

Land-use scenarios for assessing climate risk as a tool for spatial planning: a case study of the Stuttgart Region, Germany

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Introduction

Scenarios that explore the affect of urban expansion on hazard exposure can be a practical decision-making tool for regional and urban planners. However, research is lacking on how to create urban land-use scenarios that can be simulated by different hazard models and produce results that have a relevance to planning laws and processes.

Research aims:

- To measure the effect of urban expansion on hazard exposure (pluvial flooding and heat)
- To determine if through a compact and climate-sensitive urban form the needs for more housing could be met without increasing hazard exposure

Scenario definition

We designed two future scenarios, in which all **areas in the region with “potential for development”—as identified by current spatial plans—were fictitiously built upon in two different ways** (Fig.1). We defined the current baseline scenario and the two future scenarios by the following **parameters**:

- Building density
- Building height and volume
- Level of soil sealing and proportion of green space

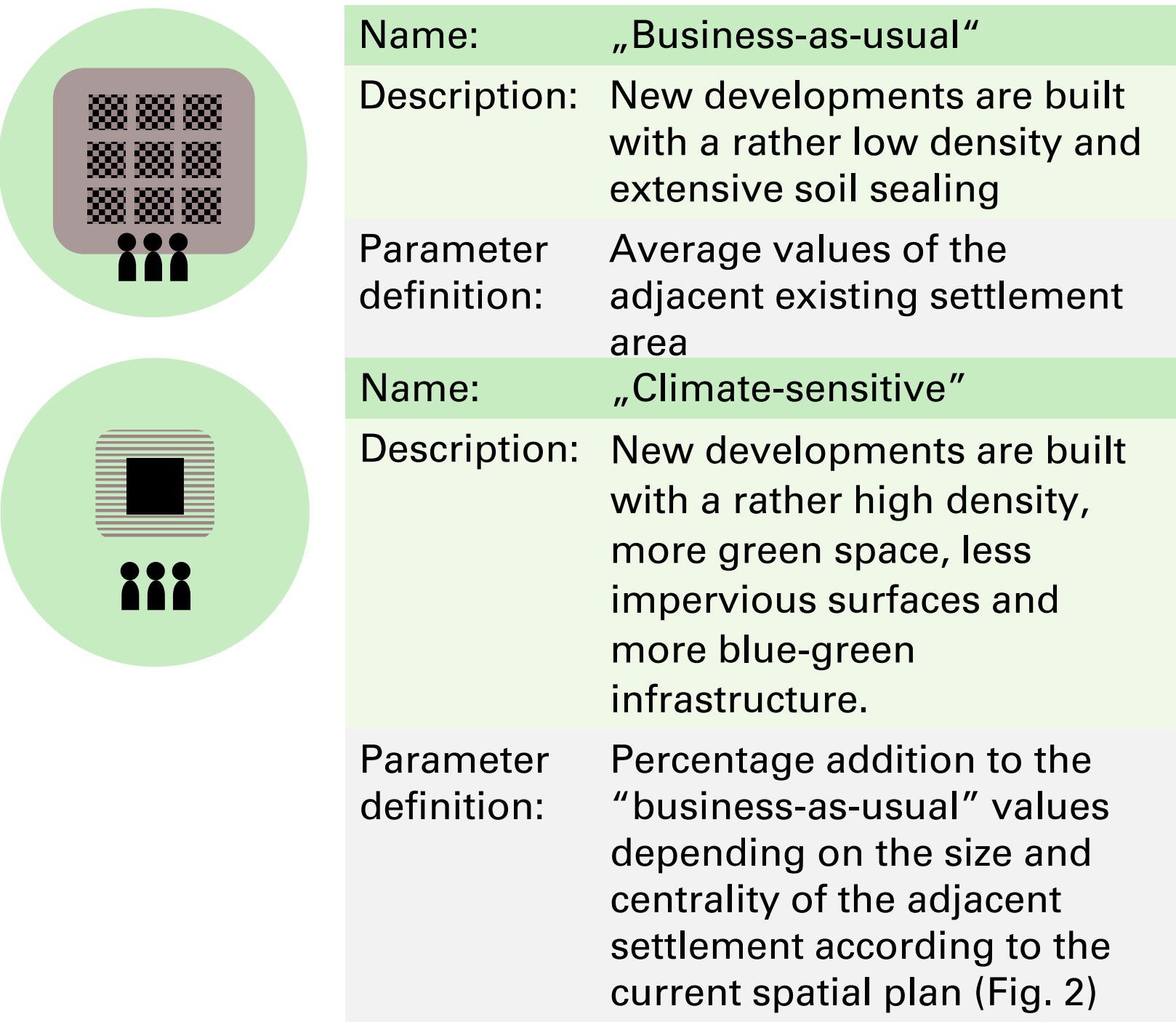


Figure 1: Description and definition of the two scenarios.

