Information Flows Ahead of the Rhine and Ahr River Flooding in Germany

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ABSTRACT

In July 2021, the swollen waters of the Rhine and Ahr Rivers rushed through communities in North Rhine-Westphalia and Rhineland-Palatinate, Germany, destroying homes and infrastructure and claiming the lives of nearly 200 people. Our research, funded by NASA, examines the information flows from the early warnings of satellite imagery down to the community-level sirens warning people of impending danger. Warnings were issued by the German National Weather Service on July 12 describing the impending dangerous weather conditions and predicted widespread damages. Because of the decentralized governance and communication systems, the messaging was inconsistently distributed, which undermined coordinated responses. Warnings were issued for several towns along the Rhine River; however, flood risk was downplayed for the Ahr Valley. Missteps left the public uninformed and resulted in circumstances like the residents of Erftstadt experienced where sirens sounded the first warnings overnight on July 14, and firefighters went door-to-door warning residents to flee to higher ground as the Erft River flooded the town. Reasons explaining why these events unfolded as they did are complicated and intertwined with issues of governance. To explore this event, we use system dynamics modeling to describe information flow from centralized data sources through agencies, governance structures, and communication channels down to the impacted populations. People decided to evacuate or not based on the credibility, timeliness, and urgency of the messaging. Using system dynamics modeling, we identify critical points in the information flow processes and how effective, timely, contextualized, and credible feedback in those processes could improve outcomes.

INTRODUCTION

The storm system that unleashed an unprecedented amount of rainfall in parts of Western Europe in July 2021 leading to the flood devastation was forecasted several days in advance. Meteorological agencies reported their forecast predictions to federal and state agencies with the expectation that emergency plans would be followed and those vulnerable to flooding would be moved out of harm's way. In many communities, this did occur. However, in several communities, the warning messages either never went out, were ignored, or failed to reach the population at risk. By the time community members at risk recognized the impending danger it was often too late for them to act. As a result, the loss of life in these communities was tragically high. The fatalities in Germany were 196 and in Belgium were 43. The question remains as to why the information flows were so encumbered that they failed to reach or motivate the population at risk.

To examine this problem, we developed a system dynamics model [1-3] to illustrate the critical points in the information flow processes where complications may have emerged. Causal loop diagrams (CLDs) are used to conceptually model dynamic systems in a holistic manner, graphically mapping how variables influence one another. These diagrams are particularly useful in uncovering a system's underlying feedback structures. Causal loop diagrams illustrate the network of cause-and-effect relationships for the considered system. The feedback effects formed may either be balancing or reinforcing loops which are denoted by ***B*** and ***R***, respectively. To define relationships, arrows are drawn and supplemented by a **+** or **–** sign to determine whether they have positive or negative relationships. An interruption of these arrows by a double line **||** symbolizes time delays [2-5].

Using this methodology, we consider the circumstances of the German towns of Alternahr and Altenburg situated on the Ahr River to illustrate where information flow and critical points failed. For comparison, we similarly show the Belgian town of Pepinster on the Vesdre River.

METHODOLOGY

A System Dynamics Causal Loop Diagram for the Information Flows Influencing Evacuation Ahead of the River Flooding

