Advanced Review

Understanding the roles of modernity, science, and risk in shaping flood management

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In the face of an unprecedented climate crisis, uncertainties over both the frequency and the magnitude of extreme weather events are positioning the development of scientific and political responses to flood hazards as pivotal to adaptation strategies. While floods are generally understood as the results of hydro-meteorological processes, their physical nature is also hiding some wider theoretical and practical dimensions that are intrinsically social. In turn, those dimensions unveil floods as social 'revealers', capable to exhibit the central role played by the fusion between science and politics in defining regimes of risk-based flood governance. From the emergence of numerical weather predictions to the increasing sophistication of meteorological and hydrological predictions, the age-old threat of flooding is increasingly viewed through a distinctively modern lens, which ultimately aims at organizing, producing, and securing futures by the consolidation of resilient societies. In spite of the considerable research efforts and resources invested into science and risk assessment instruments to underpin a more anticipatory and adaptive strategy to flooding, it is important to recognize that both science and risk politics are framing our capacity to engage with new forms of hazards that cannot be measured or quantified. © 2015 Wiley Periodicals, Inc.

How to cite this article:
WIREs Water 2015. doi: 10.1002/wat2.1075

INTRODUCTION

Floods seem to be everywhere in the realm of 24-h news. When headlines and images are not about the devastating impacts of large-scale flooding, they are about the quick and destructive flash floods spontaneously hitting mountainous terrains, cutting off roads and taking houses, cars, trees, pets, and human lives on their way. While floods can be tracked down to the numerous myths and folklore that have shaped collective imaginaries, ranging from the Great Flood in Genesis[1] to recent blockbuster films, the emphasis on portraying them as physical and supernatural (e.g., acts of God) entities has overshadowed their social and political dimensions. Beyond sensationalist images, floods are much more than biophysical phenomena delivering the promises of spectacle news. Rather, by way of their capacity to unearth the complex relationships between life, science, technology, and political institutions, they are expose tensions in the organization of the relationships connecting humans and non-humans.

With the prospect of a changing climate looming ahead, the forecasted changes in the water cycle are predicted to cause an increase in the recurrence and magnitude of floods over the next decades.[2] This in turn is imposing a change in the ways in which flood risk is dealt with, positioning structural measures such as dykes and flood walls as less central

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Conflict of interest: The authors have declared no conflicts of interest for this article.

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to adaptive strategies meant to deal with long-term climate-related risks and uncertainties.[2] The need to move away from structural measures is a view shared by international organizations involved in disaster risk management, such as the United Nations International Strategy for Disaster Reduction (UNISDR), the Emergency Response Coordination Centre of the European Commission (ERCCE), and the European Commission's Humanitarian Aid and Civil Protection Directorate-General (ECHO), which are now all promoting the development of instruments such as early warning systems and flood maps as part of adaptation strategies.[3–6] In fact, the call for further investments in early warning systems to edge against climate- and weather-related uncertainties also surfaces in the last IPCC report on the state of the climate, in which their applications for flood risk management are highly recommended.[7] However, understanding how and why the development of instruments such as flood early warning systems became central to adaptation science and policy cannot be understood without unpacking the trajectories leading science and politics to merge in the constitution of anticipatory futures and risk governance.

Thus, by looking at the social and political dimensions of floods, this review paper pays particular attention to how the idea of predicting, and thus anticipating, the future became foundational to the development of a scientific and political apparatus of risk management that finds its roots in modernity.[8] The review paper shows how the modern ideal of predicting the future has favored anticipatory action as a new form of governance within which urgency and insecurity become the main drivers of scientific and political development meant to stabilize risk and uncertainties. By looking at flood risks, the paper also argues that the emphasis on a vision of the future that is graspable has encouraged the development of quantificational relation to floods that has too often confined us to the logics of cost-benefit analysis and system analysis which have in turn established mathematics, statistics, and behavioral science as the backbones of flood risk governance. This thechnocentric vision of the future has prioritized the study of the effects and dangers of flooding rather than challenging of its societal causes, leaving us to wonder whether risk is still the right vehicle to use to engage with the threats posed by a changing climate, knowing that the challenges are more political and philosophical than scientific. Our argument unfolds into four interrelated sections.

First, we are opening our review by defining modernity broadly in order to provide a conceptual framework in which our discussion of risk and anticipatory actions is anchored. Second, by looking at the development of numerical weather predictions, the paper reviews how the dream of predicting future weather became reality through a series of social and political events enabling the consolidation of an ambitious scientific project to simulate the weather and thus the future. Building on this historical account, the third section focuses on how these transformations affecting the realm of forecasting science have influenced the development of flood forecasting science, particularly on the shift from deterministic to probabilistic forecasting with the emergence and application of the so-called ensemble prediction systems (EPSs) and their application to hydrology. While reviewing the technical implications of using EPS for flood forecasting, this section engages with some of the consequences of this new science on the institutional dimensions of flood risk management. The fourth section draws on political science to review how the fusion of risk and forecasting science became part of a modern form of governance in the context of flooding, legitimizing risk as a governing practice through anticipatory actions. This will allow us to expose how science and policy meet in the development of flood risk instruments meant to inform adaptation to and mitigation of flood risk. Finally, the paper stresses that risk, science, and politics have their limitations in helping us to engage with the wider challenges paused by flooding and climate change more generally.

