Early Warning System for Flash Floods

Catchment Analysis and Sensor Network Design

Trstená, Slovak Republic

Merατch Floodar

Concept project ~ 2026 ~

What You Will Find in This Report

This report explains how water behaves in this catchment, why the sensor network is designed the way it is, and how the warning capability is gradually strengthened — from measurement, through model training, all the way to predictive warnings.

Local Flood Warning for Trstená

The Floodar early warning system is a fully location-specific solution designed for the town of Trstená, providing warnings ahead of a flood before it forms.

It is based on a thorough hydrological analysis (the behaviour of water in the surrounding area) and geospatial analysis (what maps and geographic data tell us about your territory). Behind the design stands our team: hydrologists, specialists in working with maps and spatial data (GIS), and environmental engineers with decades of experience in floods and early warning systems.

In order for Floodar to warn you reliably and in time, a network of sensors must be built in your catchment. These sensors continuously measure key data — for example, the amount of precipitation and river water levels. The measured data are then transferred, stored and evaluated quickly and reliably. It is from their analysis that a system emerges capable of issuing flood warnings in advance.

6 951

Inhabitants in the protected area

132 km²

Catchment area

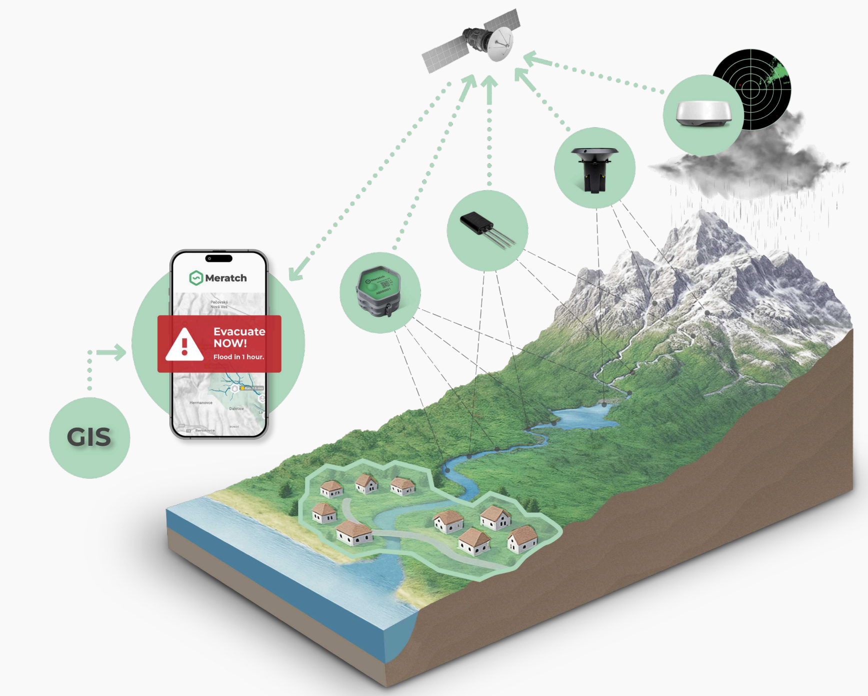
1 015 mm

Average annual precipitation

The population estimate (2025) is based on the Global Human Settlement Layer database (Pesaresi et al., 2024), modelled on harmonised census data.

What the Floodar System Consists Of

Based on a hydrological analysis of the territory and of the watercourses contributing to the flood hazard, we have designed a wireless observation network — that is, a network of sensors that are fully autonomous and require no operator. If there are structures in your location that flood repeatedly, we recommend adding a water-level sensor for each of them.



Without the Floodar System

- No observation system, or an insufficient one
- Limited response capacity and inadequate preparedness
- Restless nights and disaster preparation
- Rising frequency of extreme weather
- Lack of data for stakeholders
- Property left at the mercy of uncontrolled water

With the Floodar System

- ✓ More time to save lives
- ✓ Data mean early preparations
- ✓ Emergency responders gain more time to act
- ✓ Property protected through timely relocation
- ✓ Communities trust the town's planning
- ✓ Minimal insurance costs thanks to prevention

3. How It Works

From Catchment to Warning

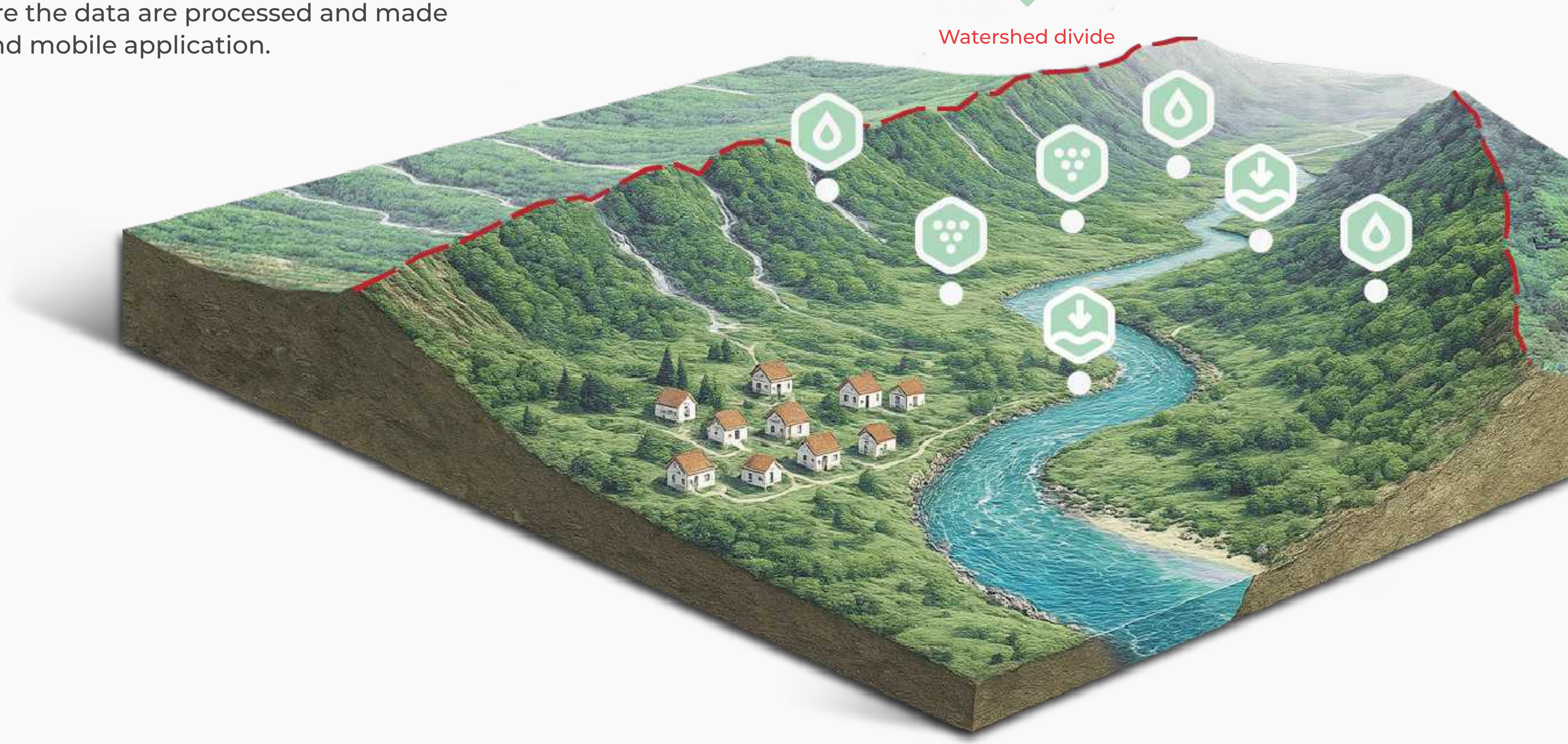
A catchment is the area from which all water (both rain and melting snow) flows down to one common point — for example, a river or a lake. Picture it as a large funnel that collects water from the entire surrounding area.

