a)-(h) were obtained from the EA, and Fig (i) and (j) were obtained from Twitter and the EA active warnings website: https://flood-warning-information.service.gov.uk/warnings, respectively. Note that these examples are not for the same dates as these were not available. The works published in this journal are distributed under the Creative Commons Attribution 4.0 License. This licence does not affect the Crown copyright work, which is re-usable under the Open Government Licence (OGL). The Creative Commons Attribution 4.0 License and the OGL are interoperable and do not conflict with, reduce or limit each other.

(a) Flood Guidance Statement



Flood Guidance Statement

15:00hrs Thursday 27 February 2020

FLOODFORECASTINGCENTRE

a working partnership between Environment Agency | Met Office

Thursday	Friday	Saturday	Sunday	Monday
27 Feb 2020 15:00-23:59	28 Feb 2020	29 Feb 2020	1 Mar 2020	2 Mar 2020
Trend since last FGS				
Steady →	Steady →	Steady →	Steady →	Steady →

Ongoing severe flooding impacts on the River Severn today becoming significant from Friday. Ongoing significant flooding impacts on the lower River Aire. Further rain from Friday may lead to new flooding impacts. The overall flood risk is HIGH.

Specific Areas of Concern Map 1: Thursday 27 February 2020

RISK AREA **A**
Impact **SEVERE**
Likelihood **HIGH**
Source **River**
Likely duration **1 Day**
Severe flooding impacts at Ironbridge, Bewdley and Worcester today (Thursday).

RISK AREA **B**
Impact **SIGNIFICANT**
Likelihood **HIGH**
Source **River**
Likely duration **5 + Days**
Significant river flooding impacts for the Lower Aire washlands next five days.

RISK AREA **D**
Impact **SIGNIFICANT**
Likelihood **LOW**
Source **River**
Likely duration **5 Days**
Ongoing river flooding impacts on the Severn.

RISK AREA **E**
Impact **SIGNIFICANT**
Likelihood **LOW**
Source **River**
Likely duration **5 + Days**
Ongoing flooding through York and in the washlands of the Rivers Aire and Ouse

RISK AREA **F**
Impact **MINOR**
Likelihood **HIGH**
Source **River**
Likely duration **1 Day**
Ongoing flooding on the River Trent

(b) Hydro-meteorological Guidance

Key Hide Maps

England & Wales | Local | MAE

PDF Issued: 6:34 BST on 30 March 2020

Headline

No increased flood risk expected over the next five days.

Days 1 to 5

Scattered showers move quickly across from North Sea coasts today in a strong north-easterly wind, these wintry over high ground. Showers tending to ease overnight to give a mainly dry day on Tuesday. Wednesday to Friday will then see some patchy light rain and drizzle in parts of the west and north of England and Wales, becoming increasingly wintry over high ground into Friday.

(c) Forecast Meteorological Data

Forecast Meteorological Data
EA North East Region

FLOODFORECASTINGCENTRE
a working partnership between Environment Agency | Met Office

Issued by the Flood Forecasting Centre on 07/11/19 at 07:44 GMT (07:44 local time)
Unique Reference No. 5918 Version 1 Morning Issue