MODERNITY AND THE ANTICIPATION OF RISK

In the social sciences, the significance of both modernity and modernization has been widely discussed by sociologists and philosophers in relation to their processes of rationalization,[9,10] domestication of nature,[11] and more recently the work of the late Ulrich Beck for its effects of individualization.[12] While defining modernity is a rather difficult task, it consists broadly of a strong division between human society and the nonhuman world (commonly called nature) in which the former transforms the latter in a spirit of free market, individualism, and democratic ideals,[13] and in which the ancient, archaic, and stable are confronted with the new and constantly moving future.[8,14] As argued by Peter Conrad,[15] Thomas Hylland Eriksen,[16] or Harmut Rosa,[8] one of the main characteristics of modernity has its roots in the acceleration of time that is felt and observed not only in the fast technological changes affecting communication, transportation, and the production of goods and services, but also, in the ways in which people relate to each other (e.g., family structures, length of love relationships) and in what is often defined as a

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symptom of modern life[17]: the feeling of alienation generated by the constant lack of time to carry out do an increasing number of tasks.[18] In modernity, the future is more than a temporal modality; it is the 'vanishing point' enabling the rise of a technological rationality that is capable of reshaping collective and individual endeavors.[19–21] This is illustrated well by the multiple risks and uncertainties that are emerging from the modern era (e.g., climate change).

For Ulrich Beck, the radicalization of modernity, through an increase in the individualization and secularization of social actors (through scientism), has led to the dissolution of an industrial society to a society in which risk is no longer containable, but rather, it is now diffused and central to the formation of a risk society. This transfiguration of social relations has been made possible by what Beck defines as 'reflexive modernization', whereby the consequences of modernization (which refers to the process that lays at the centre of modernity, capable of mobilizing the future through a fusion of capitalism, science, and scientism) are not captured by the modern and democratic political institutions, leading to a plurality of emerging risks and uncertainties on the one hand, and to a greater public awareness of the secondary effects of techno-scientific developments on the other. For Beck,[8,22] responses to these new forms of uncertainties have turned into a blind faith in technological advances that can now be used as political instruments serving the organization of risk as an underlying principle of modern societies and their futures. The impact of these ideas has been tremendous not only on the ways in which risk has become an object of study in sociology and political sciences, but also, perhaps more interestingly, in explaining how modernization, through rationalization, has framed particular governance approaches to futures in the context of flood risk management for example.[23]

In the Anglo-American world, research on risk has been driven mainly by risk analysis, favoring quantitative and metrological approaches ingrained in neo-classical economics and psychology which are associated with not only cost-benefits analysis, but also risk perception[24] and acceptability of risk.[25] The proliferation of those approaches are linked to what Henry Rothstein and colleagues[26] have defined as the 'risk colonization' process, whereby risk becomes an important category used in reshaping politics, and public policies in almost all aspects of governance, ranging from terrorism to flood risk.[27] Indeed, the shift toward a dominant culture of risk is also the product of a coproduction of politics and science through which experts transiting between academia, government, and think tanks were advocating for the application of rational choice theory[28,29] in all sectors of the state. This rationalization has led to policy making being instrumentalized through an apparatus of quantitative tools and metrological practices that have made risk a powerful instrument of governance.

Investigating risk as a form of governance implies that we should also look at the modality of time, which enables modern societies to prepare for dangerous futures through anticipatory actions. Framed in the modern, ideal, anticipatory actions are primarily animated by the desire to protect liberal-democratic life from threats of all sorts such as flooding for example.[30] This is done by assembling different tools and techniques, which above all is incarnating the modern ideal of grasping the future before it happens, and thus controlling its course and its nature in order to prevent disasters. This also means that the modality of time through which anticipatory actions takes shape consists of a constant state of emergency that is speeding up the now, resulting in an opening up of the future to desirable outcomes (i.e., free market) while blocking unwanted ends (i.e., disasters).[31] Thus, anticipation is a core quality of modern liberal governance regimes, which in turn is exposing social actors to uncertainties and indeterminacies in the state of knowledge that are meant to define and organize future risks.[30,32]

In order to understand how anticipation becomes foundational to current flood risk management, there is a need to better identify how the vision of the future as graspable and controllable entity becomes possible and key to our relationship with flooding. The following section will look back at the beginning of computation and modern scientific advances allowing the anticipation of weather through quantification tools allowing the future to be seen. We will then showing how those developments are taking place in flood forecasting and policy.

NUMERICAL WEATHER PREDICTIONS AND THE EMERGENCE OF FORECASTING THE FUTURE

In 1922, the British mathematician Lewis Fry Richardson published *Weather Predictions by Numerical Process*,[33] a book that became foundational to numerical forecasting and to the modern quest of predicting the future. By forcing arithmetical procedure to solve differential primitive equations developed by meteorologists to describe the physics of the atmosphere, Richardson pushed forward the computation of mathematical methods meant to understand atmospheric motions in time.[34–37] This mathematical intrusion

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allowed Richardson to move from forecast operations based on variables to operations based on numbers, enabling him to propose an algorithm (i.e., a group of operations carried out sequentially) capable of creating forecasts based on numerical data and to provide an answer to what the father of modern meteorology, Vilhelm Bjerknes,[38] had defined earlier as 'the one problem worth attacking, … the precalculation of future conditions' (Ref 35, p. 4). It is also in this book that Richardson famously stated that '[p]erhaps some day in the dim future it will be possible to advance computations faster than the weather advances and at a cost less than the saving of mankind due to the information gained. But this is a dream' (Ref 33, p. vii). Although the book did not create enthusiasm desired by Richardson at the time of publication,[39–41] and was criticized for the significant errors in the basic equations of atmospheric hydrodynamics,[42] Richardson's contribution to formulating the process of numerical forecasting has made both his dream and his ambitions vital to the development of meteorology and forecasting more generally.