Suitably placed sensors independently (without an operator) monitor the weather and water conditions in the catchment — that is, rainfall and river water levels — and at regular short intervals send the measured values to a centre. There the data are processed and made available to you through a web and mobile application.

The Advantage of a Local Solution

The solution is thoroughly tailored to your location and fully under your control — unlike the nationwide warnings of the country's hydrometeorological system.

Sensors distributed across the catchment autonomously monitor hydrological and meteorological phenomena.



Get to Know Your Catchment

To be able to prevent flooding, we first need to define the entire area from which water can flow into it during rainfall. This area is called the catchment (or river basin). A simple rule applies: the larger the catchment, the more water can flow into the town during a storm.

- Precipitation is drained mainly by the Oravica stream, as well as the Trsteník stream.
- On the Brezovica stream there are 3 water reservoirs (0.68 ha in total).
- On the Oravica stream there is 1 water reservoir (0.19 ha) and further smaller ones.

132 km²
Trstená catchment area

5
Water reservoirs (0.90 ha)

Catchment   Protected area

Catchment map

Catchment boundaries were delineated based on coordinates derived from our hydrological model; water bodies according to OpenStreetMap (2024).

Slope Gradient and the Risk of Flash Floods

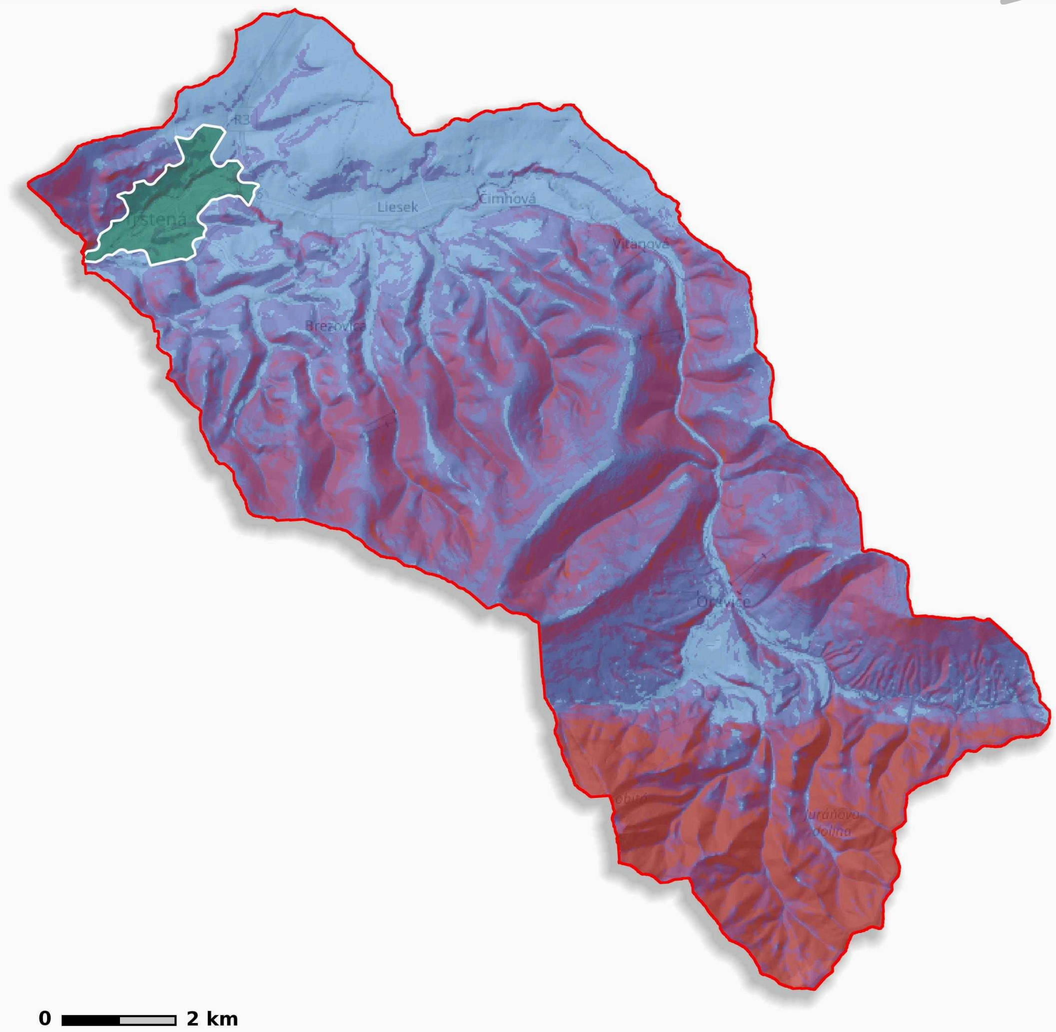
Steep slopes have a major influence on floods: the steeper the terrain, the faster and more concentrated the water flows down it. When it rains at higher elevations, water rushes rapidly from the hills into rivers and streams. Heavy rain in such elevated areas can therefore cause rapid and violent flooding — which we call flash (torrential) floods. Put simply: the greater the differences in elevation across the territory, the higher the risk of sudden flooding.

