

Signals without action: a value chain analysis of Luxembourg's 2021 flood disaster

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1. WHY THIS MATTERS

Early Warning System performance is shaped by how institutional structures and procedural thresholds determine whether available signals lead to action, not by forecast accuracy alone.

During Luxembourg's July 2021 floods, strong forecast signals were available from 7 July. Anticipatory action remained limited.

How did institutional design shape whether forecast signals led to protective action?

2. EVENT AT A GLANCE

€145M+ insured damages

6,500+ homes inundated

105.8L/m² rainfall in 24h, new record

>6 hours between red flood alert and first Crisis Unit

The July 2021 floods were Luxembourg's costliest disaster on record.

3. RESEARCH APPROACH

How was the event analysed?

WMO WWRP HIWeather Value Chain framework

- Database questionnaire
 - structured analysis across the warning chain
 - Event reconstruction
 - Independent analysis
 - Waterdrop Model
- Applied retrospectively using forecasts, warnings, and institutional records

4. INSTITUTIONAL CONTEXT

MeteoLux Weather Service, based at Findel Airport (single official station)

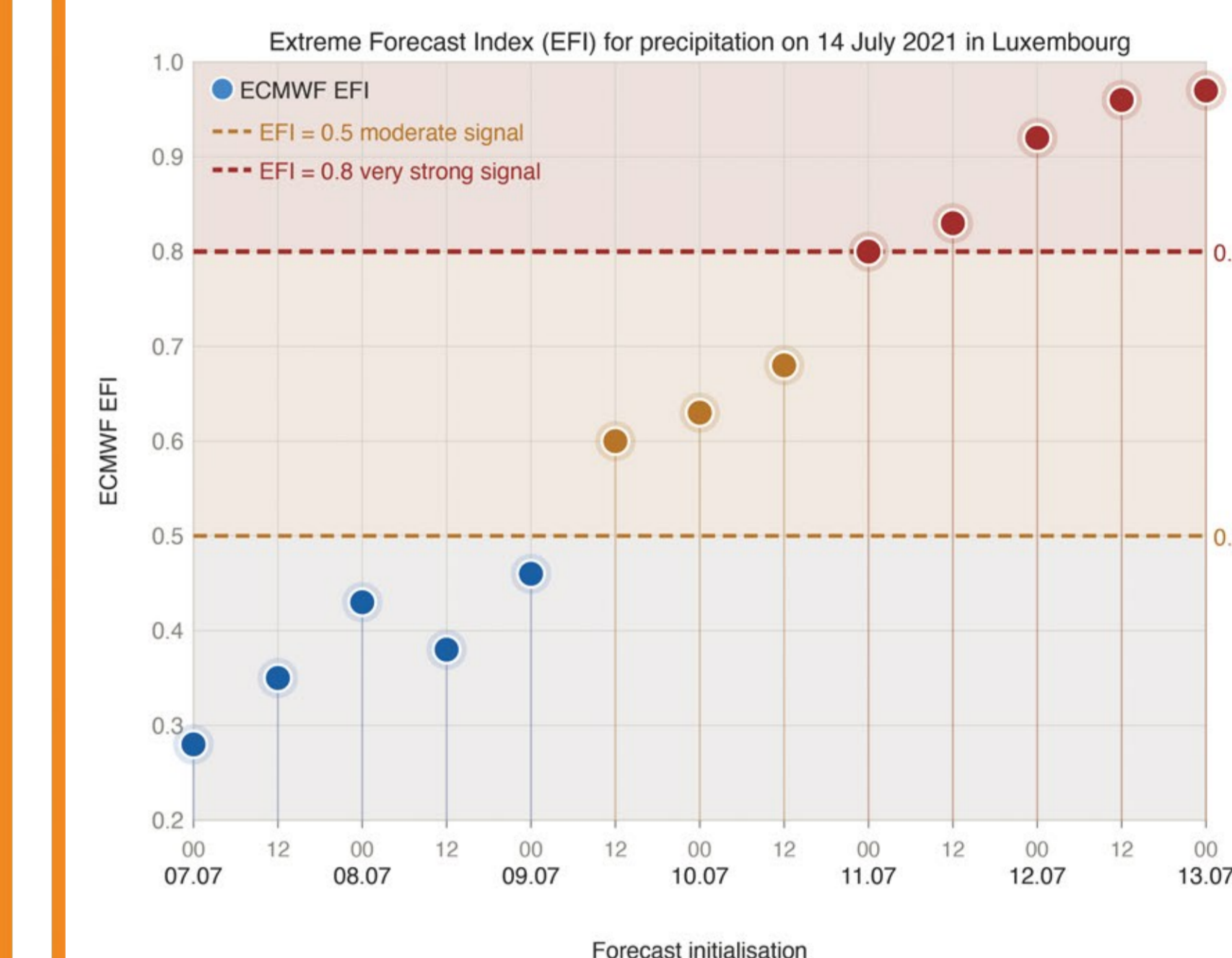
AGE Hydrological Service

CGDIS Grand-Ducal Fire & Rescue, operational emergency response

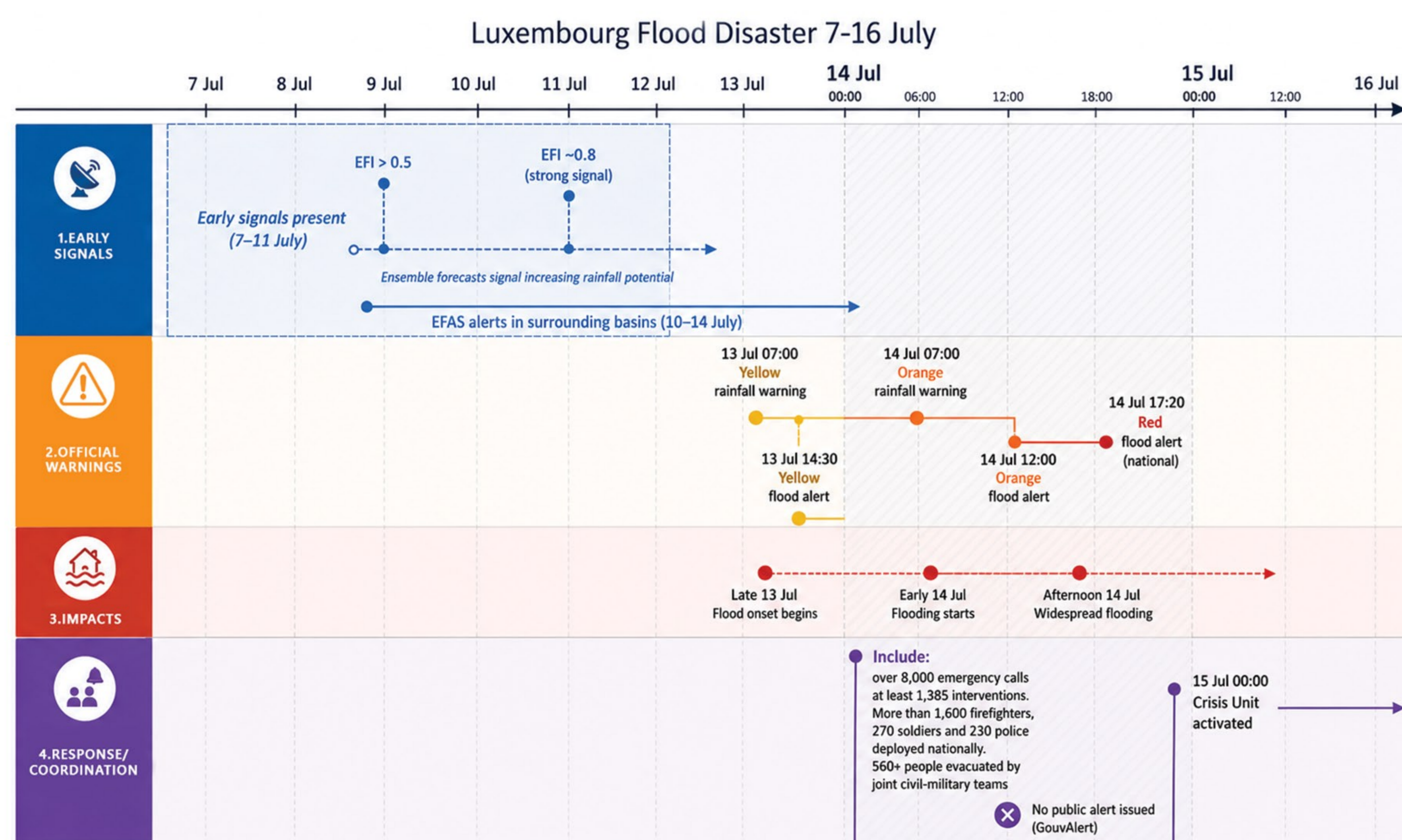
HCPN High Commission for National Protection