As a result of military demand during World War II to improve knowledge of weather systems and the dreams of controlling the weather that lay at the heart of the Cold War, the subsequent deployment of an arsenal of financial, technical, and intellectual resources dedicated to the improvement of weather forecasts have radically changed the face of weather forecasting during the 20th century.[43–45] Those changes have not only led to the unification of meteorology by grounding its principles in physical theory and thus reshaping the discipline into a 'formal science',[42] but they also opened up the field to new mathematics interested in the numerical computational methods used to solve hydrodynamics and aerodynamics problems, most of them inherited from ballistic and thermonuclear research.[46–48] Along with the development of high-speed electronic computers capable of implementing primitive equation models, the Cold War period was vital to the improvement of forecasts' algorithms linked to the refinement of global circulation modeling. These constant advancements of numerical techniques transfigured meteorology between the 1950s and the 1970s in two significant ways. First, by making numerical weather forecasting central to research programs in meteorology, a set of new institutions and networks needed to be developed in order to establish a vast campaign of weather data collection that became necessary for forecasting, and this had the underlying effect of reshaping the institutional organization of weather forecasting around the world.[45,47] For example, the European Centre for Medium-Range Weather Forecasts was formed in 1974 to address the challenge of medium-range (3–15 days) forecasting and became a world leader in producing and disseminating numerical weather forecasts worldwide. Second, by building heavily on complex theories of physics and mathematics to describe the nonlinearity of atmospheric processes, numerical weather forecasting needed to benefit from the increasing power offered by refined electronic computing. This technical contribution to the development of numerical predictions has made the pillars of numerical forecasts such as the mathematician John von Neumann and the meteorologist Jules Charney, believe that electronic computers could become new experimental and inductive devices for both operational and research meteorology.[40,46,48] These two changes have converged to make the dream of predicting the future of atmospheric processes possible through a rapid series of theoretical innovations, but they have also contributed to making computer science fundamental to the development of meteorology in the decades that followed. This latter implication is far from being trivial. On the contrary, it has also engendered wider transformations in the scientific community more generally, demonstrating the potential to run various types of mathematical models through a complex set of algorithms on high-speed computers.

Finally, another giant step in the story of numerical weather predictions comes from the work of meteorologist Edward Lorenz,[49] who pointed out that the atmosphere is a nonlinear chaotic system in which the initial state is unknown. Following Lorenz's work, it is now understood that slight changes in the initial conditions can lead to significant differences in forecasting results. Building on the increasing computer power and subsequent development of numerical weather predictions, Lorenz made it possible to bring a new set of scientific inquiries to the center of meteorological questions on the validity of physical models' equations and the errors of individual prediction models (Ref 50, p. 1). In practice, this meant that rather than issuing a single forecast, multiple forecasts were needed to represent future states and cover the probabilities caused by the uncertainties. Multiple forecasts required an increase in computational power. The combination of these new possibilities provided by chaos theory and the continually increasing computer power allowed meteorologists to include, and thus model, key factors which had previously limited the predictability of the weather, including uncertainty in the initial conditions or in the numerical presentation of physical processes. This led to the development of new types of probabilistic forecasting.[51]

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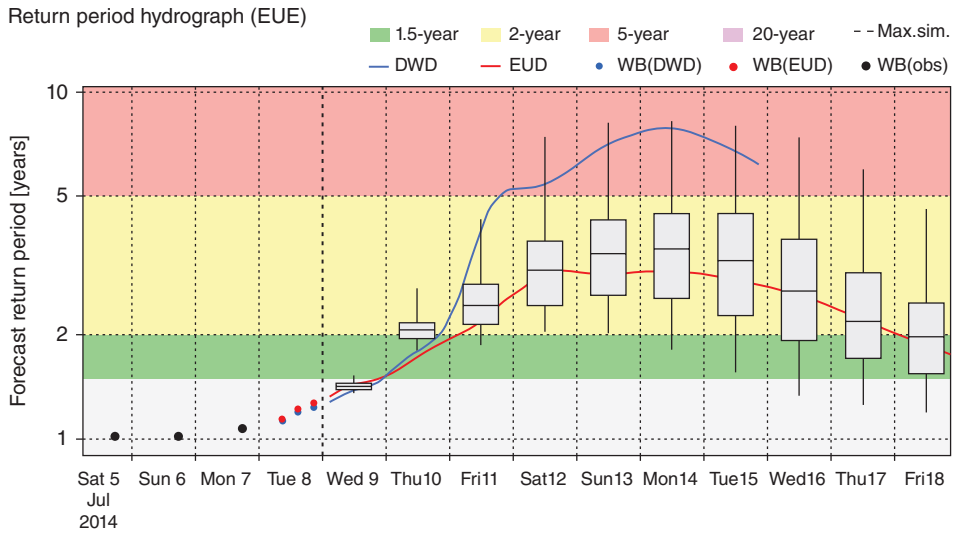

FIGURE 1 | Deterministic and probabilistic forecasts from the European Flood Awareness System. The blue solid line is a flood forecast using the deterministic model of the German weather service (Deutscher Wetterdienst). The blue solid line is the high-resolution forecast of ECMWF and the box-plots show the ensemble forecast of ECMWF.