590 m Lowest point	**875 m** Average elevation	**1 684m** Highest point

Distribution of Elevations in the Catchment

0 – 5°	22.49 %	Very low risk
5 – 10°	24.73 %	Low risk
10 – 15°	22.5 %	Moderate risk
15 – 25°	20.27 %	High risk
> 25°	10.02 %	Very high risk

The analysis suggests that the territory has a mixed character with varied landform types.



Catchment
Protected area

Elevation map of the catchment.

Geodesy, Cartography and Cadastre Authority of the Slovak Republic (ÚGKK SR) (2021). Digital Elevation Model of the Slovak Republic, DEM (Digital Elevation Model) 3.5. Distributed via: data.gov.sk.

Terrain Classification and Flood Susceptibility

Geomorphons are a way of automatically classifying terrain types. Based on the surrounding elevations, they recognise basic landforms: valleys, ridges, slopes, plains or saddles. In predicting flash floods they are useful because they show where water naturally flows, where flows converge, and where runoff first accumulates or accelerates. Thanks to them, we can identify the places most susceptible to flooding, particularly in steep or rugged terrain.

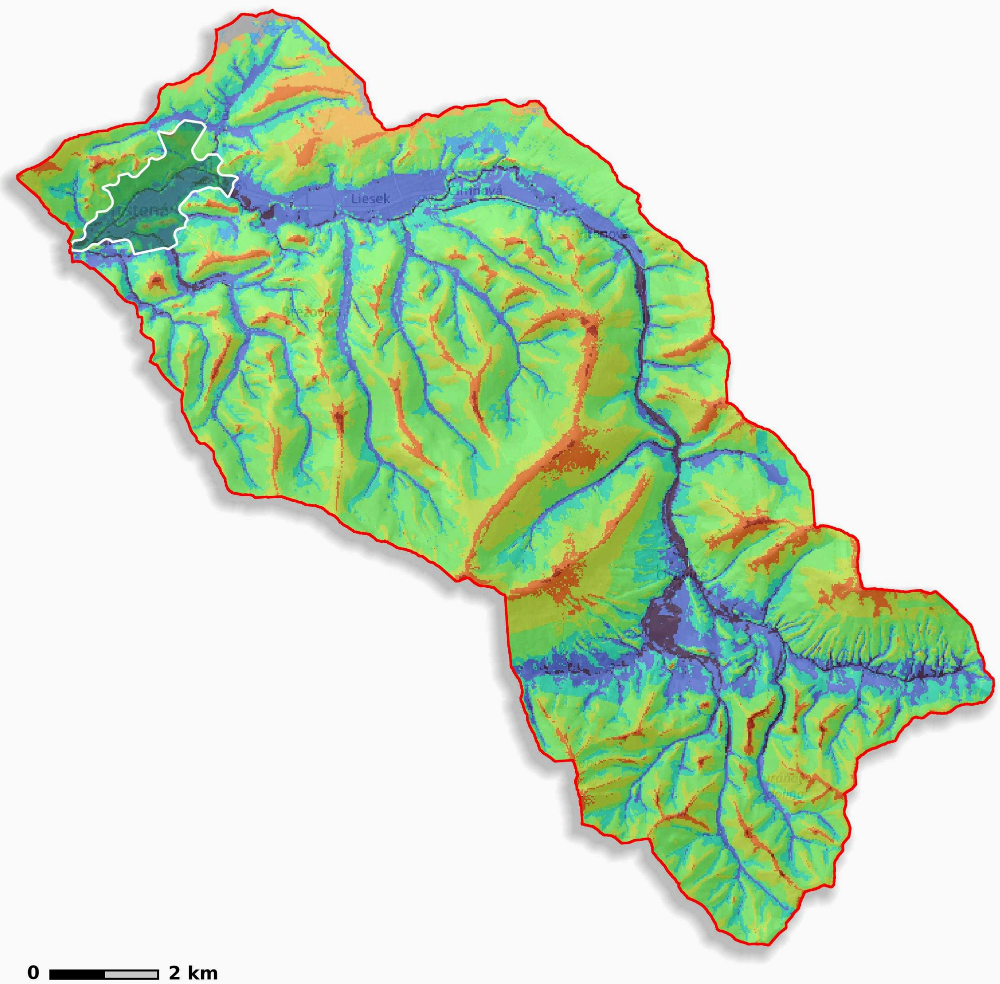
Dominant Landforms and Flood Risk

Slope 42,22 % **High risk**

Spur 19.26 % **Moderate risk**

Hollow 14,67 % **High risk**

The most common landform in the area is the slope. The territory has a mixed character with varied landform types —
a configuration typical of a rapid flood response.



Flat Peak Ridge Shoulder Spur

Slope Hollow Footslope Valley Pit

Catchment Protected area

Geomorphon map

Derived from the classification of geomorphons (Jasiewicz & Stepinski, 2013).

7. Land Cover

How the Surface Affects Water Runoff

The surface significantly influences the course of flash floods — it determines whether rain soaks into the ground or quickly turns into surface runoff (water that flows over the surface). Forests and vegetation capture rain, help it infiltrate and slow down its runoff. Conversely, impermeable surfaces — built-up areas or compacted soil — prevent water from soaking in and accelerate its runoff.