Crisis Unit Activated by Prime Minister

5. EXTREME FORECAST INDEX

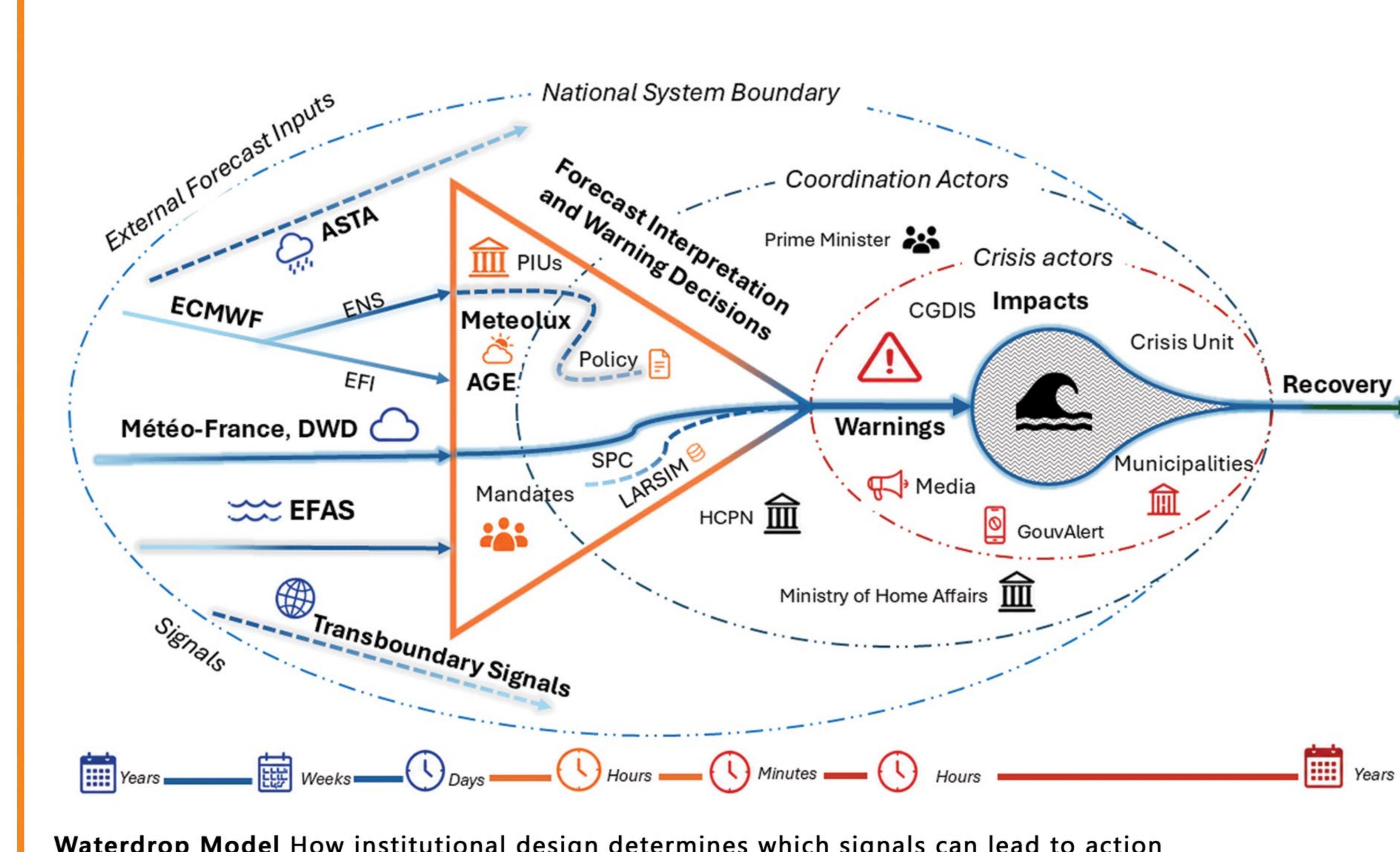


6. WARNING TIMELINE



Warning Timeline Forecast signals present from 7 July. Official alerts issued across 13-14 July

7. WATERDROP MODEL



Waterdrop Model How institutional design determines which signals can lead to action

8. KEY FINDINGS

1. Early forecast signals existed
2. Warnings remained tied to deterministic thresholds
3. Available information was not fully used
4. Thresholds delayed warning escalation
5. Coordination followed impact, not risk
6. Public alerting systems were not effectively used
7. Institutional design shaped the outcome
8. No independent post-event review was conducted

The signals existed. The procedures were followed. The mandates were respected. The system performed as designed. That was the problem.

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Abstract. Effective Early Warning Systems are essential for reducing disaster risk, particularly as climate change increases the frequency of extreme events. The July 2021 floods were Luxembourg's most financially costly disaster to date. Although strong early signals were available and forecast products were accessible, these were not consistently translated into timely warnings or coordinated protective measures. While response actions were taken during the event, they occurred too late or at insufficient scale to prevent major impacts. We use a value chain approach to examine how forecast information, institutional responsibilities, and communication processes interacted during the event. Using a structured database questionnaire alongside hydro-meteorological data, official documentation, and public communications, the analysis identifies points where early signals did not lead to anticipatory action. The findings show that warning performance was shaped less by technical limitations than by procedural thresholds, institutional fragmentation and timing anomalies across the chain. A new conceptual model, the Waterdrop Model, is introduced to show how forecast signals can be filtered or delayed within systems not designed to process uncertainty collectively. The results demonstrate that forecasting capacity alone is insufficient. Effective early warning depends on integrated procedures, shared interpretation, and governance arrangements that support timely response under uncertainty.