Precipitation Forecast Days 1 and 2

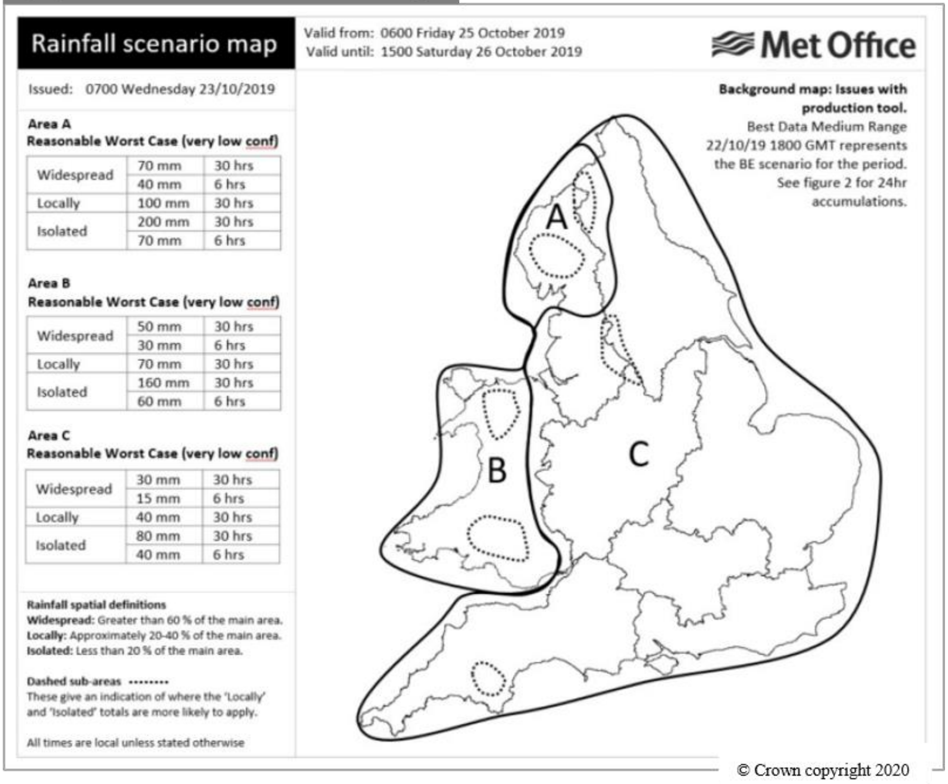
		Thursday 07/11/19					Friday 08/11/19			
		00-06 (GMT)	06-12	12-18	18-24	Day 1 Total (06-24)	00-06	06-12	12-24	Day 2 Total (00-24)
CVHT	Ave (mm)		4	(1) 2	2	(7) 8	(0) 1	2	0	(2) 3
	Max (mm)		(6) 7	(3) 4	(3) 6	(10) 13	(2) 3	(4) 5	1	(5) 7
WPN	Ave (mm)		(13) 8	(12) 8	(6) 3	(31) 19	1	(1) 2	1	(3) 4
	Max (mm)		(19) 18	(24) 20	(16) 8	(59) 45	2	(4) 5	3	(7) 8
CNPN	Ave (mm)		(13) 11	(7) 5	(5) 3	(25) 19	1	(2) 3	(2) 1	5
	Max (mm)		(21) 20	(21) 17	(16) 10	(57) 47	3	(5) 7	(5) 3	9
SPN	Ave (mm)		(18) 10	(17) 15	(12) 10	(47) 35	(6) 5	0	(0) 2	(6) 7
	Max (mm)		(23) 17	(26) 25	(22) 20	(67) 55	(11) 10	1	(1) 5	12
NEC	Ave (mm)		(4) 3	(1) 0	(1) 0	(6) 3	(1) 2	(2) 3	1	(4) 6
	Max (mm)		6	2	2	(9) 8	(3) 4	(5) 6	(4) 2	(8) 9
MOOR	Ave (mm)		(6) 3	(8) 5	(12) 9	(26) 17	(4) 3	(3) 4	(1) 3	(8) 10
	Max (mm)		(9) 5	(15) 10	(20) 16	(41) 29	(10) 7	7	(3) 7	(17) 19
	Ave (mm)		(9) 7	(15) 10	(14) 10	(38) 27	(6) 5	(3) 1	(1) 2	(10) 8

Daily Summary Days 1 – 5

		Thursday 07/11/19	Friday 08/11/19	Saturday 09/11/19	Sunday 10/11/19	Monday 11/11/19
Precipitation	Ave(mm)	See table above		(4) 6	(3) 2	(6) 2
	Max(mm)			(7) 10	(10) 5	(13) 5

		Thursday 07/11/19	Friday 08/11/19	Saturday 09/11/19	Sunday 10/11/19	Monday 11/11/19
Temperature	Min(degC)	0	-4	(-5) -6	(0) -2	(0) 1
	Max(degC)	10	(10) 11	(9) 8	11	(10) 9

(d) Rainfall Scenario Map



(e) Heavy Rainfall Alert

Heavy Rainfall Alert
EA North East Region

FLOODFORECASTINGCENTRE
a working partnership between Environment Agency | Met Office