Most Significant Classes (2020)

Tree cover **56.0065 %**

Dense short vegetation **23.9476 %**

Built-up **14.4389 %**

Cropland **5.5952 %**

Change 2010 – 2020

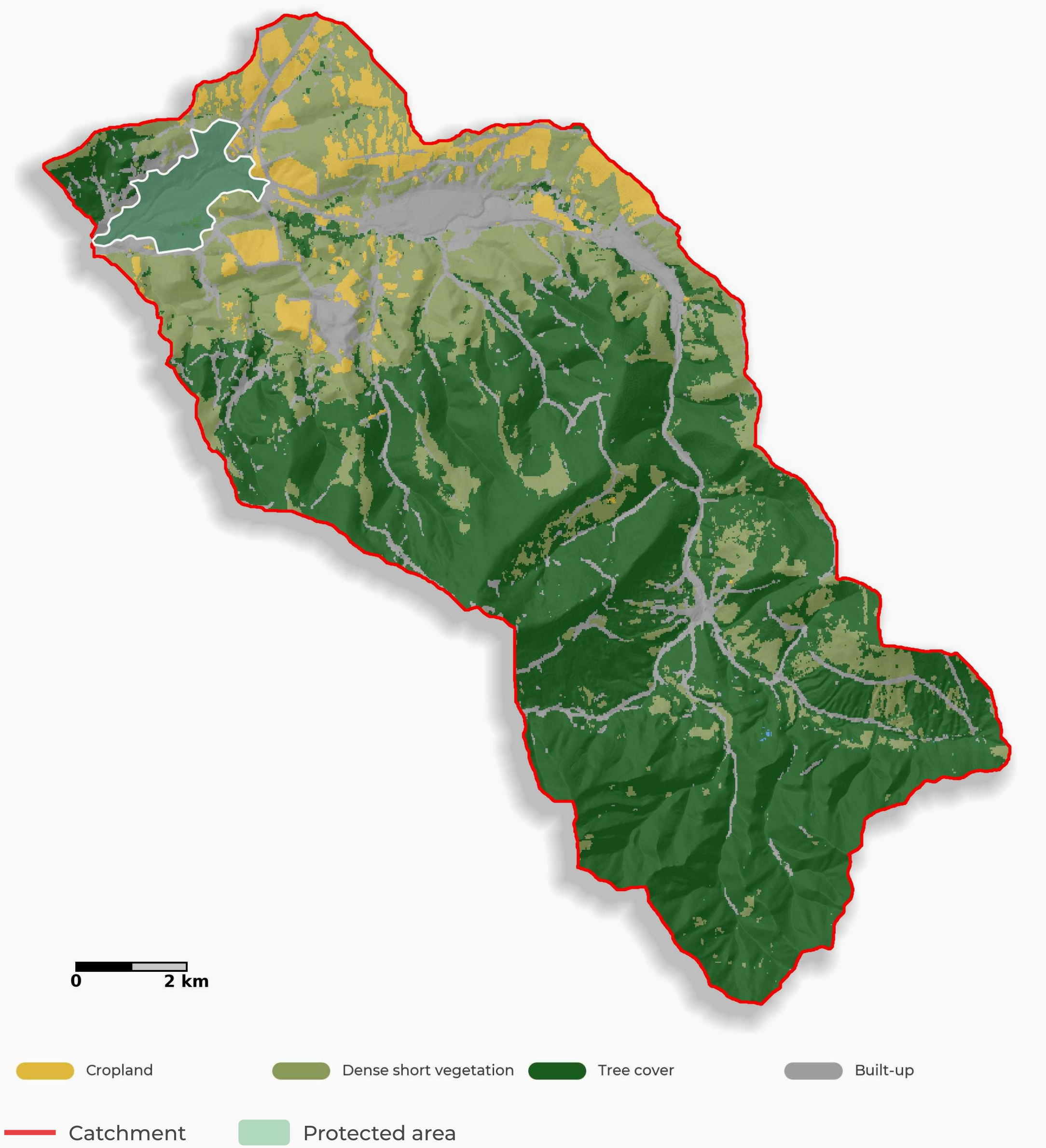
-3.59 % Tree cover

+3.54 % Dense short vegetation

+0.98 % Built-up

-0.92 % Cropland

The largest change was recorded in dense low vegetation (+3.54 %), probably as a result of the growth of low vegetation cover.



Land-cover map 2020

Global Land Analysis and Discovery (GLAD), University of Maryland. (2022). Global Land Cover and Land Use Change 2000–2020 (GLCLUC2020).