While the emergence of numerical predictions exposed some fragments of the long and complex history of forecasting in meteorology, the development and application of numerical weather predictions, along with computer power and the need for weather data, contributed to the fusion of climatology and meteorology during the 20th century. However, as we are going to show in the following section, this fusion has extended to other fields; hence, knowing how numerical weather predictions have developed is of cardinal importance to fully understanding their impacts on the development of flood forecasting techniques in the 1990s and their integration into wider risk management strategies.

FLOOD FORECASTING, ENSEMBLE PREDICTIONS, AND PROBABILISTIC RISK MANAGEMENT

Numerical weather predictions have also played a part in the emergence of present-day flood forecasting systems, which are now increasingly moving toward integrating medium-term (4–15 days ahead) probabilistic meteorological forecasts.[51] If high-speed computers and simulations are now becoming experimental sites that are used to understand flood behavior and simulate their potential extent and moment of occurrence, the universe of flood forecasting is still sharply divided into two different schools of thoughts or traditions: (1) deterministic forecasting and (2) probabilistic forecasting (see Figure 1). However, for this review, our interest is going to focus solely on probabilistic forecasting.

Knowing how to cope with uncertainty in flood forecasting has always been seen as an important source of concern on which hydrologists have concentrated their efforts in the development of methods such as the ensemble streamflow prediction (ESP) system put in place in the 1970s. This allowed them to use deterministic hydrological and scenario-based models that used historical data, which in turn made it possible to generate an ensemble of streamflow hydrographs.[52] While the initial idea did not use meteorological forecasts, ESP forecasts were used to compare the current and recent past simulations and observations. They assessed how similar the current hydrological situation was to historic situations and then picked a number of those historic situations as a forecast for the future, fusing uncertainties from both meteorology and hydrology together. While these systems are widely used today for seasonal weather forecasts (e.g., in Australia amd tje, USA), both medium- and short-range flood forecasting systems remained stubbornly deterministic.[53] Although the development of probabilistic forecasts has generated significant debates among hydrologists since the mid-1990s,[54,55] the number of probabilistic flood forecasting systems currently operational in the world is still very low in spite of a net popularity for their development,[56,57] which can be attributed on the one hand to the general acceptance in the flood forecasting community that forecasts always contain uncertainties. On the other hand, this acceptance of uncertainty among the hydrological community is also the product of the wider 'risk colonization' process that is

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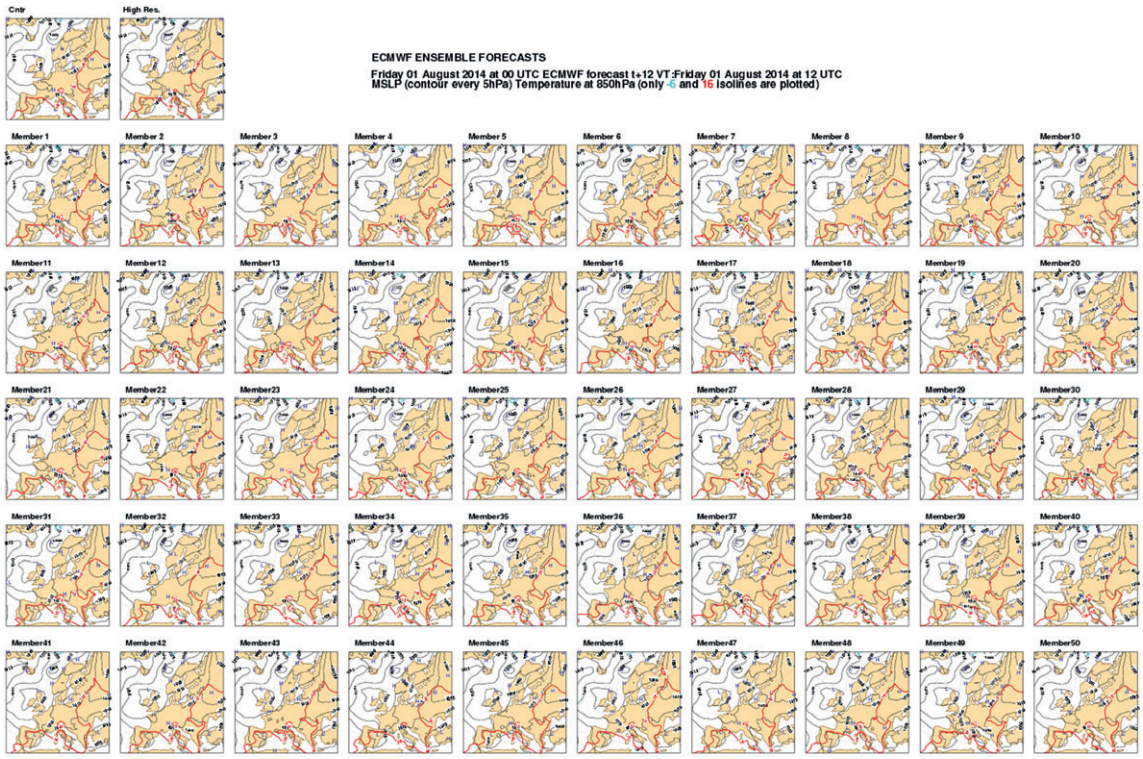

