IMPACT-BASED FLOOD WARNINGS IN SWEDEN
DEVELOPMENT AND FIRST EXPERIENCES

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SUMMARY

The Swedish Meteorological and Hydrological Institute SMHI has in October 2021 introduced impact-based flood warnings in addition to the existing warnings for high flows. The flood warnings can capture **fluvial flooding** along rivers and lakes where the upstream area is larger than 50 km^2. Pluvial flooding cannot be simulated within this setup, but it is taken account of in a meteorological warning, "cloud burst".

The general procedure of calculating the flood extent is similar to the Rapid Impact Assessment within EFAS and builds on a **flood inundation map library approach** (Fig. 1).

First experiences show that the system is working reliably, but also that there is a high number of wrongly highlighted areas that need to be manually rejected.

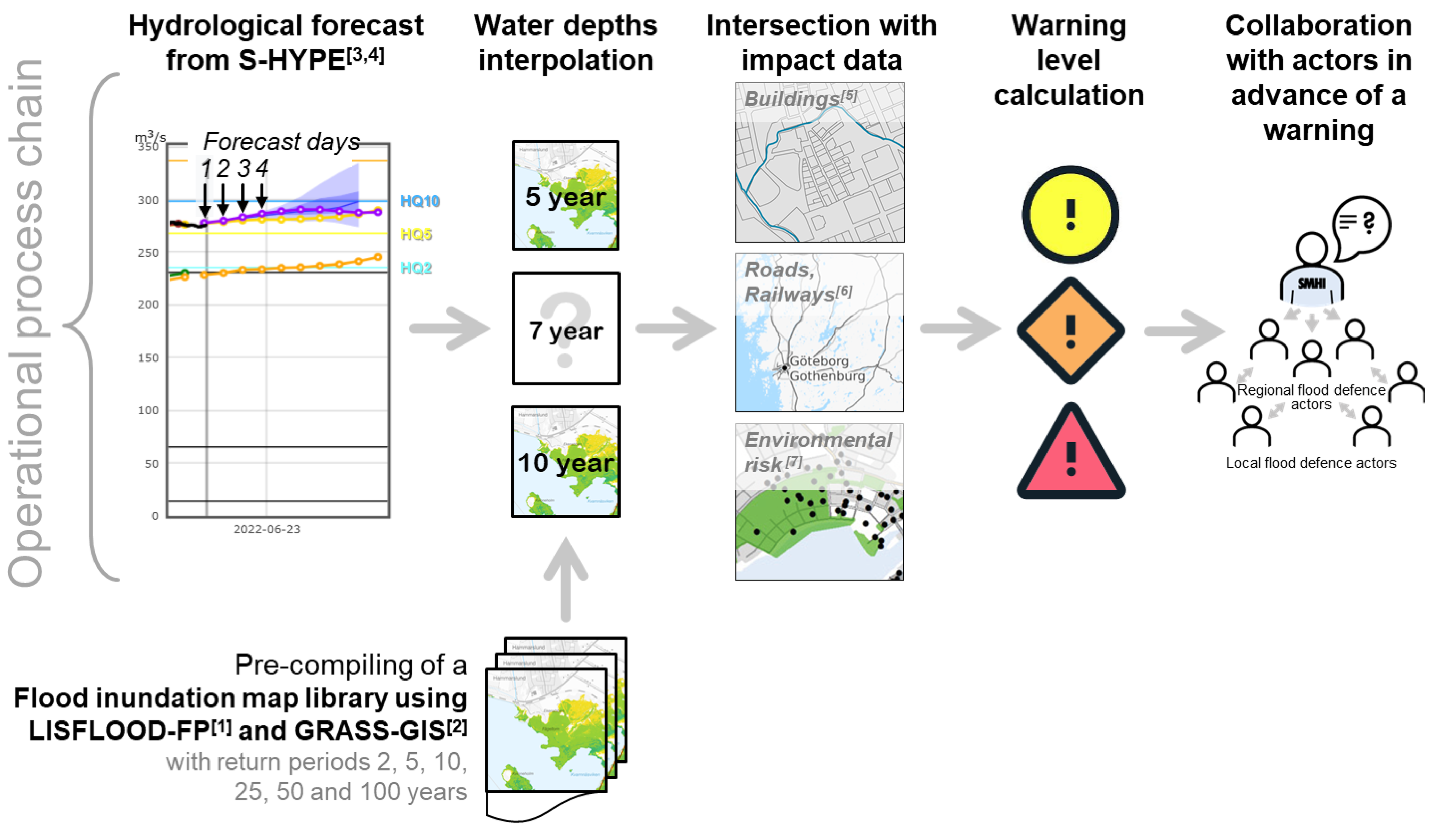

Fig. 1 *(to the right)*: **MODELLING STRATEGY**
Schematic of the modelling strategy used for the impact-based flood warnings in Sweden. A flood inundation map library is created in advance in offline simulations and applied in the operational process chain run twice daily.

GENERAL MODELLING SETUP

Floods are simulated for 13,500 sub-catchments of the national hydrological model S-HYPE[1,2]. Only sub-catchments with an upstream area larger than 50 km^2 are included. Approximately 10,000 river catchments are modelled with the coupled 1D-2D hydraulic model LISFLOOD-FP[3] and around 3,500 lake catchments are modelled with a simplified GIS-interpolation model in GRASS-GIS[4], where inundation is a function of water level from S-HYPE.

