ASECAP DAYS
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Celebrating 50 YEARS OF Successful TOLL ROAD PROJECTS

ROAD INFRASTRUCTURE RESILIENCE TO CLIMATE CHANGE

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ICA
YAVUZ SULTAN SELİM BRIDGE AND NORTHERN RING MOTORWAY

Table of contents

Road Infrastructure Resilience to Climate Change:

A Hydrological-based Model for Flood Risk Assessment and Preventive Asset Management

Table of contents

Road Infrastructure Resilience to Climate Change:

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1. Climate Change Impacts

/ In the 21st century, climate change and changing rainfall patterns are of great interest for their potential impact on society, the economy and the environment, as well as on critical infrastructure such as bridges and storm water drainage systems.

/ The impact on infrastructure is of particular concern given its long lifespan and high initial cost, as well as the essential role it plays in society and the economy.

/ Infrastructure may be vulnerable in a changing climate, as it may not have been designed to withstand extreme weather conditions such as sea level rise, heavy rainfall, severe flooding, extreme cold, heat waves, droughts, heavy snowfall, high winds, etc..

1. Climate Change Impacts

/ The impact of climate change on flooding requires a thorough analysis of the effects of temperature and heavy rainfall, as the magnitude of these changes is important for hydraulic design.

/ The intensity, frequency and duration of heavy rainfall have increased in recent decades and are expected to continue to increase as the climate warms. The magnitude of floods has also increased, but with large geographical and seasonal variations.

/ The return period of these events is undoubtedly decreasing, and it is therefore necessary to assess the predicted changes over the next 50 to 100 years to determine how design standards should be adapted to mitigate future climatic uncertainties.

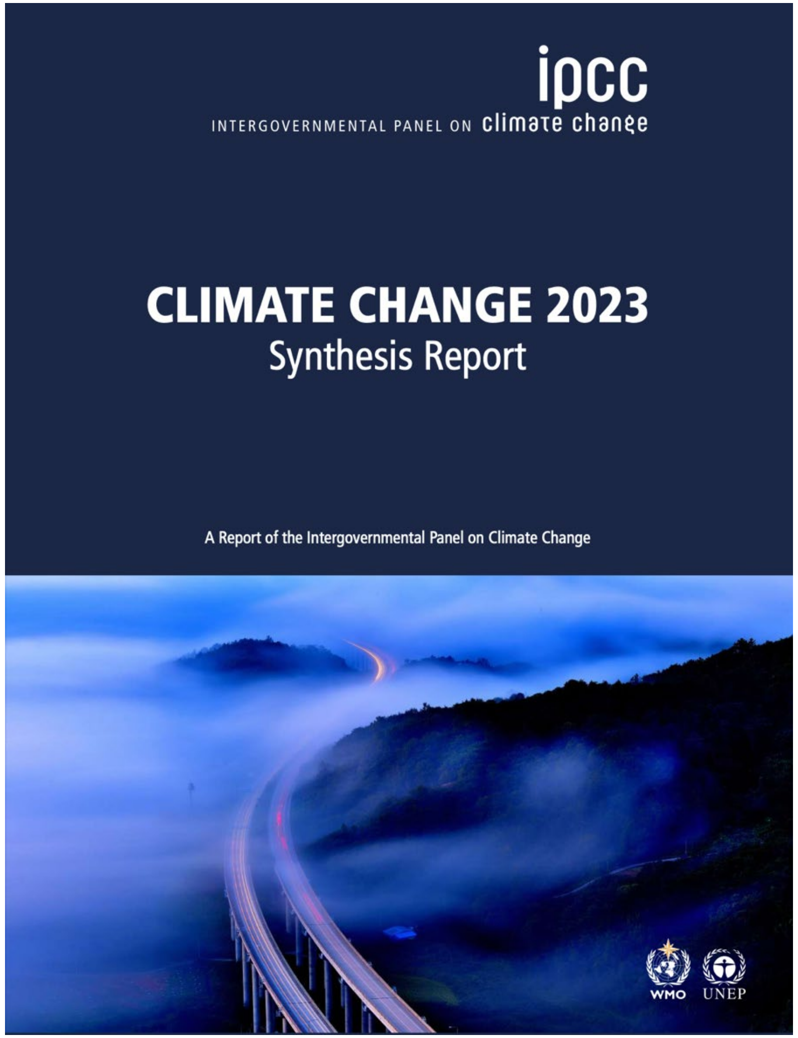

Table of contents

Road Infrastructure Resilience to Climate Change:

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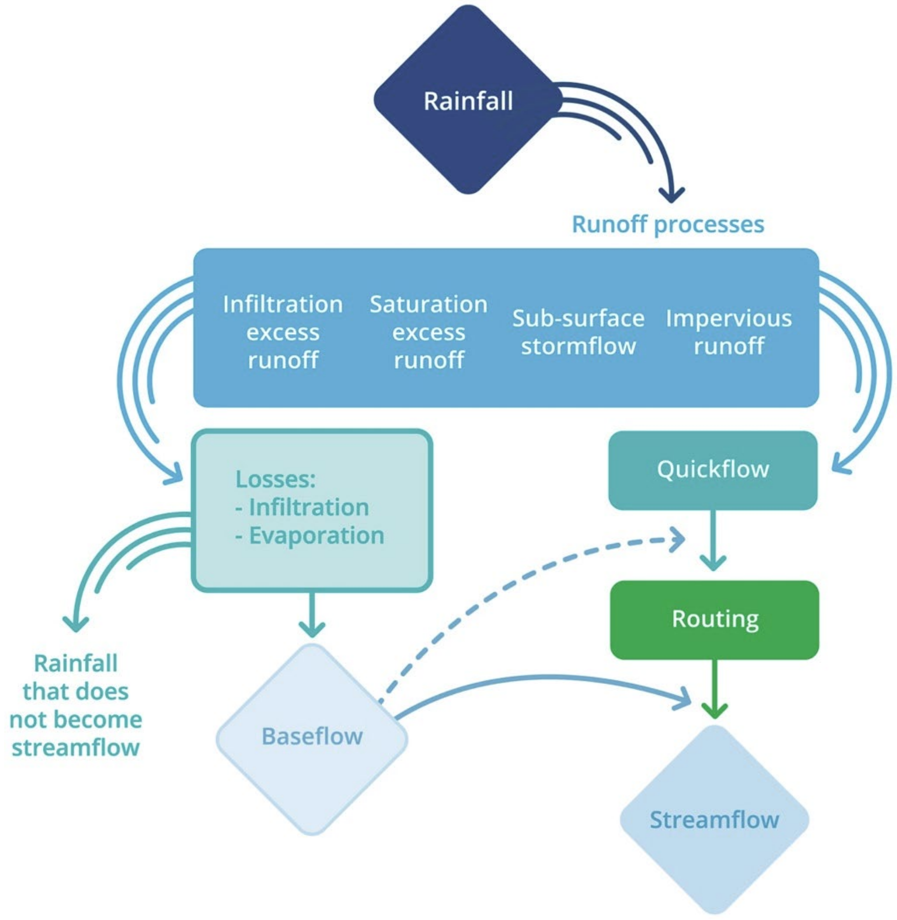
2. Hydrology and Hydraulics

/ The link between rainfall and streamflow is mediated by hydrological processes.

/ Rainfall that falls on the catchment can be converted into runoff in different ways, depending on the infiltration rate and soil saturation. The runoff generation processes that can lead to flooding are related to infiltration and saturation excess runoff, sub-surface stormflow and impervious area runoff.

/ Typically, only a small proportion of rainfall becomes streamflow, with the remainder evaporating, perhaps after being intercepted by vegetation, stored in surface depressions or infiltrated to become soil moisture or groundwater. Some groundwater may contribute to floods through baseflow.



2. Hydrology and Hydraulics

/ Culvert design requires a hydrological study of the rainfall phenomena and runoff generation processes, as well as a hydraulic study to define the flood flow characteristics such as flow rates and velocities.

/ The hydrological study is of paramount importance as it is the basis for almost all, if not all, decisions regarding modifications to the natural flow regime.

/ It consists of estimating the flood hydrograph of the catchment area and analysing flood flows in order to predict their consequences and define solutions to prevent or mitigate the adverse effects of floods, thus ensuring the safety of the works without endangering human life or causing significant damage to property.

Table of contents

Road Infrastructure Resilience to Climate Change:

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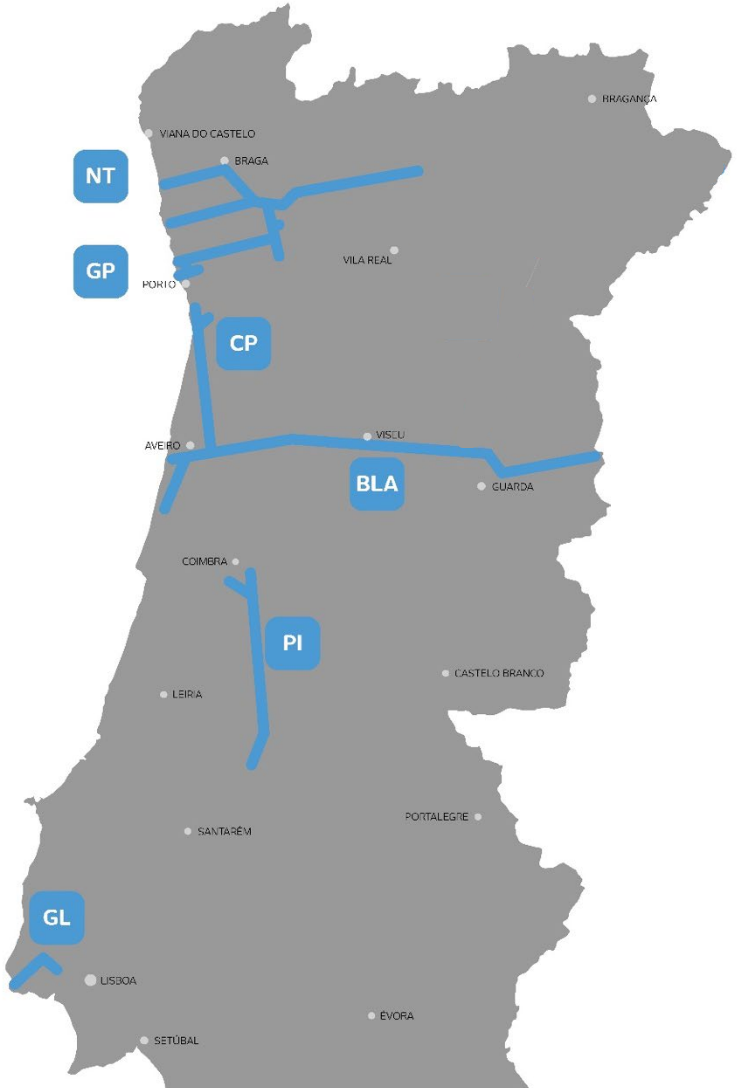
3. The Problem

/ The hydrological phenomena of rainfall and runoff generation processes are influenced by climate change, but also by constant changes in soil imperviousness over time.

/ There is evidence that, for a given rainfall intensity, the volume of surface runoff increases and the hydraulic response time decreases. These changes increase the vulnerability of infrastructure and therefore require flood risk assessment and preventive asset management to mitigate the impact of flooding on assets, road users and the environment.

/ To this end, a research project has been launched in partnership between Ascendi and the University of Minho…



3. The Problem

Design Criteria

- Rainfall intensity available data/outdated
- Climate change effects not included
- Runoff coefficient as static land use
- Simplified methods for flood flow estimation