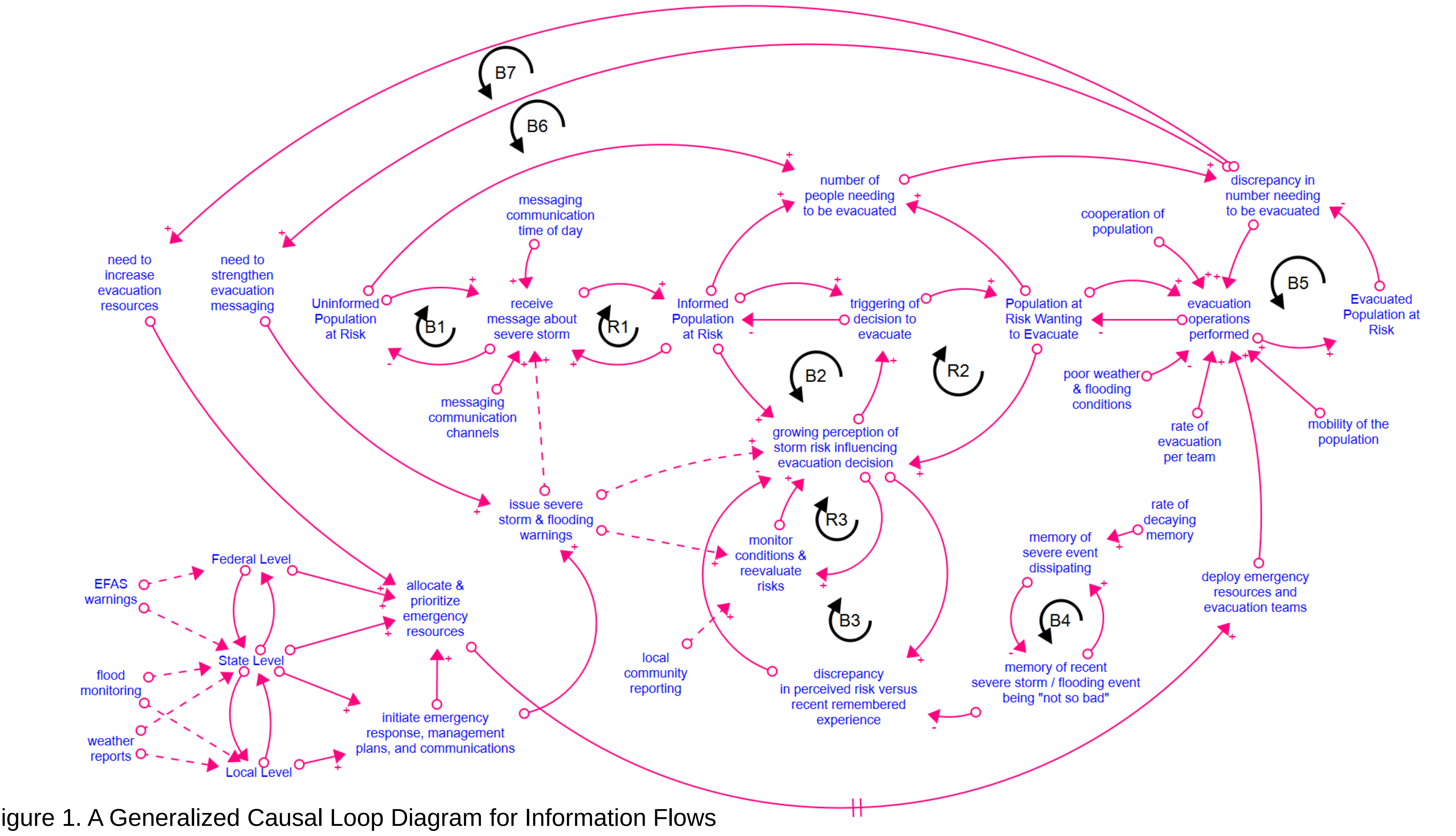

Figure 1. A Generalized Causal Loop Diagram for Information Flows

RESULTS

Altenahr, Rhineland-Palatinate, Germany

Altenahr is a municipality situated on the river Ahr. In July 2021, the town received the warnings but perceived the event to be low risk because the recent flood of 2016, considered severe, did not result in significant damage [6]. Figure 2 highlights the CLD failure point with the past memory being "not so bad" outweighing the updated warnings and ongoing reevaluation. Figures 3(a,b) show the event aftermath in August 2021 [7].