Issued by the Flood Forecasting Centre on 06/11/19 at 18:21 GMT (18:21 local time)
Unique Alert Reference No. 2922_NORTHEAST_1117 Version 2

UPDATE

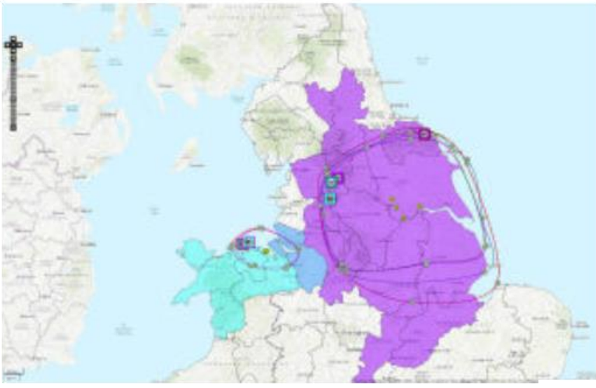
Start of meteorological event: 0300 GMT on 07/11/19

End of meteorological event: 0600 GMT on 08/11/19

Summary of Alert Criteria Met

Alert Criteria	HRA Areas covered	Confidence
10 mm (or more) in 1 hours (or less)	North East Coast, West Pennines, Central & Northern Pennines, South Pennines, Moors, Vale & Wolds	L
15 mm (or more) in 6 hours (or less)		
	North East Coast, West Pennines, Central & Northern Pennines, South Pennines, Moors, Vale & Wolds	H
40 mm (or more) in 12 hours (or less)		
	North East Coast, West Pennines, Central & Northern Pennines, South Pennines, Moors, Vale & Wolds	M

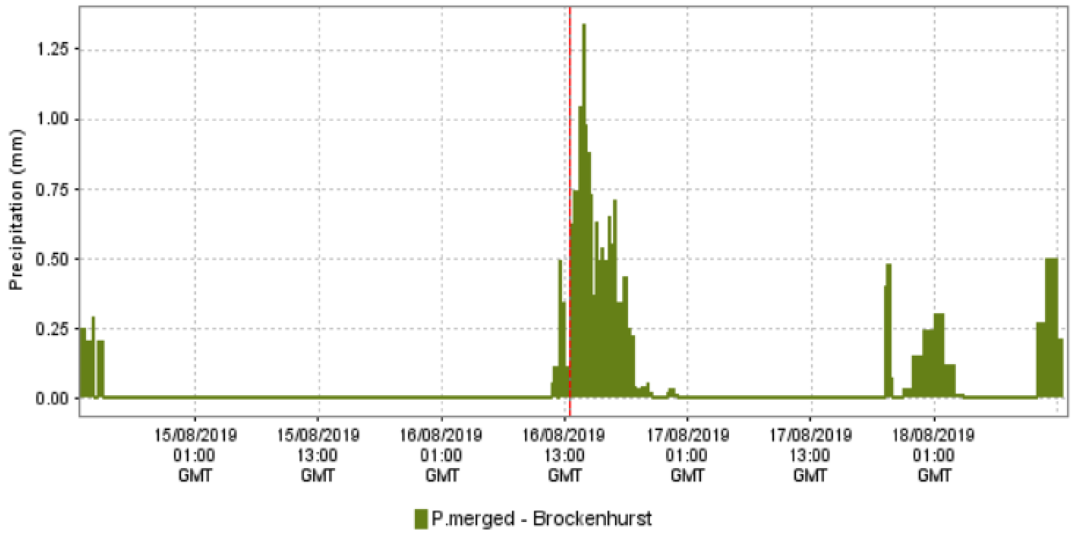
Notes:
- ***Confidence:*** *The probability of this threshold being achieved anywhere in the specific HRA Area within the time periods outlined by the Heavy Rainfall Alert. H = more than 60%; M = 40 – 60%; and L = 20 – 40%*
- *Issue of a Heavy Rainfall Alert means the probability of rainfall thresholds being met or exceeded during the meteorological event is within the bands indicated by the confidence levels above.*
- *All Alert criteria should be defined in this table. If it is predicted that some criteria will not be exceeded, these boxes should be greyed out*