The simulated catchments have an average size of 8 km^2. The spatial resolution is generally 5 m, but was locally increased to 1 m where dam structures were not properly reflected. A flood inundation map library was generated that includes water depth maps for 6 return periods (2, 5, 10, 25, 50, 100 years) for each of the simulated catchments.

HYDRAULIC MODEL FOR RIVER CATCHMENTS

The river channel in each catchment model needs to be defined with depth, width and friction (Manning's coefficient). These values are constant throughout the whole channel. Hydraulic geometry[8] is used to derive depth and width values on a national scale.

Constant inflow at defined return periods during 72 hours is used as upstream boundary condition. Downstream boundary conditions can be either a lake or the sea with a constant level or normal depth in absence of a lake/sea level.

The channel friction parameter was calibrated and the models were classified according to their deviance from observed water levels (Fig. 2).

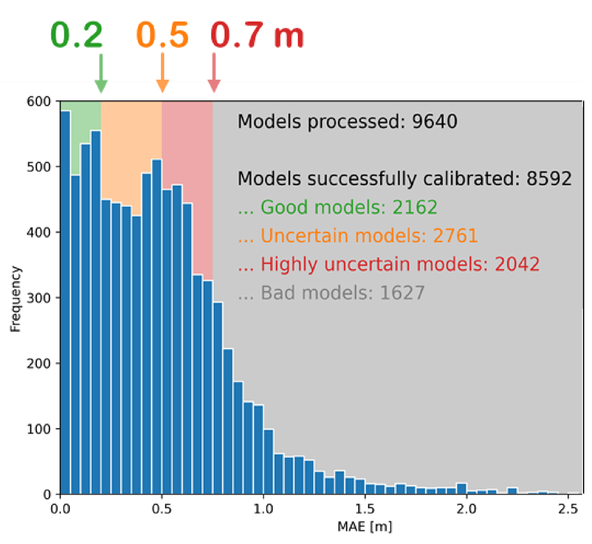

Fig. 2 *(to the right)*: **CALIBRATION RESULTS FOR RIVER MODELS**
The hydraulic models for the river catchments were calibrated and classified according to deviance from observed water levels.

