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The SPR systems model as a conceptual foundation for rapid integrated risk appraisals: Lessons from Europe

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ABSTRACT

Coastal floodplains are complex regions that form the interface between human, physical and natural systems. This paper describes the development, application and evaluation of a conceptual foundation for quantitative integrated floodplain risk assessments using the recently-developed SPR systems model. The SPR systems model is a conceptual model that combines the well-established Source–Pathway–Receptor (SPR) approach with the concept of system diagrams. In comparison to the conventional approach, the systems model provides spatially explicit quasi-2D descriptions of the floodplain in terms of constituent elements and possible element linkages. The quasi-2D SPR, as it will henceforth be referred to in this paper, is not the final product of this work, but is an important intermediate stage which has been pursued as part of a wider European flood risk project THESEUS (www.theseusproject.eu). Further research is currently on-going to provide full quantification of the quasi-2D SPR, and to add further refinements such that hydraulic assessments could follow on easily and rapidly from the results of these appraisals.

The first part of the paper synthesises current conceptual treatment of coastal floodplains and identifies areas for improvement in describing coastal floodplains as complex systems. The synthesis demonstrates that the conceptual foundation of a 'typical' flood risk study often achieves a less comprehensive and integrated description of the floodplain than the quantitative models which it informs. From this synthesis, the quasi-2D SPR is identified as a more robust and informative conceptual foundation for an integrated risk assessment. The quasi-2D SPR has been applied to seven European coastal floodplains as part of the THESEUS project. The second part of the paper discusses in detail the application of the quasi-2D SPR to three contrasting floodplain systems — an estuary, a coastal peninsula and a mixed open coast/estuary site. The quasi-2D SPR provides a consistent approach for achieving comprehensive floodplain descriptions that are individual to each coastal floodplain. These are obtained through a robust, participatory model-building exercise, that facilitates developing a shared understanding of the system. The constructed model is a powerful tool for structuring and integrating existing knowledge across multiple disciplines. Applications of the quasi-2D SPR provide key insights into the characteristics of complex coastal floodplains — insights that will inform the quantification process. Finally, the paper briefly describes the on-going quantitative extension to the quasi-2D SPR.

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1. Introduction

Extreme events in the past decade, such as Hurricane Sandy (Schultz, 2013) and Hurricane Katrina (Seed et al., 2008) in the US and Storm Xynthia in France (Kolen et al., 2010), have demonstrated that it is impossible to completely control or prevent damage due to a flood event. Coastal floodplains world-wide are focal points for human settlement (McGranahan et al., 2007; Small and Nicholls, 2003) and often span large areas crossing administrative and geo-political boundaries (de Moel et al., 2009; EXCIMAP, 2007). They form the interface between human, physical and natural systems, which are in turn influenced by multiple natural (Friess et al., 2012; Gibson et al., 2007) and human-induced pressures and drivers (Hallegatte et al., 2013; Nicholls and Klein, 2005).

Several large-scale flood risk studies recognise that for effective strategic flood risk management, coastal floodplains should be analysed as regions of interacting physical, socio-economic and ecological systems (Hanson and Nicholls, 2012; Mokrech et al., 2011; Safecoast, 2008). Flood risk studies also recognise the need for expanding the spatial and temporal scales across which floodplains are studied (Dawson et al., 2009). Strategic flood risk management therefore requires risk appraisal models that are rapid as well as comprehensive. An exploratory risk appraisal model is currently being developed for the initial stages of a flood risk study, to identify the need for more detailed assessments. For the model to be comprehensive, a robust conceptual understanding of the floodplain is necessary. A strong conceptual foundation is an essential step to understanding the floodplain, framing the study problem and identifying knowledge gaps (Robinson, 2007). To ensure integration within the flood risk study, and ensure ownership of the problem by multiple stakeholders, this conceptual foundation will need to encourage a participatory approach to floodplain mapping (Priest et al., 2012). Narayan et al. (2012a) combined the Source–Pathway–Receptor (SPR) approach with system diagrams to provide an alternative conceptual model for descriptions of coastal floodplains. This conceptual model, referred to in this paper as the quasi-2D SPR, facilitates the development of a shared, comprehensive understanding of coastal floodplain systems.