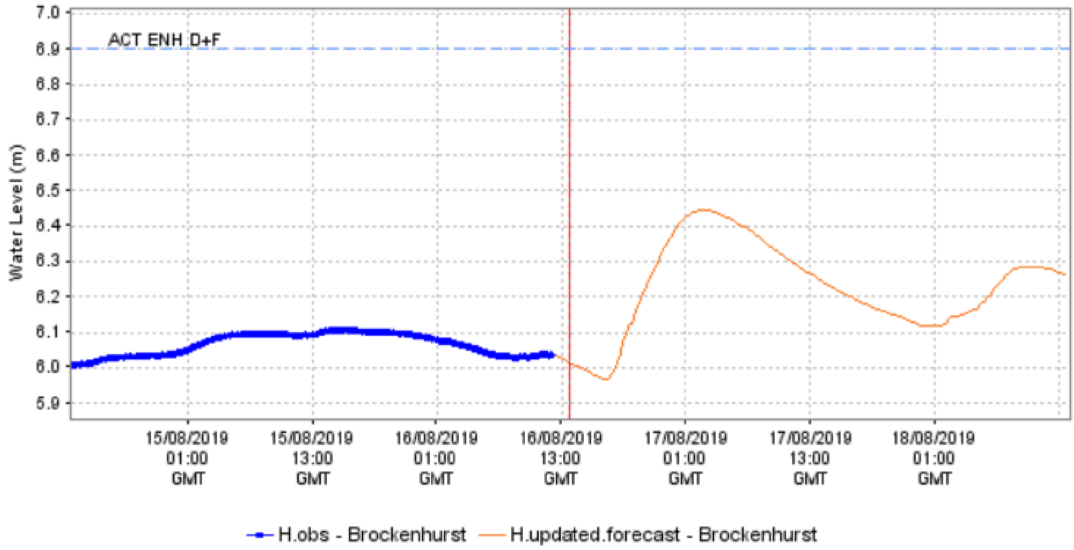


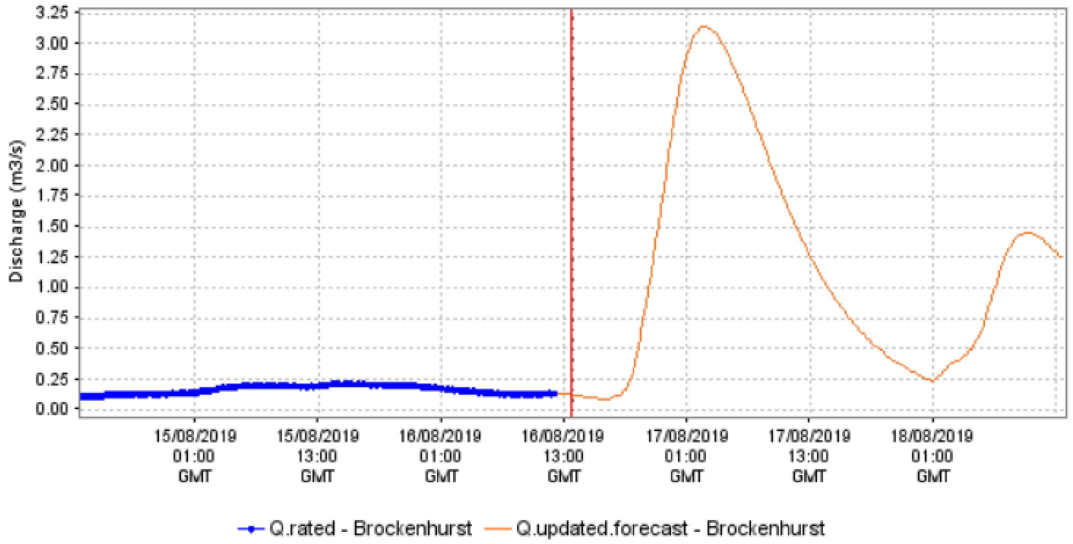
(e)

Area:	Hampshire and IoW
Region	Southern
Forecast name:	Fluvial_Forecast Fluvial Current 2 day (every 12h)
Forecast time (T0):	16/08/2019 13:30 GMT
Time of Report	16/08/2019 13:50 GMT