The years go by…

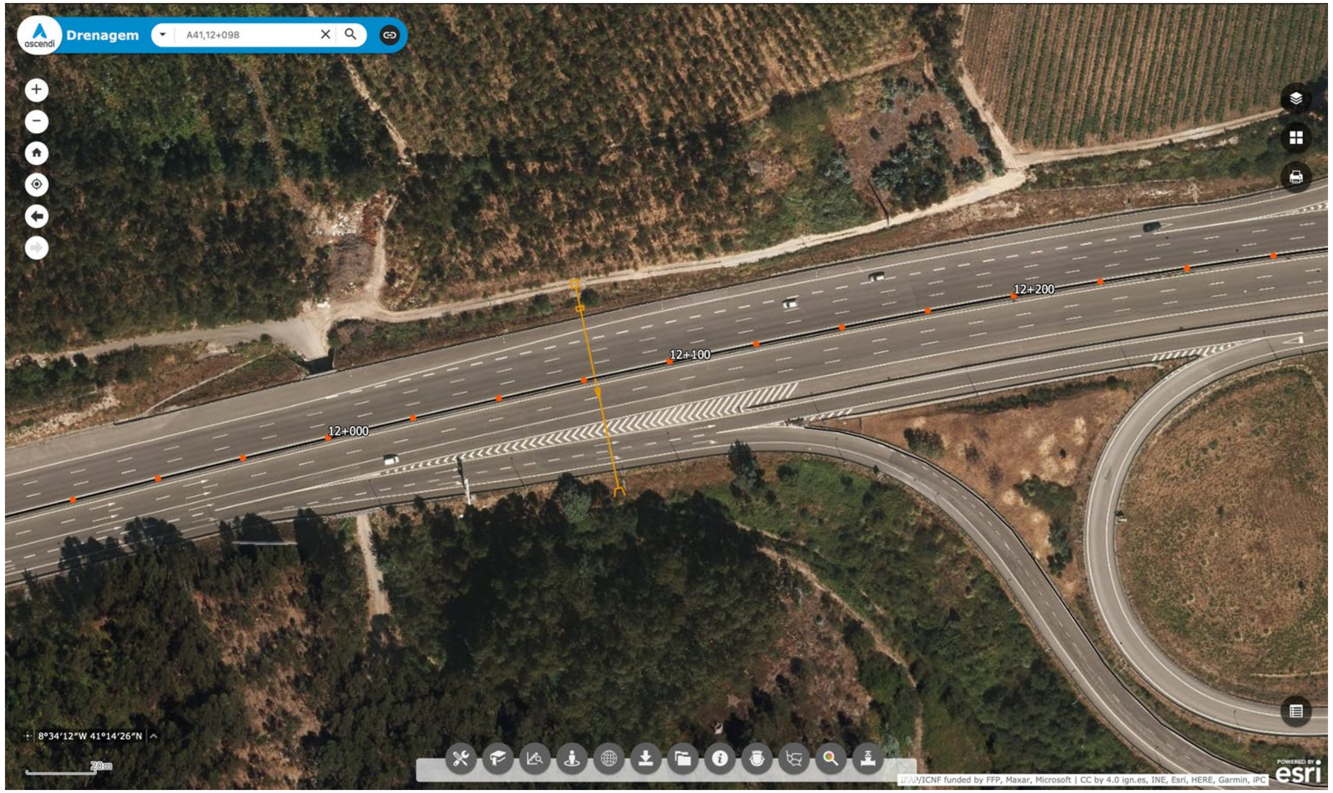
Operational Concerns

- Rainfall intensity in short-term/updated
- Climate change effects included
- Runoff coefficient as dynamic land use
- Hydrological-based model for flood routing