IMPACT CALCULATION

The only calculation that is done operationally is the interpolation of the water depth map to the forecasted flow return period (Fig. 1). The associated impacts are automatically calculated through intersection of the interpolated water depth map with different impact data maps, e.g. roads and railway network or buildings[5,6]. The impacted objects are automatically summarised for minor warning areas (around 5 km of a river stretch or lake shore) and visualised in a hydrological forecasting system that the officer on duty analyses twice daily (Fig. 3).

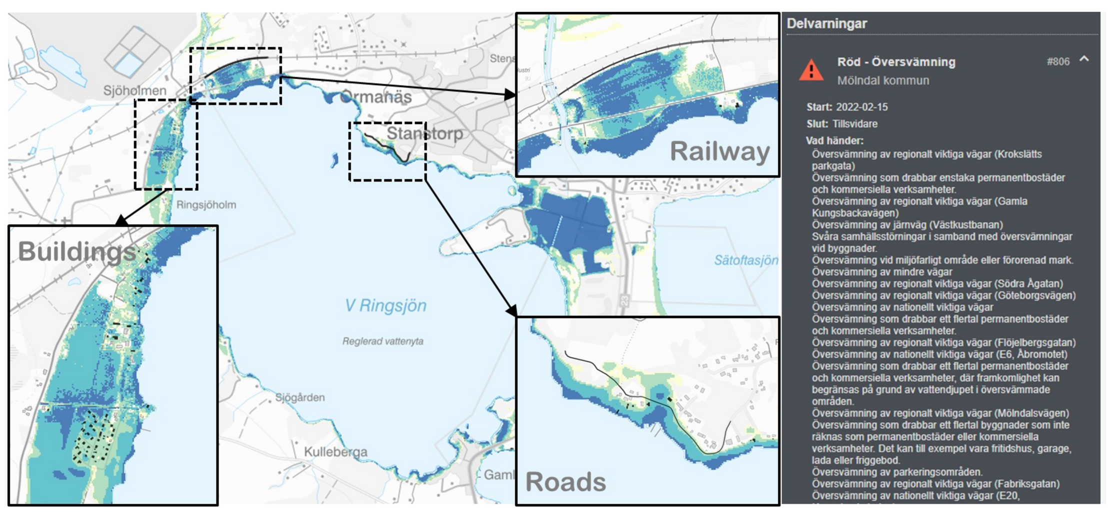

Fig. 3: VISUALISATION IN FORECASTING SYSTEM
The impacted objects are automatically calculated and summarised for minor warning areas (dashed rectangles) .

Table 1: WARNING CRITERIA
Summary of warning criteria for the different types of impact data (roads and railways, buildings, other areas) per warning level.

	Yellow *)	Orange	Red
Roads/railways	Flooding of **local** road infrastructure	Flooding of **regional** road infrastructure Flooding *near* (i.e. within 50 m) rail infrastructure	Flooding of **national** road infrastructure or rail infrastructure
Buildings	Flooding of buildings that are not used for residential housing or commercial businesses	Flooding of buildings that are used for residential housing or commercial businesses	*Similar to orange*, but with water depth > 30cm.
Other areas	Flooding of parking areas or agricultural land	Flooding of environmentally hazardous areas or contaminated land	
Vital functions			Flooding of vital societal functions (e.g. rescue services, hospital)

*) *Currently no yellow warnings until the system has been tested and applied for a certain time*

ISSUING WARNINGS

The warning level is automatically assessed according to pre-defined criteria (Tab. 1). A unique feature of the impact-based warnings in Sweden is the mandatory collaboration with regional flood defence actors in advance of a warning, allowing to incorporate local knowledge into the warning.

Flood warnings are aggregated and summarised for warning areas in a rather general way on the warning homepage (Fig. 4). No detailed water depth maps are shared with the public.