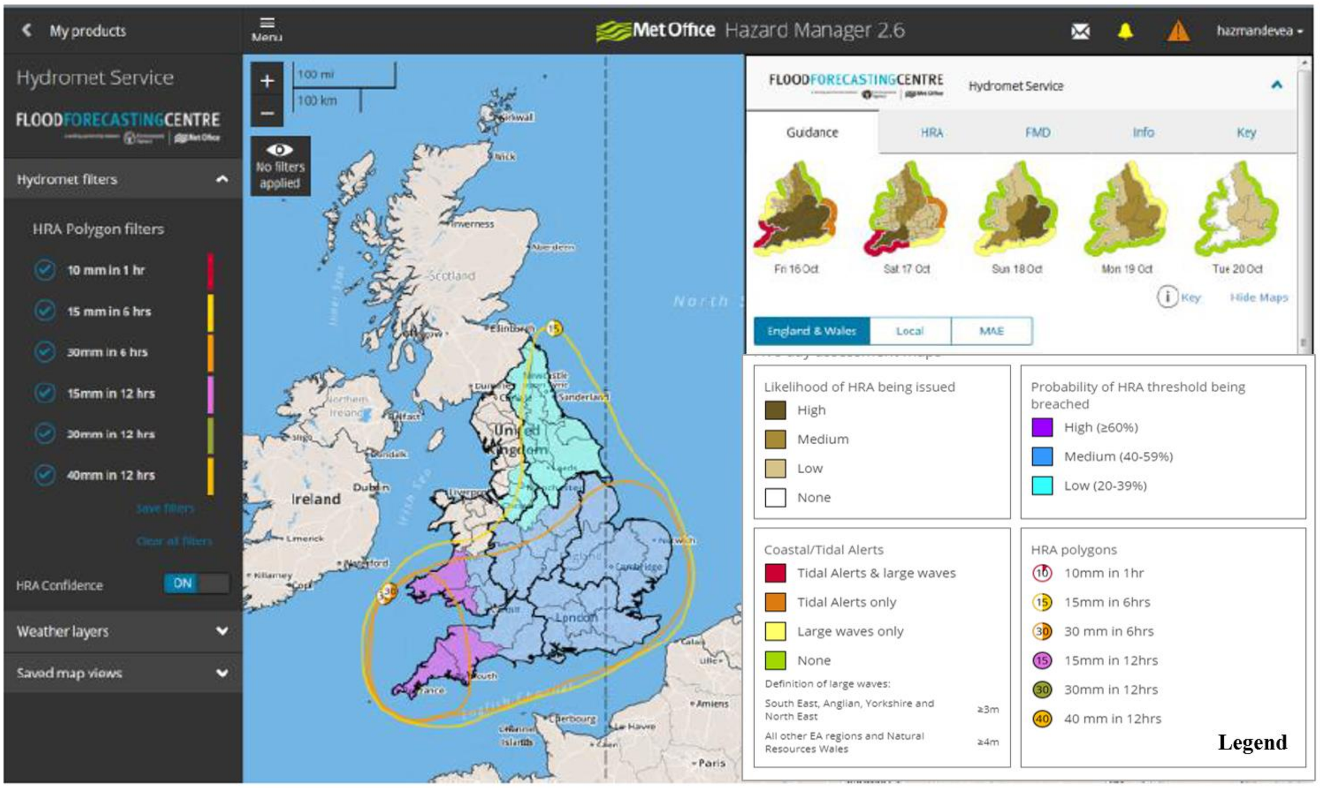
Forecast Data



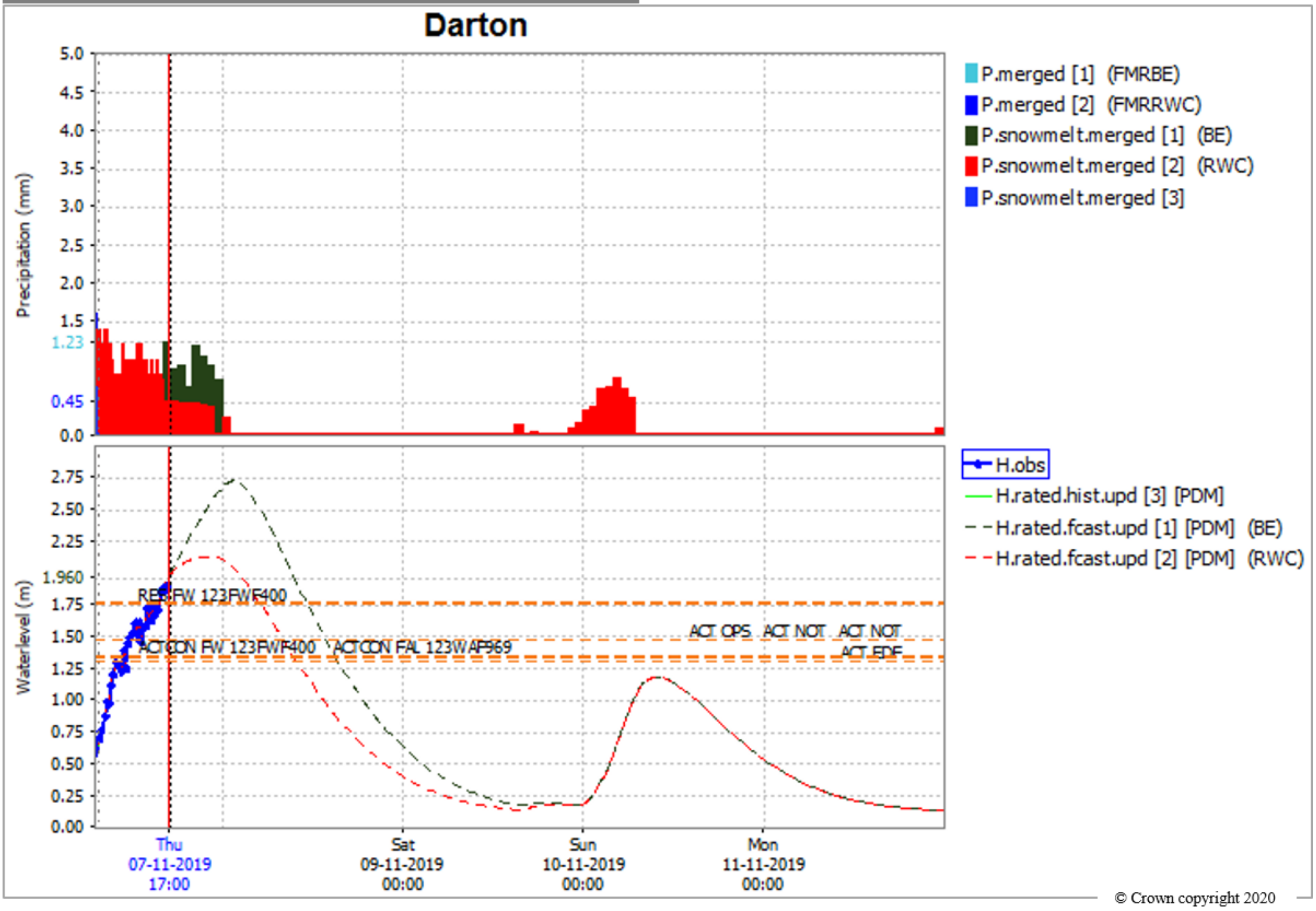




(f) Heavy Rainfall Alert



(g) BE and RWC scenarios on the NFFS



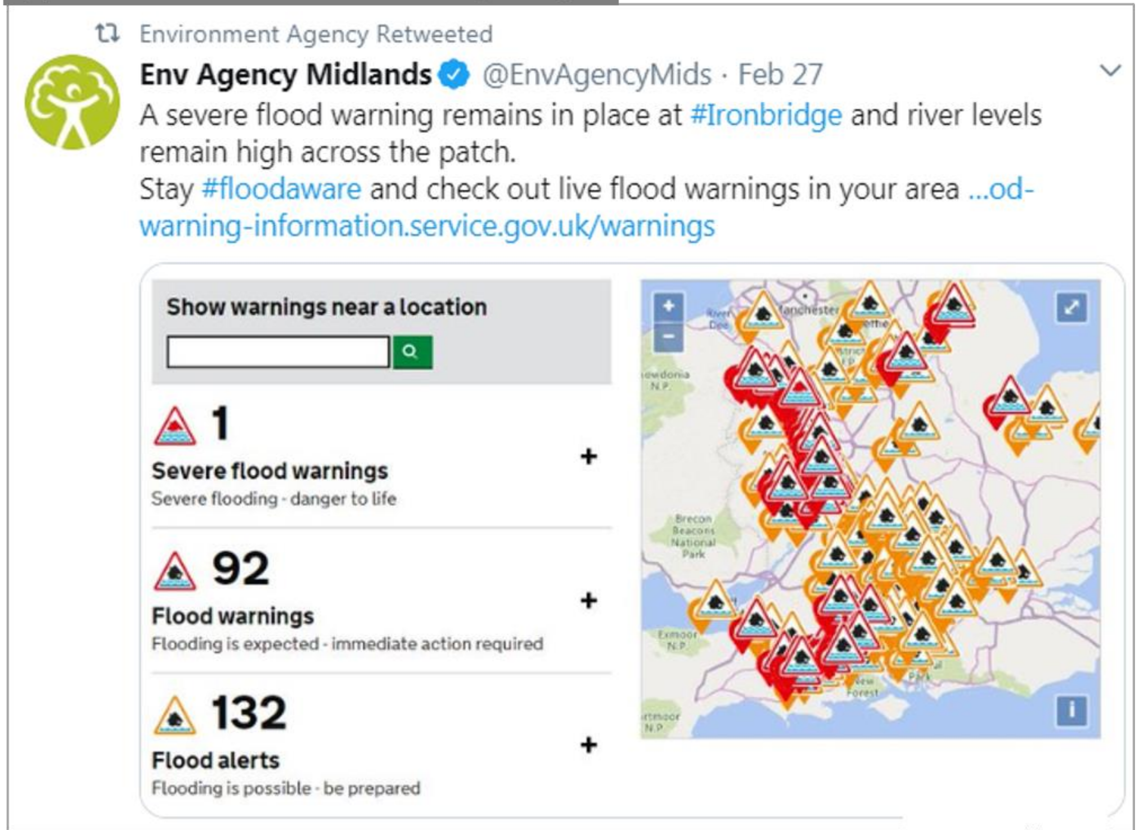
~~**Appendix C. Interviewees' quotes in relation to their perceptions (opportunities, neutral and challenges) associated with a transition to probabilistic forecasts.**~~

(h) Written description of a forecast for 1 March 2020

"The rain fall over Saturday night didn't cause much response on the upper catchments. With this we are not expecting a significant increase in the lower catchments (including the Aire).
Based on current forecasts:
- *Based on the BE does not see Carlton Bridge reaching the 4.4 –4.5m stage we do not expect to see it start to fill the West Marsh Washlands.*