3. The Problem

Grande Porto Concession

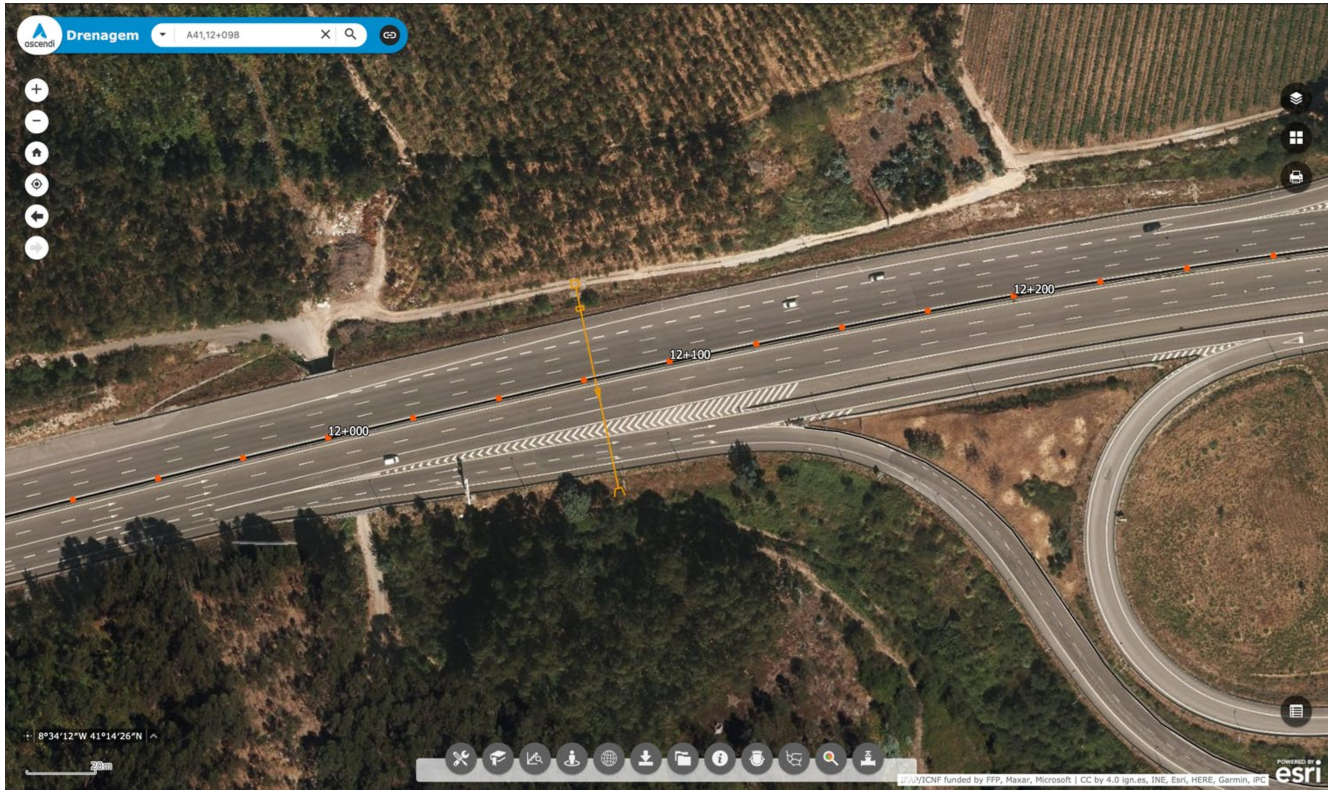
/ A41 motorway in 2016



3. The Problem

Grande Porto Concession

/ A41 motorway in 2019



3. The Problem

Beiras Litoral e Alta Concession

/ A25 motorway in 2020

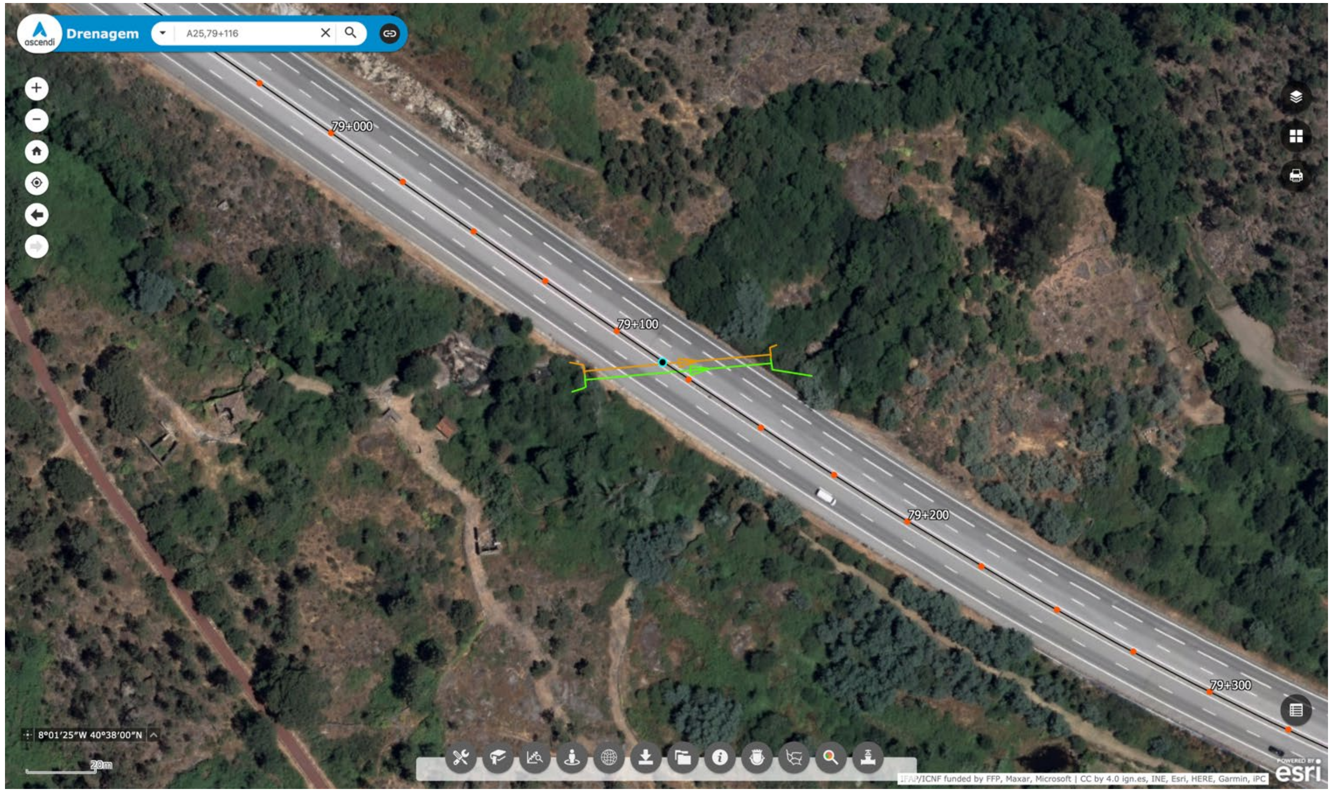


Table of contents

Road Infrastructure Resilience to Climate Change:

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4. The Research Question

How will the design criteria for the existing culverts perform over the lifespan of the motorway ?

i. Are the intensity-frequency-duration curves used to estimate rainfall intensity still appropriate given the meteorological station records over recent decades ?

ii. Have the land use and soil imperviousness in the catchment area changed over time and, if so, are they consistent with the predicted runoff coefficient ?