This paper describes the development, application and evaluation of the quasi-2D SPR as the conceptual foundation for a probabilistic rapid risk appraisal model. The first part of this paper synthesises current conceptual treatment of coastal floodplains within large-scale integrated flood risk studies. The synthesis highlights the necessity for an integrated and comprehensive conceptual model of the coastal floodplain and the relevance of the quasi-2D SPR in this context. The second half of the paper describes the application of the quasi-2D SPR to three exemplary coastal floodplains, out of a total of seven sites, representative of a peninsula, an estuary and a mixed open coast/estuary. Lessons learnt regarding coastal floodplain systems are discussed and the model is evaluated with regard to its consistency, usefulness and universality across the seven pilot sites. The quasi-2D SPR is demonstrated in its applications to be a robust and useful conceptual foundation for further quantitative assessments. In conclusion, the paper also briefly discusses the use of the quasi-2D SPR in the next stages of development of the quantitative risk appraisal model.

2. Coastal floodplain conceptualisation in flood risk assessments

2.1. Conceptual models and frameworks for coastal floodplains

Risk has long been recognised as a central concept in coastal flood protection (Evans et al., 2006; Sayers et al., 2002). Coastal flood risk studies – which focus on the evaluation of coastal flood impacts on human assets – conceptualise the coastal floodplain in terms of two components: 1) flood defences that prevent or reduce the ingress of flood water; and 2) the floodplain behind the defences comprising all features considered to be at risk from flooding (Bakewell and Luff, 2008; FLOODSite Consortium, 2008; Naulin et al., 2012). The quantitative evaluation of risk in these studies is usually performed using numerical hydraulic models. Most flood risk estimation methods break the process down into four components — occurrence *probability* of an event; degree/extent of *exposure*; *susceptibility* of exposed assets to damage and; *value* of a harmed asset (Gouldby and Samuels, 2005).

Large-scale integrated flood risk assessments use conceptual frameworks to describe the relationship of the coastal floodplain system to external drivers and pressures (e.g., Evans et al., 2004; FLOODSite Consortium, 2009; Safecoast, 2008; North Carolina Division of Emergency Management, 2009; Naulin et al., 2012). In all of these studies, the state of the coastal floodplain is described using a well-established concept — the Source–Pathway–Receptor–Consequence (SPRC) conceptual model (Gouldby and Samuels, 2005). The SPRC model describes the floodplain in terms of the process of flood risk propagation — the initiation of a hazard at the shoreline, and its propagation through a flood pathway to a receptor with particular (negative) consequences (Fig. 1). The model was first used in the environmental sciences to describe the movement of a pollutant from a source, through a conducting pathway to a potential receptor (Holdgate, 1979) and was first adapted for coastal flooding in the UK by the Foresight: Future Flooding study (Evans et al., 2004).

The SPRC model presents a snapshot of the floodplain state. This is in turn is driven by inputs operating at a range of spatial and time-scales such as off-shore water levels and waves, climate change effects, and human influences such as coastal zone management decisions and actions. Therefore the model is usually nested within broader frameworks such as the Driver–Pressure–State–Impact–Response (DPSIR) that conceptualise the influence of pressures and drivers external to the floodplain (Kristensen, 2004). In this manner cause–effect feedbacks between the floodplain system and external influences can be conceptualised and described. Fig. 2 shows the relationship between the DPSIR framework and the SPRC model. Fig. 2 illustrates that the SPRC model can be divided into two components based on its nesting within the DPSIR — a floodplain state description (S–P–R) and a description of the consequences to changes in this state (C). Flood risk assessments typically follow this division, using the S–P–R model to assess flood probabilities of elements within the floodplain and separate economic models to evaluate flood consequences. This paper also focuses on describing the floodplain state and will henceforth only discuss the SPR model.

2.2. The SPR model: role and function in floodplain risk assessments

One reason for the popularity of the SPR as a conceptual model for floodplain state descriptions is that it readily translates to the components of risk estimation (see Fig. 3).

The SPR model describes flood risk propagation across the floodplain as a linear process from Source to Receptor although it allows conceptualisation of far more than just risk propagation. In practice, specific and often detailed, numerical models and analysis techniques exist for individual floodplain systems and elements and each step of the process

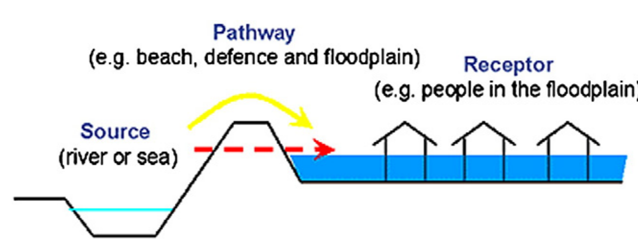

Fig. 1. 1D SPR-C model for coastal flooding. (FLOODSite Consortium, 2009).