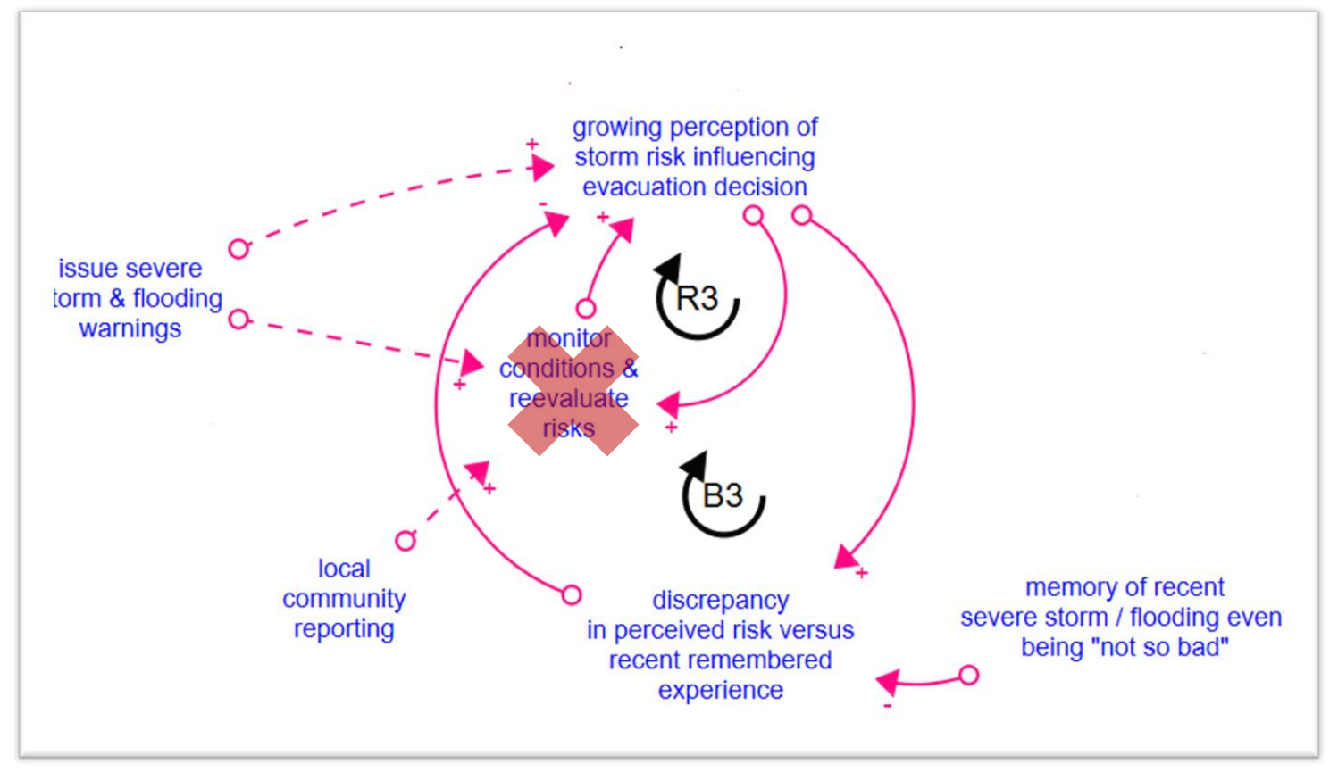

Figure 2. CLD failure points for Altenahr

Figure 3. Altenahr's AM Tunnel (a) damaged bridges, water treatment facility, railway, and roadway; (b) damaged buildings, roadway, and tunnel; credit: GEER Team, August 2021

Altenburg, Rhineland-Palatinate, Germany

Altenburg is a village adjacent to Altenahr, also situated on the river Ahr. They also received warnings but did not realize the severity of the event [6]. Figure 4 highlights the CLD failure points associated with not monitoring ongoing warnings and revising perceived risks and not reaching a decision to evacuate. Figures 5(a,b) show Altenburg during the pre-event and flood event states.