Deforestation and Management

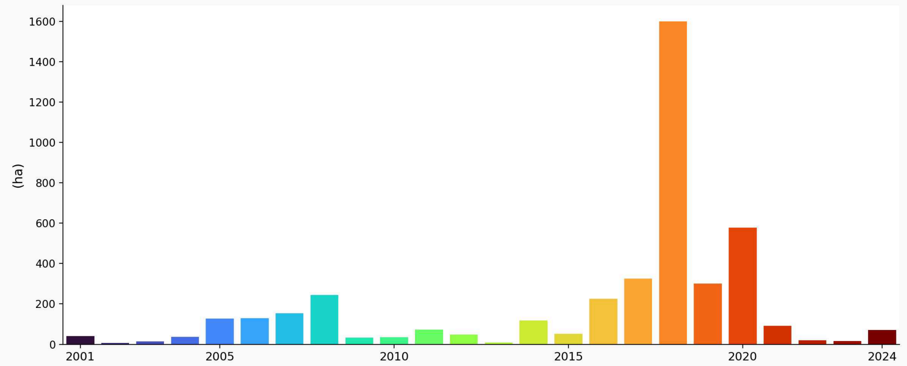
-4 348 ha
Deforested in 2001 – 2024

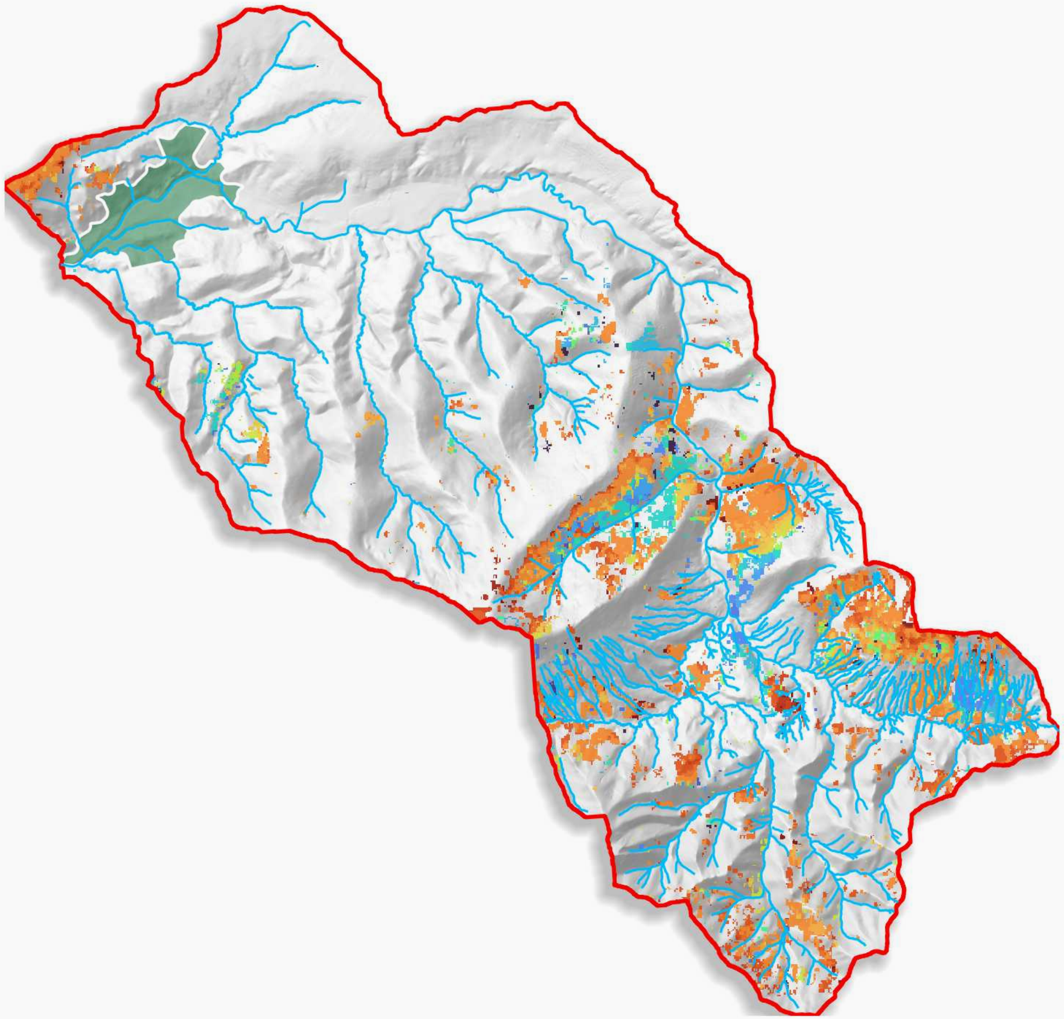
-1 599 ha
Largest annual loss (2018)

Deforestation reduces the catchment's ability to retain and slow down water, thereby increasing the volume and speed of runoff during intense precipitation.

Economic Land Use

The map on the right captures the actual use of the territory — forests, grasslands, arable land and built-up areas. These layers feed into the runoff model.





Catchment
Protected area

Deforestation map

Sources: Hansen et al. (2013), Global Forest Change; Potapov et al., Global Land Use.

Regional Characteristics and Seasonality

1 014,6 mm
Average annual precipitation

143,1 mm
Wettest month — July

51,2 mm
Driest month — February

133,7 mm
Wettest season — summer

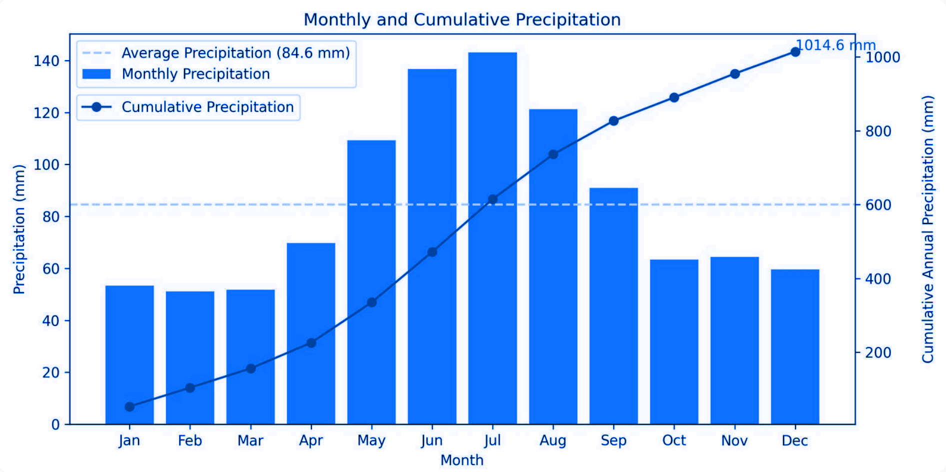
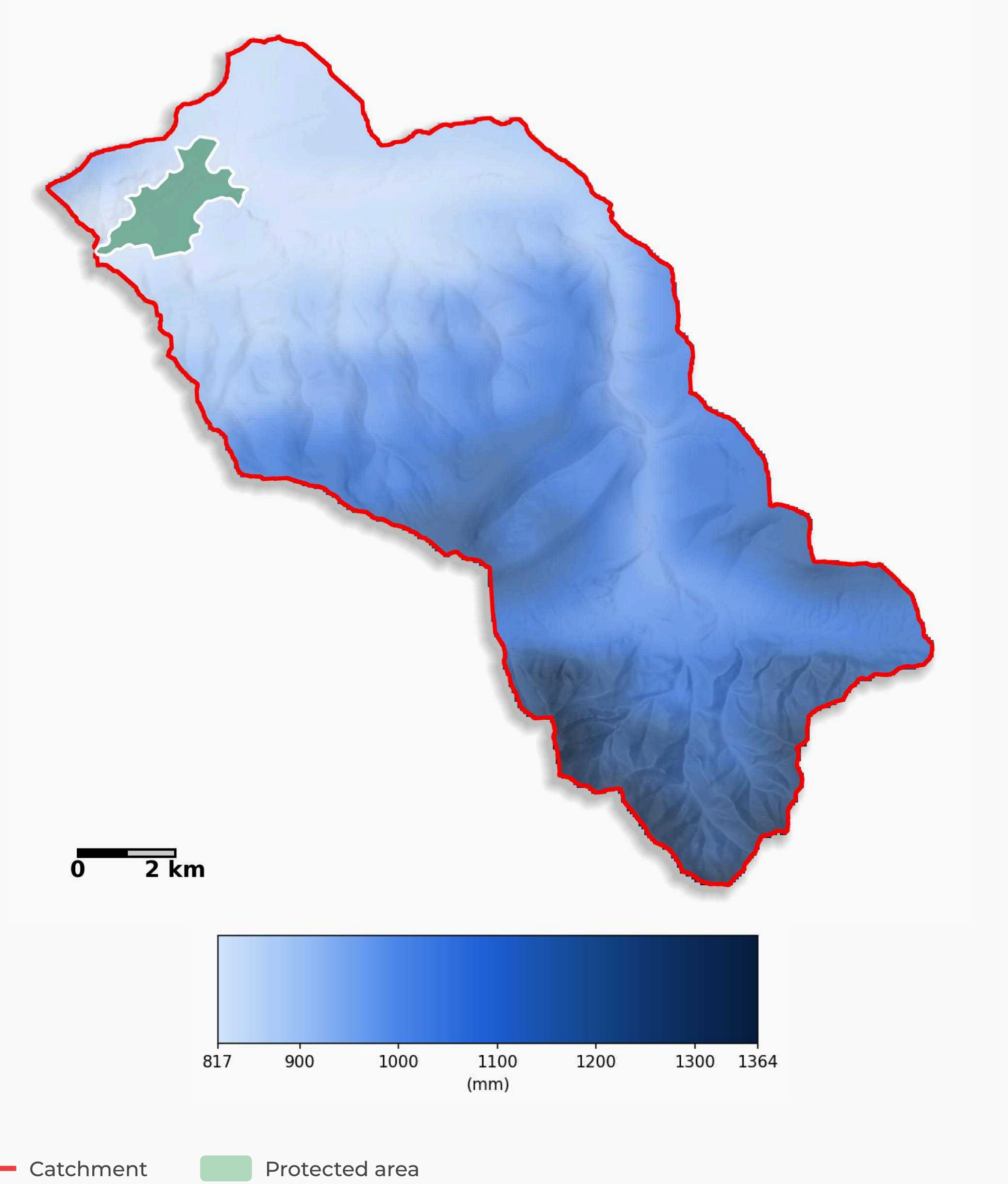