- *Based on the RWC (with a +3 degree Celsius increase to account for snow melt) we do not expect to reach the 4.4 –4.5m stage @ Carlton Bridge*

The forecast for the coming week is as follows: Light wintery showers feeding in from the west in the next couple of days. Tuesday –further signals of showers for 5-10mm of rain / snow over the high grounds. This is represented in the river forecast @ Carlton Bridge, however levels will remain below 4.4m Stage. Wednesday to Thursday –further low pressure is expected, however confidence is extremely low and currently expected to impact south of the country."

(i) EA flood alerts and warnings map



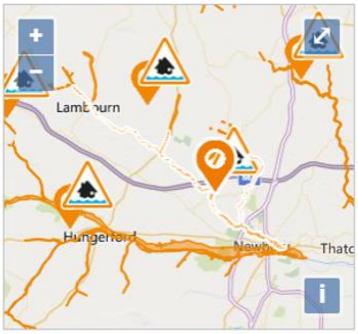
(j) EA fluvial food alert message

River Lambourn and its tributaries from Upper Lambourn down to Newbury

Flooding is possible - be prepared

Property flooding is not currently expected. River levels are high but stable on the River Lambourn as a result of high groundwater, particularly in the Eastbury area where the flood control structure continues to operate. Levels are high on the Winterbourne at Bagnor where the river is still out of banks and will be sensitive to further rainfall. The risk of flooding of low-lying land, footpaths and roads remains. Please remain aware of your local surroundings and stay safe by avoiding contact with flood waters. The forecast is for dry weather with some scattered showers until Friday. Please refer to the 'River and Sea levels in England' webpage for current river levels and remain safe and aware of your local surroundings. This message will be updated tomorrow, 01/04/20, or if the situation changes.