FIGURE 2 | Simultaneous ECMWF forecasts, showing 50 perturbed ensemble members, the high-resolution operational model and the control run that can be seen in the above two top left images. The control run is similar to the high-resolution run as it is produced without perturbations, but with the same resolution than individual members, which are produced at a lower resolution than the high-resolution perturbations images. Those differential runs are created to provide a reference run making it possible to compare differences in forecasts depending on resolution. When talking about the full ensemble, this usually means an inclusion of the control run, making it 50 + 1 members or 51 members.

forming through the development of mathematics meant to improve risk analysis and decision-making under uncertainty such as Bayesian statistics, which enable the production of scenarios with different parameters.[27]

Additionally, advances in meteorological sciences resulting from the rapid development in numerical weather predictions and the unceasing increase in computer power opened the door to new forecasting techniques, such as the development of EPS at the beginning of the 1990s,[58,59] whose main characteristic is to provide multiple forecasts for the same time period (Figure 2). EPS forecasts are known not only for their added value in terms of greater skill and longer lead time measurements, but also for their capacity to generate a suite of forecasts that provide a way to quantify forecasts' uncertainties.[60–62] By using EPS, it is now possible to account for the uncertainty of numerical weather predictions that are used in hydrological flood forecasting, a possibility that did not exist before the beginning of the 2000s. Currently, there are multiple meteorological centers across the globe issuing EPS, most of them generating uncertainties based on different methods (e.g., models, data assimilation, ensemble generation, etc.), which are in turn used to improve hydro-meteorological flood forecasting through a combination of techniques.[63]

EPS and their transformation into ensemble flood forecasts have generated new constellations of networks involved in refashioning the institutional organization of flood forecasting and the meteorological information needed in the management of extreme weather. This can be seen through a myriad of new channels through which those forecasts are now produced, disseminated, and communicated. A good example of this new organization of flood information is the European Flood Awareness System (EFAS) (Figure 3), which has been developed as a technological, thus political, response by the European Commission to the 2002 floods of the Danube, Elbe, and Oder rivers which were responsible for displacing 500,000 people and killing more than 80.[64] Although EFAS was created and made operational by the European Joint Research Centre, the EPS used to generate its forecasts were produced by the European Centre of Medium-Range Weather Forecasts (ECMWF), which were then used to disseminate innovative ensemble

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flood forecasts to the 29 forecasting agencies that have signed the Memorandum of Understanding.[65]

There are several hydro-meteorological centers across the globe which are now issuing ensemble flood forecasts; although there were only a handful of centers at the beginning of the century,[56] there were over 20 in 2014, and they are changing the geography of scientific production and the dissemination of flood forecasting. Since generating EPS demands computer power that is capable of performing additional post-processing in order to remove systematic biases, most centers interested in developing ensemble flood forecasts need to merge other data, models and forecasts with their own 'in house' models and products, resulting in what Paul Edwards[45,47] has termed 'data friction'. These 'data frictions' correspond to errors and further tensions in the ways in which the coarse scale of meteorological EPS should be downscaled statistically into a hydrological model and, when this is done, to how those new forecasts are then used in relation to 'in house' models. These 'frictions' have been identified as one of the factors limiting predictability (other factors include catchment characteristics, e.g., catchment response time) and impacting on these novel ensemble flood forecasting systems. Thus, behind the promises of better forecasting skills, ensemble flood forecasts are slowly reshaping the world of flood forecasting, implying a shift from a risk culture based on deterministic thinking and risk prevention to one based on probabilistic knowledge and preparedness for risk, and hence enforcing a new kind of organization of risk and management strategies yet to come.[66] With the possibility of providing informational value on uncertainties and the capacity to predict future extreme weather through enhanced numerical weather predictions, the scientific trajectory leading to the development of ensemble flood forecasts becomes an example of how the colonization of quantifiable risk has been changing the practice of hydrological forecasting and human relations to floods. The next section will expose how risk-based governance has not only accelerated the quantification and measurement of dangers, but has also situated insecurities and dangers as focal to futures imagined, raising important concerns about whether it is still the right intellectual frame to use to face current challenges such as more recurrent and extreme flood events.

THE PROMISES AND PITFALLS OF RISK-BASED FLOOD MANAGEMENT

While the development of risk as an instrument of governance can be tracked down to the use of probabilities by the insurance sector during the 17th and 19th centuries,[27,67,68] it is not before the 1970s and 1980s that its predominance in shaping new categories affecting both public and private spheres of governance could really be felt in Western liberal democracies.[27] With neo-conservative regimes flying high during the mid-1980s in the Anglo-American world (Reagan in the USA and Thatcher in the UK), risk was not only a discourse extending the economy to every dimensions of social life, but also a way of being.[69] In many advanced capitalist societies, but more particularly in Anglo-American contexts, it has been argued that risk- and evidence-based approaches to governance are on the rise.[26,70] For instance, under the New Labour government in Britain, risk was to become 'the governing concept'[71] in all changes of regulation.[72–75] Beyond Britain and the Flood Directive, the EU has been active in promoting risk-based approaches to governance. The European Commission, for instance, notes that