Chart of monthly averages 1970 – 2000



Map of average annual precipitation 1970 – 2000

Climate data 1970 – 2000, source: Fick & Hijmans (2017), WorldClim 2.

Intense-Rainfall Probability Table (IDF)

The risk of flash floods depends both on rainfall intensity and on the total accumulated amount of water. Heavy rain over a short period can cause immediate flooding, while moderate rain lasting several hours can together produce even greater runoff.
This relationship is described by the so-called IDF analysis (Intensity–Duration–Frequency). From historical records it quantifies how much precipitation falls within a given time and how often such a situation can be expected.

Return period (years)	5 min	15 min	30 min	1 h	6 h	24 h
5	6,4	11.2	16.0	23.7	58.2	89.6
20	9,5	16.0	22.2	32.6	68.7	125.6
50	14,3	21.9	28.4	37.2	72.4	137.2

How to Read the Table

Each row expresses the rarity of an event — an event with a 20-year return period is expected on average once every 20 years. Each column shows the total amount of precipitation accumulated over the given duration. For example, the value 22.2 mm in the 30-minute column at the 20-year return period means that a half-hour storm of this or greater intensity is expected, on a long-term average, once every 20 years.

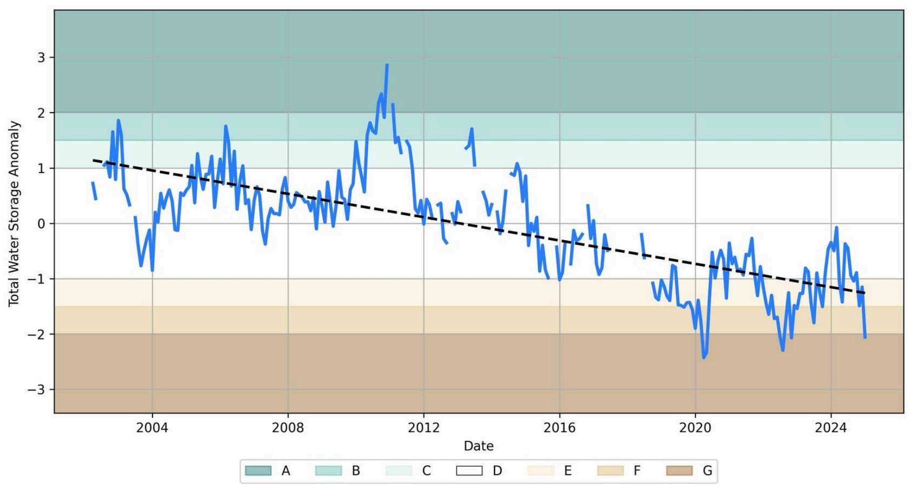
11. Changes in Water Storage

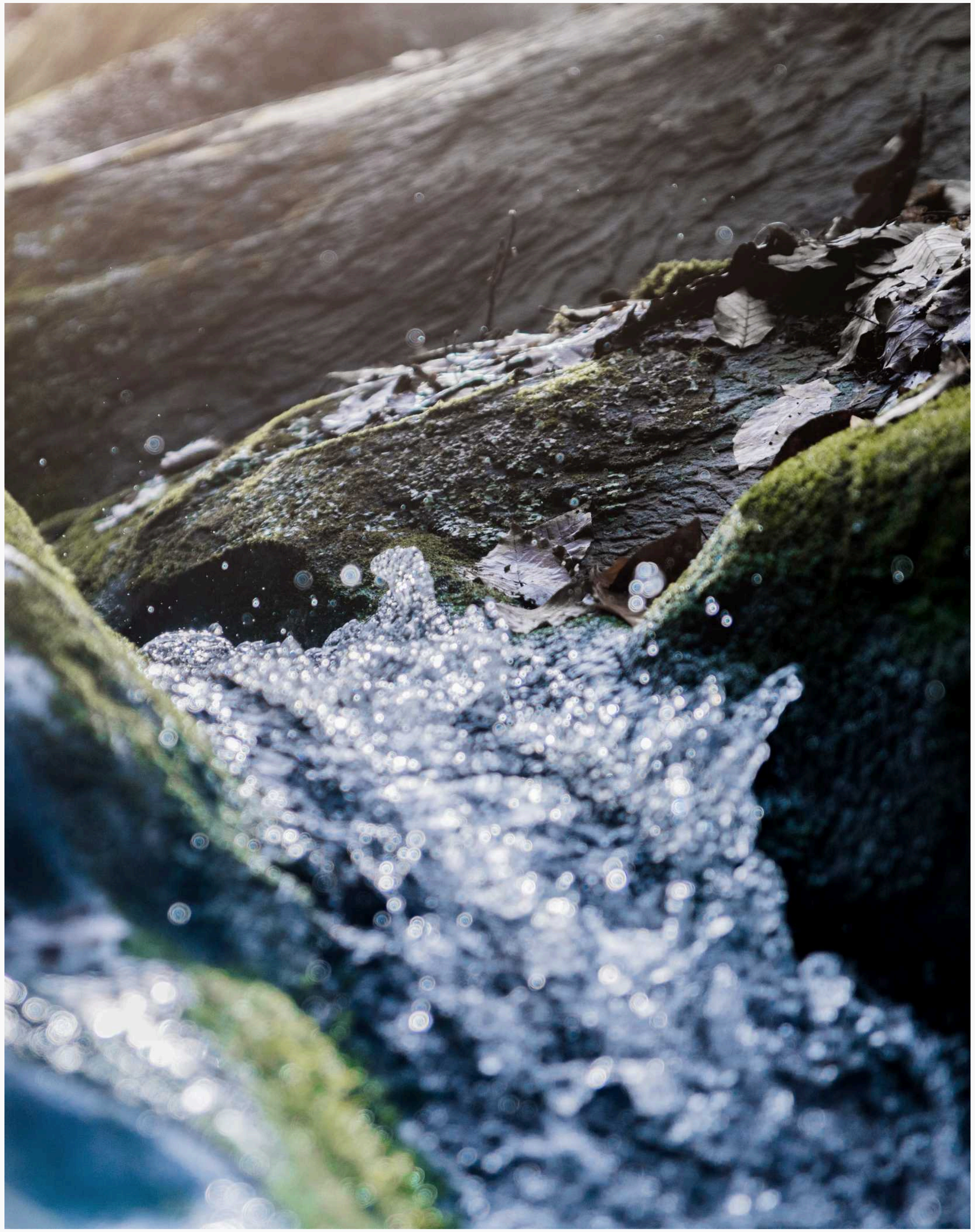
Total Water Storage Anomaly (TWSA)

The total water storage anomaly indicates how the overall amount of water in the catchment changes over the long term, including soil moisture, groundwater and surface water. It influences how the territory will respond to a flood.

Why It Matters

If the TWSA is negative over the long term, it means that water reserves are depleted and the landscape has a reduced ability to "soak up" sudden water. During heavy rain, water then runs off more quickly and floods can be more violent.





Source: European Commission, JRC — Global Drought Observatory, TWSA (GRACE satellite mission), v2.1.1. Period 2002 – 2024.

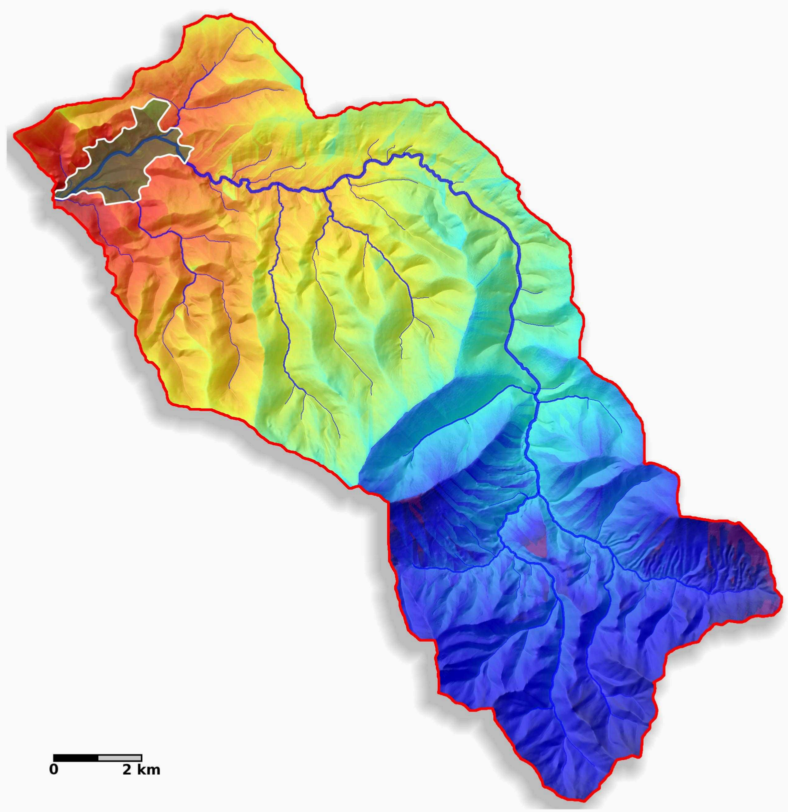
How Much Time to React Does the System Give You?