Introduction
 1.1 Early Warning Systems

Effective Early Warning Systems are essential for disaster risk reduction. They identify, assess, and monitor upcoming hazards, allowing people to take action to safeguard communities and livelihoods before a hazard event occurs (Glezer and Ponce, 2023; Kelman and Glantz, 2014; Tupper and Ponce, 2023; WMO, 2023). Early Warning Systems have therefore become central to disaster risk management (UNDRR, 2015), yet their performance remains inconsistent, even in well-resourced settings (Allert et al., 2012).

Early Warning Systems for hydro-meteorological hazards consist of interconnected components, including weather and hydrological forecasting, communication technologies and behavioural science (WMO, 2024a). Improving and implementing effective Early Warning Systems requires a holistic, interdisciplinary perspective that recognises the complex interactions between science, technology and decision-making (Hermans et al., 2022; Oliver-Smith, 2018).

There is an increasingly agreed definition of an Early Warning System, as disciplinary and institutional perspectives vary (Kelman and Glantz, 2014). The United Nations Office for Disaster Prevention and Relief (UNDRR) defines an Early Warning System as:

“... a system that provides timely and accurate information and advice to enable people to take action to reduce the risk of loss of life and property” (UNDRR, 2015).

As hydro-meteorological hazards become more frequent and intense, global efforts to expand and improve early warning capabilities have gained renewed urgency (Tupper and Ponce, 2023; WMO, 2023). Early Warning Systems have therefore become central to disaster risk management (UNDRR, 2015), yet their performance remains inconsistent, even in well-resourced settings (Allert et al., 2012).

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