This information was last updated at **10:53am Tuesday 31 March 2020**



Hide other warnings and alerts

Opportunities

~~**O1:** *"If you've got a huge spread then you know that there's a very wide range of impact potentially, but if [...] everything's within a couple of centimetres of each other, it gives you a lot more confidence in saying, no I think we're going, we're not going to see a threshold crossing. So [...] it will help decision making I think" [MFDO3]*~~

~~**O2:** *"I think in a good way [...] it will [...] reveal the uncertainty that's hidden by apparent simplicity" [I1]*~~

~~**O3:** *"The new flood forecasting system is being developed at the moment so it's going to replace the NFFS. [The] benefits to that I suppose [...] are that if we can look to be more consistent across the country in even simple things like what displays look like [...] we're more interoperable if we need to" [MFDO1]*~~

~~**O4:** *"I think in an incident I'm happy that that's [...] a useful range of things to know, like you said, you probably warn for the lowest one and plan for the highest one and we can interpret between them" [FWDO2]*~~

~~**O5:** *"We're talking about some of these decisions that have got a long lead time, we're going to move people around the country, we're going to move equipment. It takes a long time to do that" [I1]*~~

~~**O6:** *"Between us [duty officers], it's probably OK because we've got that understanding of the roles" [FWDO3]*~~

~~**O7:** *"I can see some benefits to it, especially when you've got less experienced staff [...], you're almost [...] showing them the breadth of what a catchment could do given a range of responses" [MFDO2]*~~

Neutral

~~**N1:** *"Uncertainties are very tricky to deal with, whether probabilistic forecasting and a switch to that is going to help?" [MFDO2]*~~

~~**N2:** *"I think the MFDO role won't change, it will still be to communicate a forecast but the [...] wording of the forecast may change slightly" [MFDO1]*~~

~~**N3:** *"I think from our point of view it will just mean a bit more interpretation of forecasts and then [...] just a slightly different way of passing it on [...]. But I don't think it will change the process" [MFDO3]*~~

Challenges

C1: *"All the comms research we hear about generally says [...] the public message has to be as simple as possible, so that is working the opposite way to any proposal for probabilistic forecasting" [FWDO2]*

C2: *"A lot of local authorities standing their staff up, putting them on standby for a weekend is quite a big budget thing [...]. So [...] if we say, it is going to flood, they can justify the spend on it [...]. If we pass it on as shades of grey, a lot of them, they'll appreciate the information but some of them would actually resent having the decision forced on them because they will struggle to then justify doing something or they'll be blamed, either way, blamed for spending money if it doesn't happen and blamed for not spending enough if it does happen." [FWDO2]*

C3: *"That would be my concern that it's even more information and more uncertainty and it's kind of like, well what do you do with this information? And which bit do you communicate to who?" [FWDO3]*

C4: *"It is something to bear in mind with that if probabilistic forecasting put too much pressure and stress on decision making on the people in these roles, the system probably would just collapse, people would walk away" [FWDO2]*

C5: *"You're still going to have this overriding issue with fast responding catchment where one scenario says we might need to issue a flood warning but 99 of them say no. Someone has to make a decision" [MFDO1]*

C6: *"I think still for a lot of people the question they [...] want answered is am I going to flood?" [I2]*

C7: *"I think my role is going to be the one where it has to stop and it can't be probabilistic because it [...] does come to a yes or no, issue it, don't issue it. So to some extent, probabilistic forecasting does feel like everyone else just pushing things down the line saying you make the decision, [...], we have to make the decision because we're the last ones on the line" [FWDO2]*

C8: *"Having probabilistic forecasting just moves the burden of making a decision further down the tree" [MFDO2]*