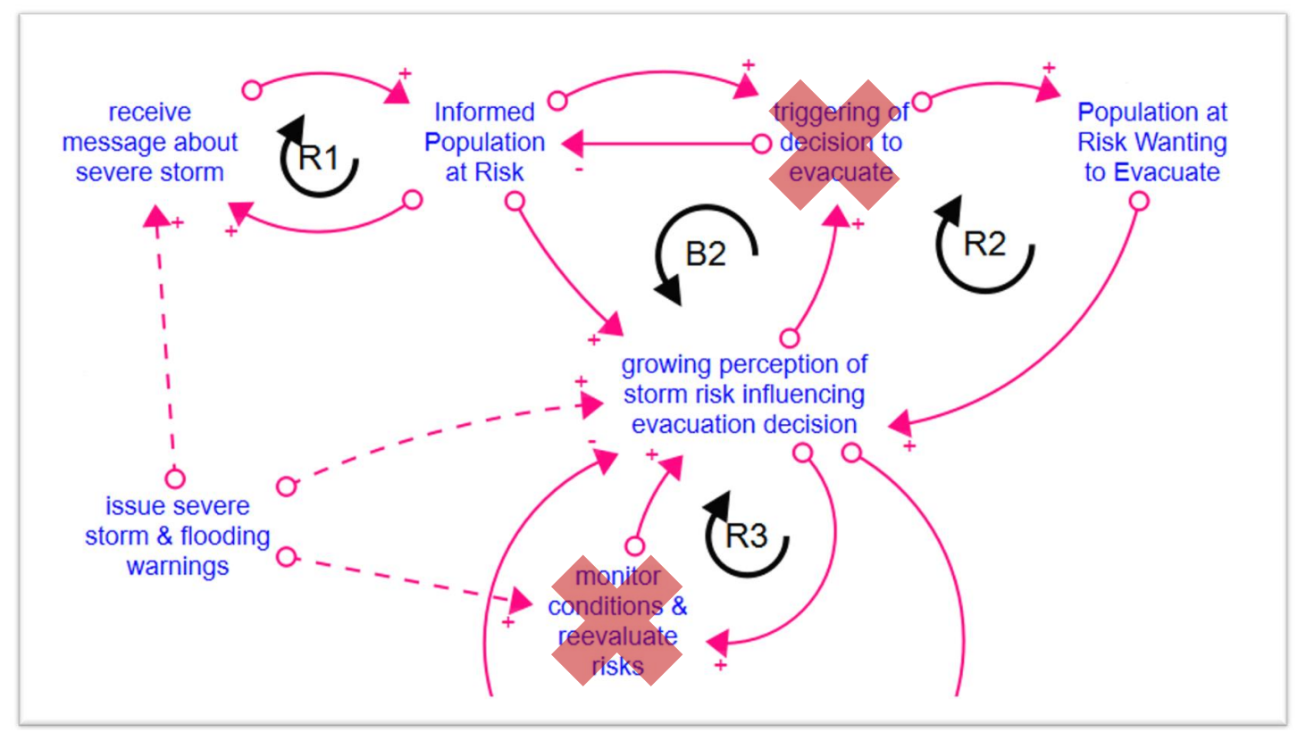

Figure 4. CLD failure points for Altenburg

Figure 5. Altenburg aerial images (a) pre-event state, and (b) flooded state July 17; credit: Gerhard Launer and Polizei, Picture Alliance

Pepinster, Wallonia, Belgium

Pepinster is a municipality situated on the river of Vesdre. In July 2021, the village did not receive the EFAS warnings and was excluded from the Be-Alert warnings based on districting [6]. The event, which began to unfold overnight, blindsided the community. Figure 6 highlights the failed warnings and responses. Figure 7 shows the aftermath.