The flood warning lead time (abbreviated FWLT) is the time that elapses from the issuing of a warning to the moment when the flood actually arrives. It is the window during which you can manage to take protective measures before the area begins to flood. Obtaining the longest possible such time is the main goal in designing the Floodar system.

In order to know when a flood will arrive and from where the danger threatens most quickly, we had to analyse in detail how water flows through this specific catchment. The result is the isochrone map below. Each coloured band marks a part of the catchment from which water reaches the town in the same amount of time. The zones closest to the town have the shortest travel time — it is precisely here that a sudden local storm triggers the fastest flood, and where there is the least time for a warning.

The Primary Line of Defence — Nowcasting

For floods of this type, the first line of defence is therefore so-called nowcasting — a very short-term weather forecast for the coming minutes and hours. Our hyperlocal (precisely focused on your territory) meteorological model detects incoming precipitation and issues a probabilistic alert even before it starts to rain — that is, exactly when every minute counts. The sensor network then confirms the event in real time and continues to track the flood, verifying and refining the alert according to the measured values.



Water Travel Time Map

Colour indicates the water travel time to the protected area; the histogram on the right shows the relative area in each time band (scale up to the 99th percentile).

From a Sensor Network to Flood Forecasts

A reliable warning system is built step by step. It begins with the construction of the sensor network and the collection of data.

1

Measurement & Threshold Alarms

In this phase, three layers work together so that a warning can be issued as early as possible for every type of event. From the very launch, the municipality obtains real-time measurements — precipitation, river water levels and soil moisture in the catchment — together with threshold alarms that are triggered whenever a monitored value exceeds a predefined limit.