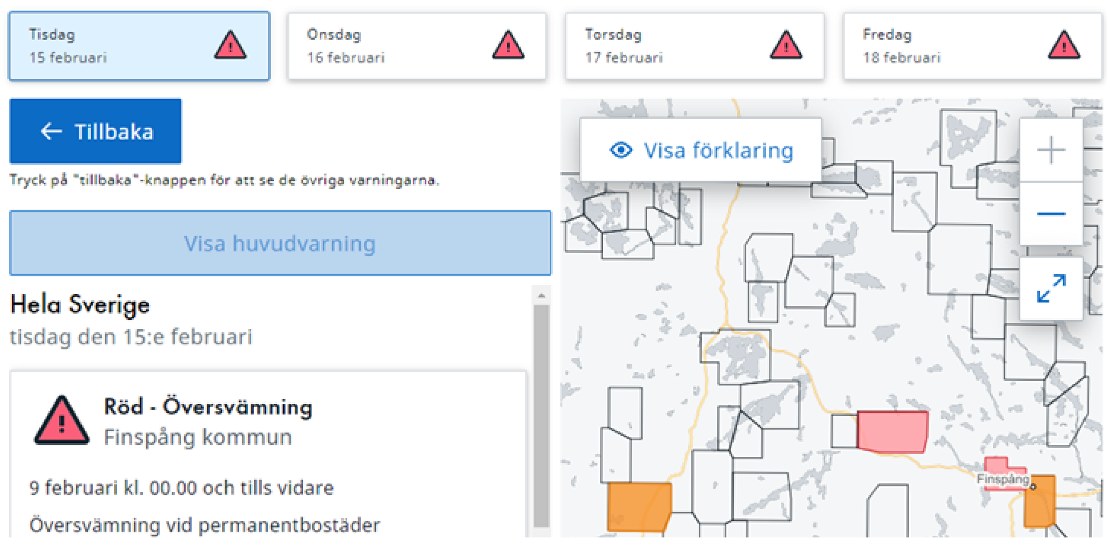

Fig. 4: WARNINGS FOR THE PUBLIC
View can be switched between the 4 days in the forecast period.

VALIDATION

A validation for case studies in southwestern Sweden in 2020 shows promising results for higher flow return periods.

Fig. 5: QUALITATIVE VALIDATION
Validation using aerial images from a flooding event in 2020.

LESSONS LEARNED

- Occasionaly high workload for officers with many wrongly highlighted warning areas in the system.
- Flooding due to flows of lower return periods (5-10 years) tends to be overestimated and thus even the associated impact.
- Collaboration with regional actors in advance of a warning proves to be an effective quality check, possibly avoiding both false and missed warnings.

FUTURE DEVELOPMENTS

Short-term

- Adjustment of warning criteria
- Updated input data (DEM, river network)

Long-term

- Local parameterisation of critical catchments (measurements)
- Variable inflow instead of constant

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[2] Neteler, M., Bowman, M.H., Landa, M. & Metz, M., 2012. GRASS GIS: A multi-purpose open source GIS. Environmental Modelling & Software, 31: 124–130.

[3] Lindström, G. 2010. Development and test of the HYPE (Hydrological Predictions for the Environment) model – A water quality model for different spatial scales. Hydrology Research, 41(3–4): 295–319.

[4] Strömqvist, J., Arheimer, B., Dahné, J., Donnelly, C. & Lindström, G. (2012). Water and nutrient predictions in ungauged basins: set-up and evaluation of a model at the national scale, Hydrological Sciences Journal, 57:2, 229-247.

[5] Lantmäteriet. https://www.lantmateriet.se/en/geodata/geodataportal/ (several data layers, e.g. buildings, water courses, DEM).

[6] Trafikverket. https://bransch.trafikverket.se/ (several data layers: roads, railways, bridges).

[7] Swedish county administrative boards. EBH-kartan, https://extgeoportal.lansstyrelsen.se/standard/?appid=ed0d3fde3cc9479f9688c2b2969fd38c (open source, in Swedish).

[8] Leopold, L.B. & Maddock, T. 1953. The hydraulic geometry of stream channel and some physiographic implications. U.S. Geological Survey Professional Papers, 252: 57p.