> risk governance–embracing risk identification, assessment, management and communication–has become a crucial (…) component of public policy (Ref 76, p. 23)

In Europe, the extension of risk to flood-related disasters culminated in the 1990s. This was largely related to the increasing number of flood events occurring during this decade, and with the subsequent record-breaking economic damage and loss of lives, engineering-driven solutions (e.g., dykes, flood walls, dredging) to deal with flood risk were challenged by new forms of technological and political responses such as flood warnings and preparedness strategies. This change of mentality became more perceptible in many European countries where governments sought this transformation through programs such as 'learn to live with floods',[77] 'make space for water' (in the UK),[78] 'room for rivers' (in the Netherlands) and 'space for rivers' (in Germany)[79] at the beginning of the 21st century.[80,81] More concretely, these technocratic strategies were driven by economic theory and sought to adapt socioeconomic processes, and progress, to biophysical processes, through a combination of long-term (e.g., land-use regulation in flood plains) and short-term (e.g., flood forecasting) interventions. In conjunction with scientific developments meant to reinforce the calculability of risk (such as EPS), these long- and short-term strategies aimed to deliver adaptation while protecting populations from floods.

Central to these strategies is the increasing reliance on anticipatory actions. With an emphasis on quantification tools and models able to grasp the

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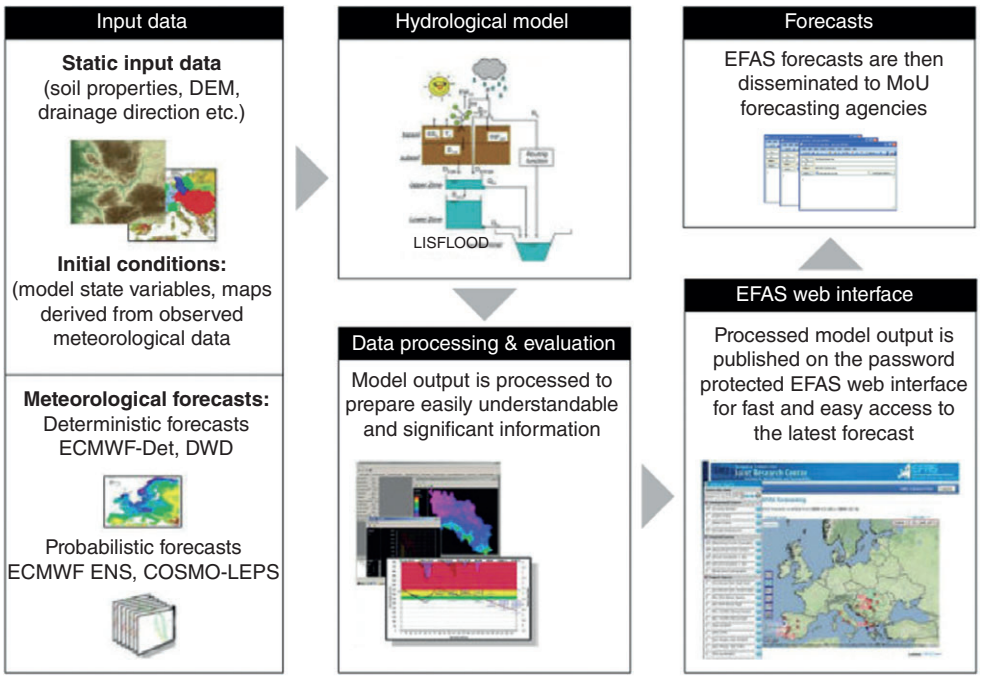

FIGURE 3 | Schematic view of the EFAS system, showing the institutional organization of forecast production and dissemination.

future, anticipation becomes the catalyst for the intervention of science in the development of flood forecasting, early warnings and flood hazard maps. These approaches can be simply summarized as being a blend of governance resources, such as information, regulation and authority, and financial resources which are allocated on the basis of risk levels that are previously identified by scientists and later on used by regulators or policy-makers. A second characteristic of these risk-based approaches is the recognition of the uncertainty that surrounds the risk assessments, as we saw in relation to the identification of uncertainties in flood forecasting through EPS.[82,83] While the development of flood forecasting technologies and flood hazard maps are only one element of the adoption of risk-based approaches to flood management, these approaches are instrumental for planning emergency response measures (e.g., evacuation procedures, preparing pumps, having enough staff on standby, etc.) or increasing the preparedness of those members of the public judged as being at risk. Benefitting from the same scientific advances and models as flood forecasting, flood hazard maps displaying spatial zones that might be inundated in future, showing different probability of occurrence and associated material damage, enable governments, for instance, to regulate land use and construction in accordance with different levels of risk[84] (Figure 4). Flood mapping has become an integral part of the recent flood-related legislation in Europe. For example, in the EU Floods Directive,[3] EU member states were required to produce flood risk maps, undertake risk assessments and prepare risk management plans so that they were to be ready for 2015.

In addition to anticipating and managing specific threats, a risk-based approach uses risk as a tool for optimizing the coordination, prioritization and effectiveness of governance. Economic calculus is still central here, so that the effectiveness and efficiency of public interventions are ensured through (risk-) proportionate allocation of resources. For example, in a strategy document on environmental management for the '21st century',[85] the UK's Environment Agency (with mandates limited to England and Wales) highlights that resources allocation should be better targeted and proportionate to interventions and that this should maximize benefits while reducing the regulatory burden. Similar arguments are made by the Organisation for Economic Cooperation and Development (OECD) in which risk-based governance implies being capable of 'targeting mitigation investments to their greatest benefits' (Ref 86, p. 5).