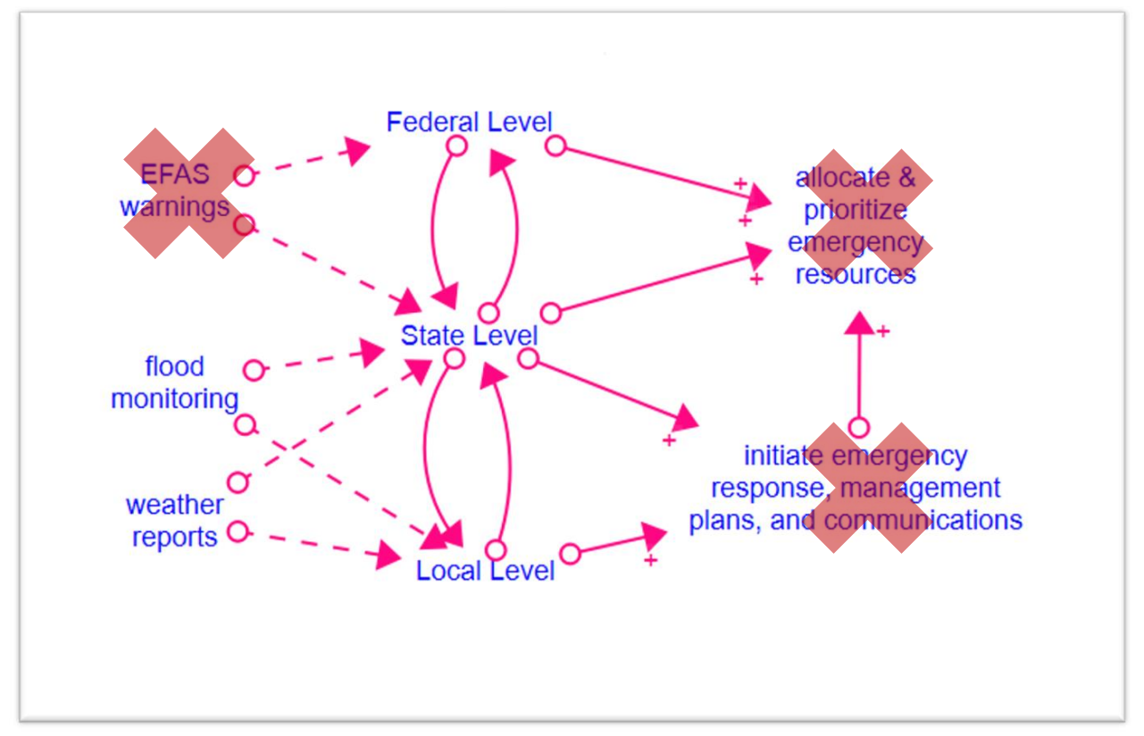

Figure 6. CLD failure points for Pepinster

Figure 7. Pepinster post-event state July 18; Credit: Daily Mail Co. UK, July 2021

DISCUSSION

The response to emergency warnings concerning severe weather and flooding can vary dramatically between communities. The response, or lack of one, can have a dramatic impact on whether lives are lost or safeguarded. The causal loop diagram (CLD) in Figure 1 illustrates the dynamics of the information flows influencing evacuation ahead of the river flooding. Feedback loops in the CDL are identified as either balancing (***B***) or reinforcing (***R***) loops, with a reference. The feedback influence, either in promoting or resisting evacuation, is detailed below.

B1: Warning messages received transform the uninformed to informed at a rate based on the effectiveness of the communication channel and the time of day. Transformation reduces the number of uninformed.
R1: Growing number of informed influence the rate uninformed are converted to informed based on information through word-of-mouth.
B2: Informed must evaluate the applicability of the warning information to establish their perception of risk and determine the need to evacuate.
R2: Perception of risk may increase, triggering evacuation commitment, as the number already committing to evacuate grows (i.e., FOMO).
B3: Perception of risk may decrease as reflections on previous severe storms and flooding provide local context dispelling threat concerns.
R3: Perception of risk may increase as new warning information and the local context of the situation are made available and revised.
B4: Memory of recent severe storms and flooding deteriorates over time according to a rate of decaying memory.
B5: Discrepancy in the number of evacuated and the number needed to be evacuated drives the requirement to expedite evacuation operations.
B6: Discrepancy in the number of evacuated and the number needed to be evacuated initiates the need to strengthen and intensify evacuation messaging to influence those not yet committed to evacuating.
B7: Discrepancy in the number to be evacuated initiates the request to increase emergency resource capacity to help facilitate the evacuation.

Using this qualitative causal loop diagram as a guide, a quantitative stock and flow system dynamics model could be developed using estimated parameter values and numerical relationships [3-4].

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