Table of contents

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5. The Project

/ PHASE 0 Definition of scope and project team

/ PHASE I Data analysis to define the methodological baseline

/ PHASE II Methodology and framework definition

/ PHASE III Culvert performance during extreme events

/ PHASE IV Evaluation and validation of the methodological assumptions

PROJECT STI-0417

ANALYSIS OF THE RESILIENCE OF ROAD INFRASTRUCTURE DRAINAGE SYSTEMS (CULVERTS) ON THE ASCENDI NETWORK TO EXTREME EVENTS

5. The Project

PHASE 0

/ Definition of scope and project team

PHASE I

/ Data analysis to define the methodological baseline

/ Bibliographic review and state of the art

/ Definition of experimental stretches of motorway and data analysis

PHASE II

/ Methodology and framework definition

/ Design of the framework

/ Verification of meteorological stations and statistical analysis of historical records

/ Identification of risks and vulnerable areas of the motorway

PHASE III

/ Culvert performance during extreme events

/ Development of an experimental hydrological-based model

/ Hydrological modelling of the catchment based on rainfall hyetographs and runoff coefficients to estimate flood hydrographs

/ Analysis of model performance

PHASE IV

/ Evaluation and validation of the methodological assumptions

/ Extension of the hydrological-based model to other stretches and sub-stretches of motorway

/ Definition of flood mitigation measures to improve the resilience of infrastructure to natural hazards and prevent damage

5. The Project

/ The aim is to establish the relationship between changing spatial and temporal patterns of heavy rainfall and constant changes in soil imperviousness, and flooding.

/ This will be achieved by developing a hydrological-based model using updated rainfall records and higher resolution satellite data.

/ The outcome will be the definition of flood mitigation measures to improve the resilience of infrastructure to natural hazards, and improved design criteria to increase the effectiveness of culverts against flooding. It will also be possible to contribute to asset management strategies while reducing operating costs.

6 Motorway Concessions

20 Rest Areas

630 km in Operation

~1200 Bridges

~1800 Culverts

~5K Slopes/Retaining walls

Table of contents

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6. Conclusions

Simplified flow estimation methods generally neglect spatial and temporal variations in rainfall intensity and constant changes in runoff coefficient over time.