These optimization strategies suggest that there is more to the rise of risk-based governance than simply the availability of technology, scientific advances and the state's interest in managing threats, such as flooding, more effectively. In fact, the interaction between politics and science creates new forms of governance that are embodying the dream of

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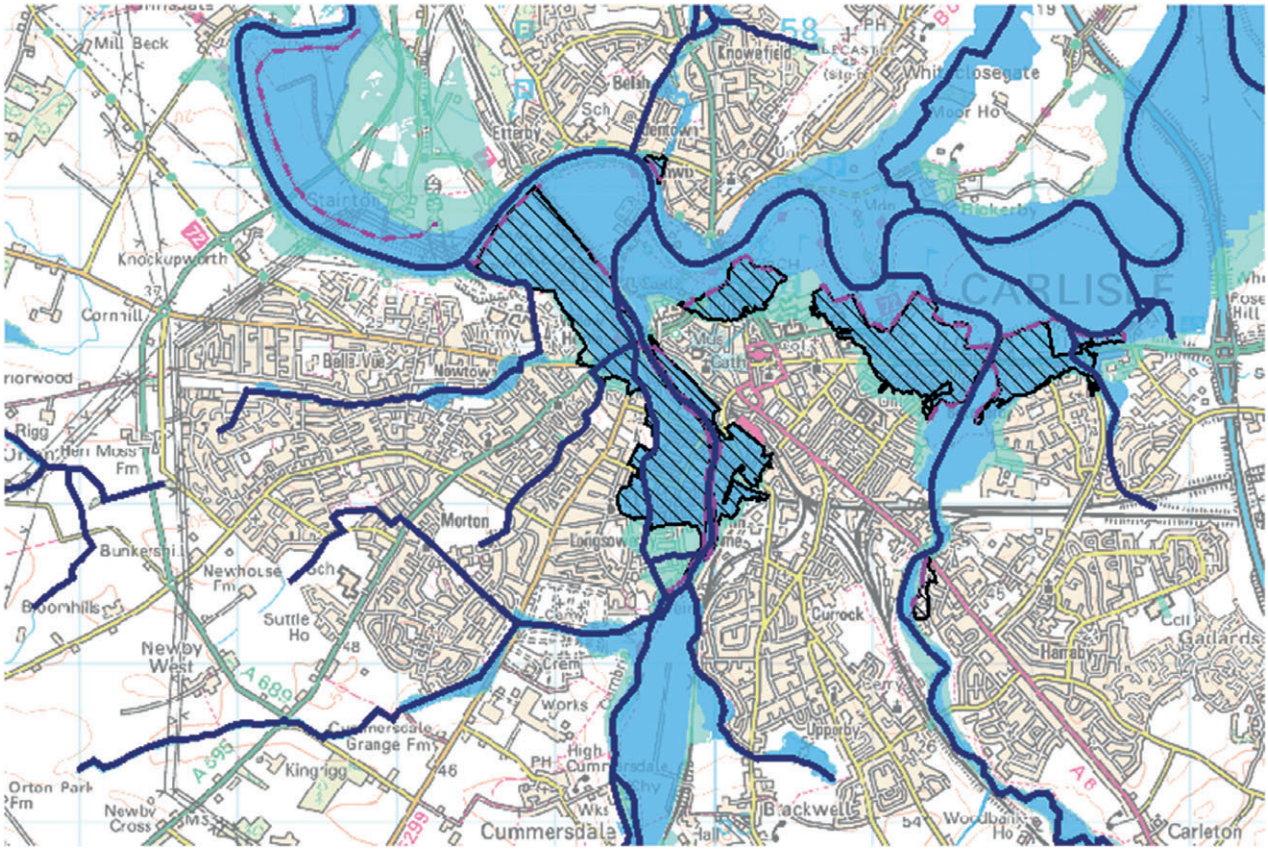

FIGURE 4 | Example of flood risk mapping taken from the riven Seven in the UK.

modernity, in which technological means are promoted and used through a rationalization process meant to transform public policies and shape collective futures. More precisely, risk-based approaches to governance can be associated with three overlapping types of rationalization processes: (1) rationalization through science; (2) rationalization through economics; and (3) rationalization through accountable governance.

With its roots in positivism and quantification methods, the first rationalization process aims at building trust in and objectivity of modern institutions.[68–70] The underlying idea is that science-based and/or evidence-based decision-making is a superior and objective way of solving the problems of modern society.[87–89] In the case of flooding, this first type of rationalization process uses scientific disciplines such as hydrology and hydraulic engineering to provide crucial inputs to understanding the properties of a particular hazard and how to deal with it. In addition, risk becomes a category of understanding,[90] or a particular lens through which a particular situation is being analyzed by drawing on mathematics and statistical methods.[91] This rationalization process is seen in the use of flood risk assessments that in turn are supported by mathematical models which help to identify behavioural, regularized patterns in flood events and thus increase the predictive and anticipatory powers of decision-making.