2

Model Training

The gradually accumulating data serve to "teach" (train) the Floodar models, which are already pre-configured for this catchment. The quality of the measurements and the placement of the sensors directly determine how quickly the model reaches reliability.

3

Warnings from Forecasts

The result is a warning capability that strengthens over time: it begins with reliable measurement and simple alarms and gradually matures into a forecasting system.

4

Outcome

The outcome is a system that sees the threat even before it fully develops and tracks it throughout its entire course — combining nowcasting, sensor confirmation and soil moisture.

Prevention Officer and Flood Action Plan

The system gives you time to react, but it does not decide for you who will alert the population, when they should evacuate, and who will look after the system to keep it up to date. This remains up to the town. We therefore recommend appointing a specific person as the officer for flood prevention and early warning, and placing them under crisis management.

The Officer Is a Co-Author of the System

They determine where and what kind of sensors are installed at endangered locations, set the thresholds at which a measured water level becomes a warning, and take over the care of the hydrological and hydraulic models (calculations of how water behaves in the territory and in the channels) within the system. They are responsible for operability, the interpretation of outputs and the updating of parameters.

For towns with more than 50,000 inhabitants, we recommend establishing a two-member expert team, in which one member takes over the administration of the system and models and the other operational coordination.

Flood Action Plan

An indispensable part of implementing the system is the preparation of a Flash Flood Action Plan, which defines:

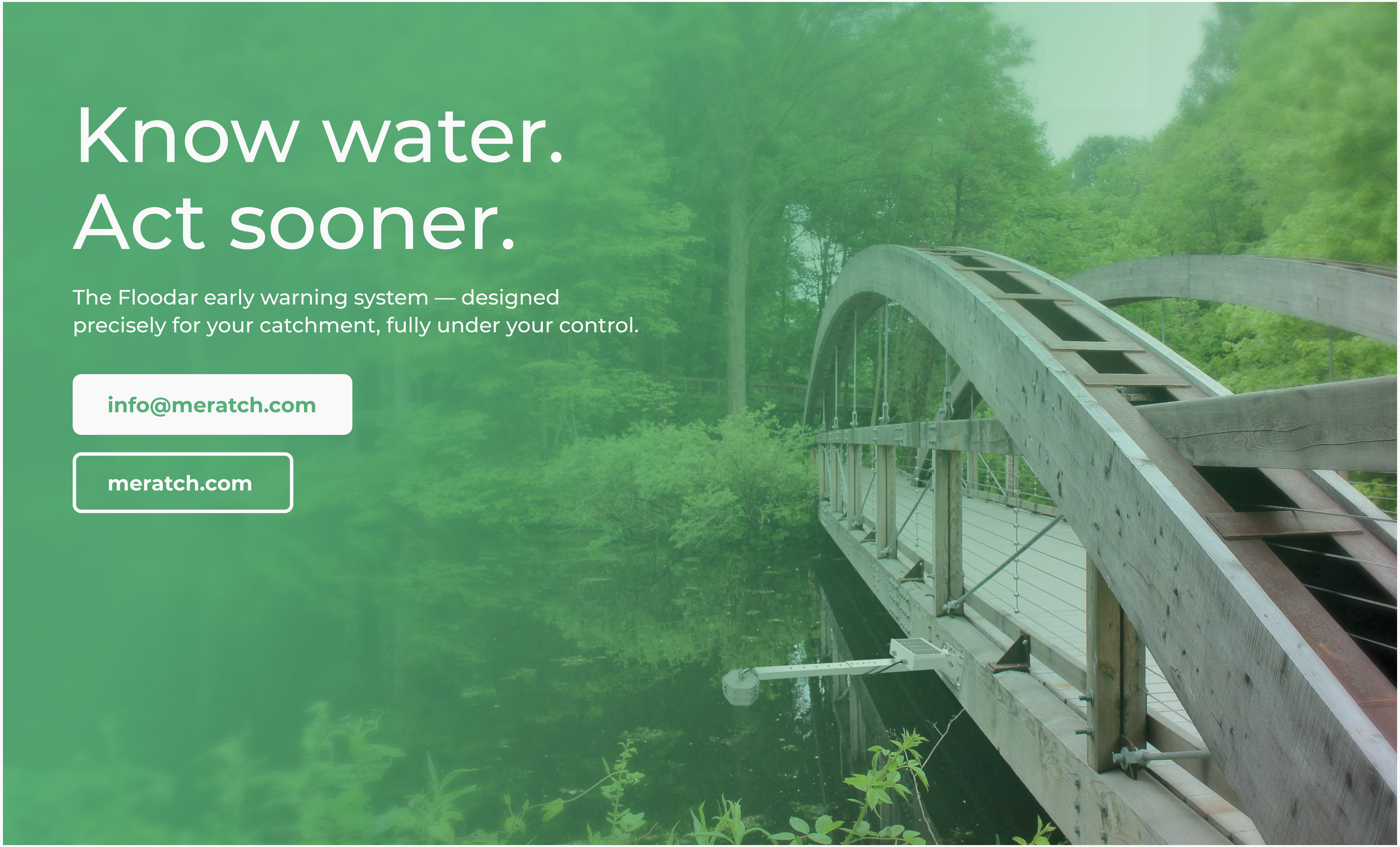
- Procedures for distributing warnings through various channels — sirens, SMS, mobile applications, media
- A hierarchy of measures according to the level of threat
- The responsibilities of the Integrated Rescue System components and municipal departments
- Scenarios for the possible evacuation of risk zones

The officer is responsible for this plan, updates it regularly and organises practice drills (exercises).

Disclaimer

This report is intended to provide an indicative overview of the catchment based on the best available geospatial and open datasets at the time of its creation. The results may not fully reflect real conditions, because the authors did not carry out a site visit. All underlying data were obtained from publicly available sources considered reliable; nevertheless, inaccuracies in these data may be reflected in the report.

Local knowledge and experience are a valuable contribution to improving the accuracy and relevance of the findings. We welcome any corrections or feedback at info@gospace.tech. This report should not be used for legal, engineering or other professional purposes without consulting the relevant experts. Neither the authors nor GOSPACE LABS are liable for any damage or loss arising from the use of this report or its content.



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Act sooner.

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