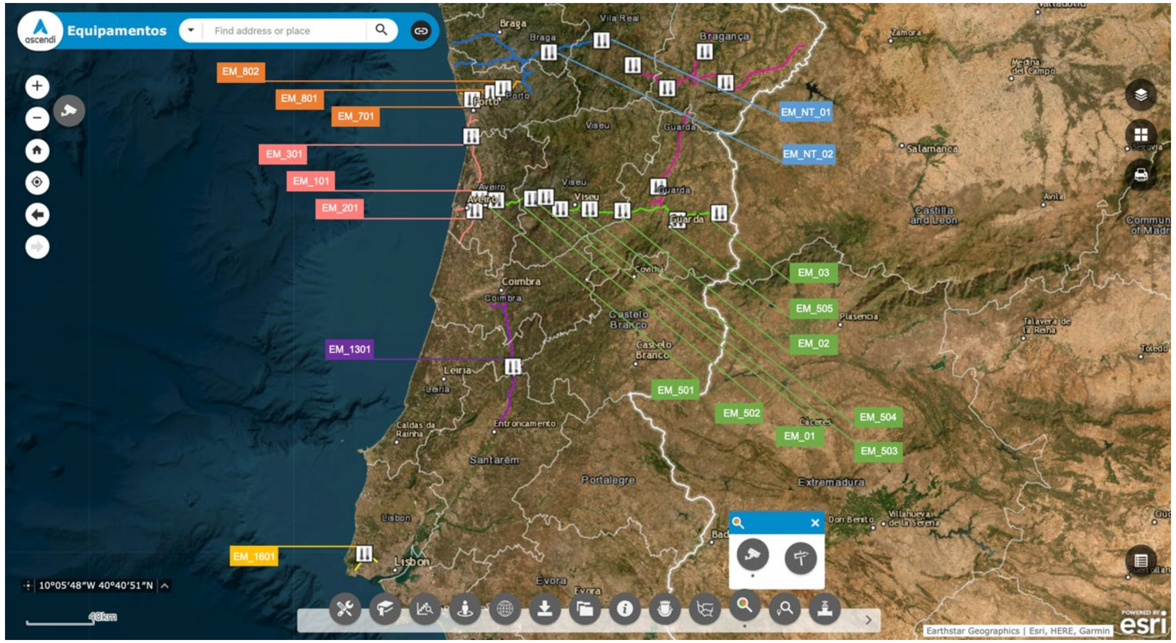
However…

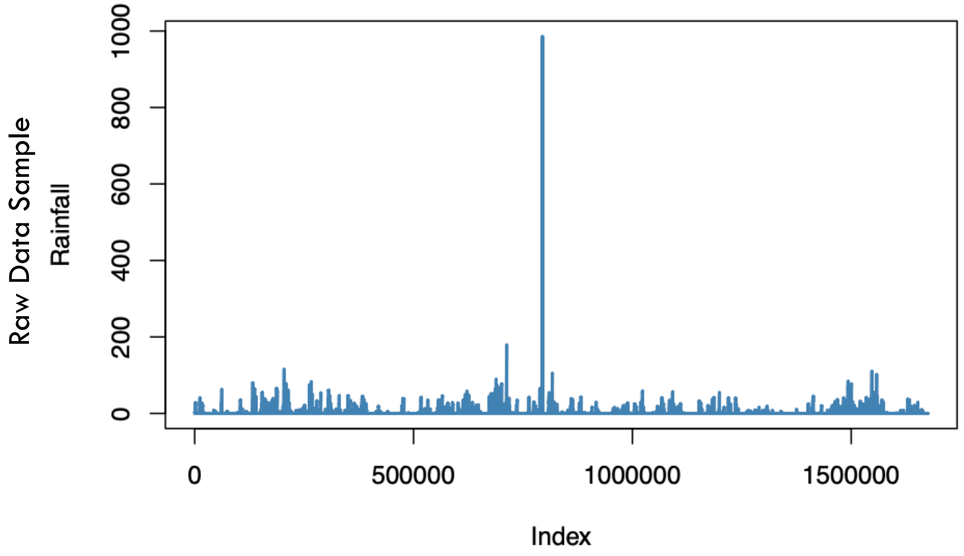
- The runoff coefficient varies with time, e.g. due to afforestation, urbanisation, etc..
- The seasonality of rainfall events influences the runoff coefficient, e.g. losses are lower on saturated soils in the wet season than on unsaturated soils in the dry season.
- Soil moisture prior to rainfall events influences the runoff coefficient, e.g. a saturated soil acts as an impervious surface, increasing the effective impervious area.
- Rainfall intensity is effective rainfall, i.e. rainfall intensity is not divided into effective rainfall and losses.
- The IFD curves are decades old and do not include the last 40 years of rainfall records, so the effect of climate change on rainfall patterns is not included.

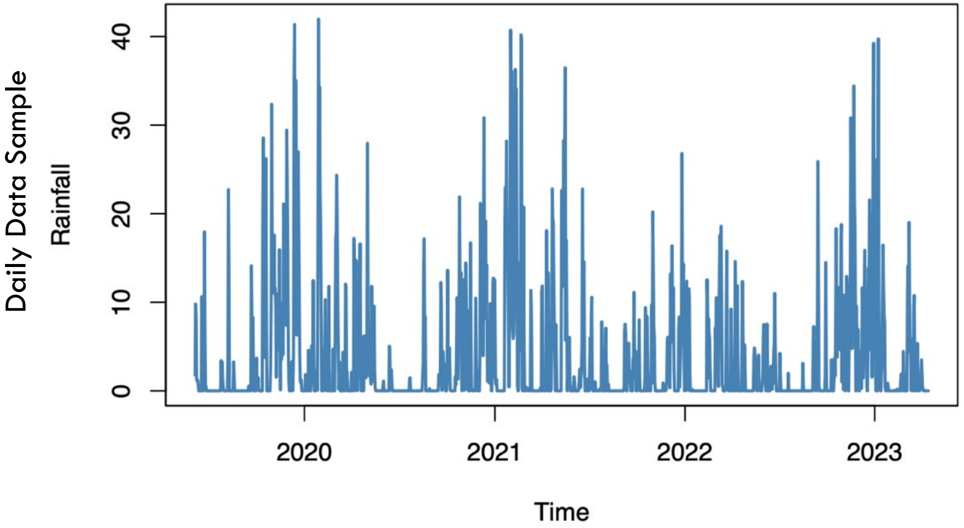
6. Conclusions

Statistical analysis of rainfall records from the Ascendi network of meteorological stations is underway…

- 18 meteorological stations between northern and central Portugal
- Rainfall records up to the minute