Also grounded in mathematics and disseminated by economists working on risk, economic rationality is associated with neoliberal 'governmentality' or, put simply, as the ensemble of practices whereby individual freedoms, rights, and relationships to others can be defined, organized and instrumentalized by a form of governance that has neoliberalism as its main engine.[92] The most common expression of this kind of rationality is the so-called cost-benefit analysis, which provides quantitative, comparable, often monetary values of the adverse outcomes of different courses of action. In the context of flood management, such rationality takes the shape of investments in the development of structural measures such as dykes and, more recently, new flood forecasting systems allowing both the protection of private properties and the evacuation of people and the protection of goods before the flood peak. It is also a form of rationality that has played a significant role in the colonization of risk to several areas, including flood management.

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The third rationalization argument is concerned with the way in which risk can contribute to a greater legitimacy of governance by making explicit the limits of governance.[82,83] Set in a context of high accountability and transparency pressures of modern societies, as well as rampant blame games in the case of risk management failures, policy-makers face significant institutional and political challenges when managing risks such as flooding. Those challenges can range from declining popularity and judicial proceedings, to budget cuts and trimming the responsibilities of agencies to fit with individual resignations. In the case of flooding, the transfer of responsibility from the state to the individual by the use of probabilistic forecasting is transforming power relationships whereby risk becomes used by nonexperts to challenge the position on flood risk and to reinstate the category of risk as the main realm within which floods are dealt with.

If optimization, rationalization, and quantificational methods have allowed risk to become an instrument of the governance of modern society, especially of late modernity (1960s onwards), risk communication has also proliferated as a modern instrument of control, enabling the containment of public reaction to dangers and threats rather than engaging with the very nature of those dangers[93] along with securing trust.,[94,95] Thus, risk communication has played a role in instrumenting anticipation governance by defining the acceptability of risks, suggesting that decision-making under uncertainty is shaped by various cognitive biases[96–98] and emphasizing the merit of communication as a tool for fixing a deficit in public understanding of science and risk.[99,100] In flood risk management, risk communication has mainly developed through the realm of social psychology, which is extending the modern ideal that risk communication could be used to achieve behaviour change,[101] or to improve democratic uptake in the science defining acceptability of risk though public participation.[102]

Although risk communication has been criticized for ignoring how risk is constructed and contested,[12,103] the role of mathematical models and social psychology in defining risk perception has been focal to the development of intellectual frames serving to reshape collective, individual, and institutional identities animating the futures of the anticipatory action they propose.[27,104,105] With the current development of probabilistic flood forecasting, flood risk communication becomes another means of governance as a nonstructural measure, offering the possibility of transferring responsibilities for interpreting the uncertainties to nonexperts,[66] thus enabling a novel form of governance to emerge whereby the principles of technical rationality and modernity can be fully materialized into political institutions and governmental principles.

Finally, while risk instruments enable the ideal of modernity to take shape through different processes of economic quantification, optimization and rationalization, the development, refinement, and application of technological means such as probabilistic flood forecasting methods or flood hazard mapping are becoming powerful ways to organize collective relationships to floods. However, it is important to note that risk-based approaches to governance have been widely contested. One important argument comes from the sociology of organizations and builds on the criticism that risk-based approaches to governance are incompatible with institutionalized values, structures, and procedures that take place in different national contexts.[93,103] Thus, different attitudes to risks and governance can come to undermine any attempt to provide a universal model of a risk-based approach to flooding.[106] Notions such as trust in the state's ability to provide security to its population,[107] the role of the insurance industry and the significance of private property can vary enormously from one state to another, leading to different responses to risk.[108] More recently, the Francophone sociology of risk has also questioned the validity of 'risk society' a relevant concept to the issue of contemporary threats[109], arguing rather that recent historical enquiries in the development of risk have demonstrated that risk society and environmental reflexivity are not the products of contemporary societies and postmodernity, but rather, phenomena which have persisted since the eighteen and nineteen centuries.[110,111]

CONCLUSION

The Fusion of Science and Politics in Flood Risk Management

From the first calculations leading to numerical weather predictions and the refinement of electronic computers to current EPSs involved in predicting the likelihood of flooding, the principles of modernity and the modernization of political institutions have fused with one another to give rise to current flood risk management. As we have shown in this review paper, understanding the evolution of flood risk management requires paying attention to the development of both science and governance regimes. This in turn makes it possible to localize how foreseeing the future scientifically and controlling its outcomes politically becomes possible.

We have demonstrated that the early scientific dream of predicting the future was animated by the

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belief in modern capacities to stabilize and organize our relation to time and uncertainties in the state of knowledge, allowing us to speed up the now through anticipative actions tailored for a dangerous and unstable future. We have also shown that the spectacular scientific development in computation was aided not only by scientific ingenuity but also by the particular contexts within which military interest in mastering the weather has played a significant role. The spill-over of forecasting from meteorology and climatology to flood management demonstrates how increasingly institutionalized scientific methods and approaches, such as reliance on computer power, quantification methods and social psychology, have helped to frame risk as an instrument of governance colonizing other areas of scientific and technological development and changing how scientists and practitioners in another field view and approach the world. The general shift towards anticipatory forms of governance based on science and risk illustrates most distinctively how scientific advances is also a necessary condition for understanding contemporary-risk governance regimes. A closer look at the relationships between risk and flooding makes it possible to uncover the wider politics of using science in defining the modern ideal of controlling the future.

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