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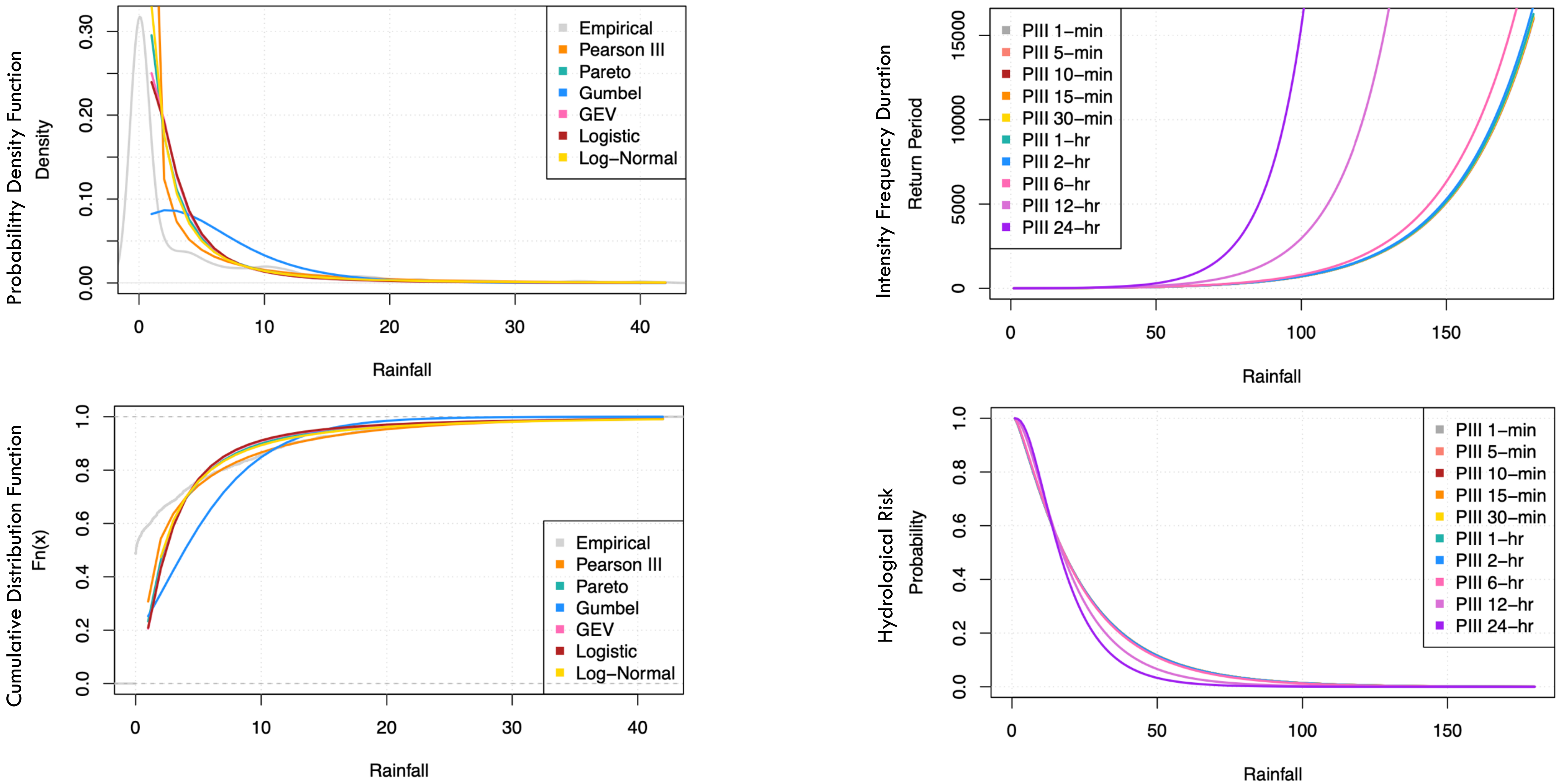
6. Conclusions



6. Conclusions

Statistical analysis of rainfall records from the Ascendi network of meteorological stations is underway…

/ Preparation of sample data from the meteorological stations for use in the statistical analysis, e.g. checking for outliers, recording errors and failures, etc..

/ Statistical analysis of time series by testing the probability distributions most commonly used in hydrology and selecting the one that best fits the sample to estimate the return period of rainfall events, as well as the hydrological risk of rainfall events.

Next steps…

/ Development of a hydrological-based model using inputs from meteorological stations, discharge measurements using radar technology, satellite mapping data, …

/ Definition of flood mitigation measures to improve the resilience of infrastructure to natural hazards and prevent potential damage.

THANK YOU

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