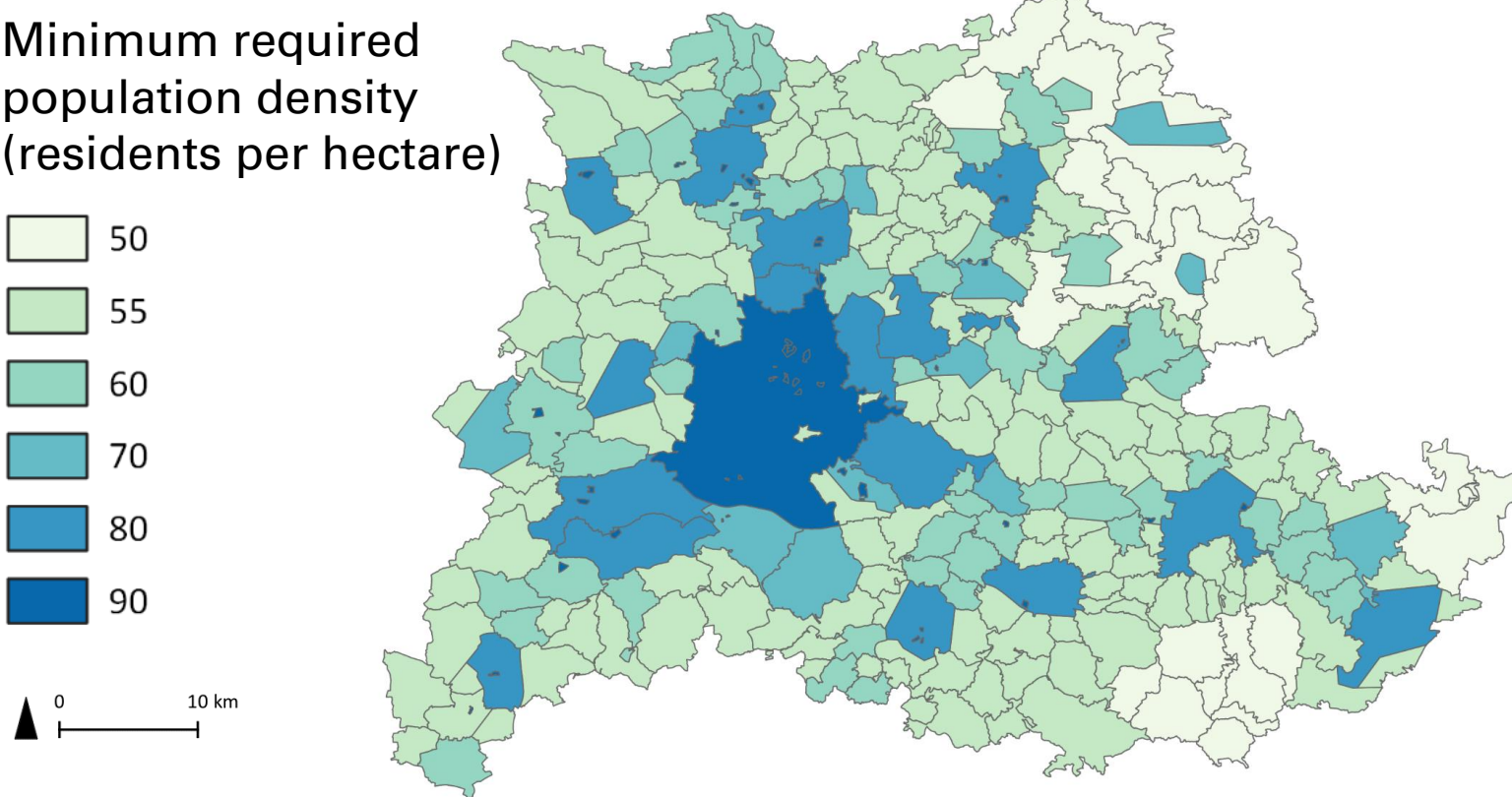
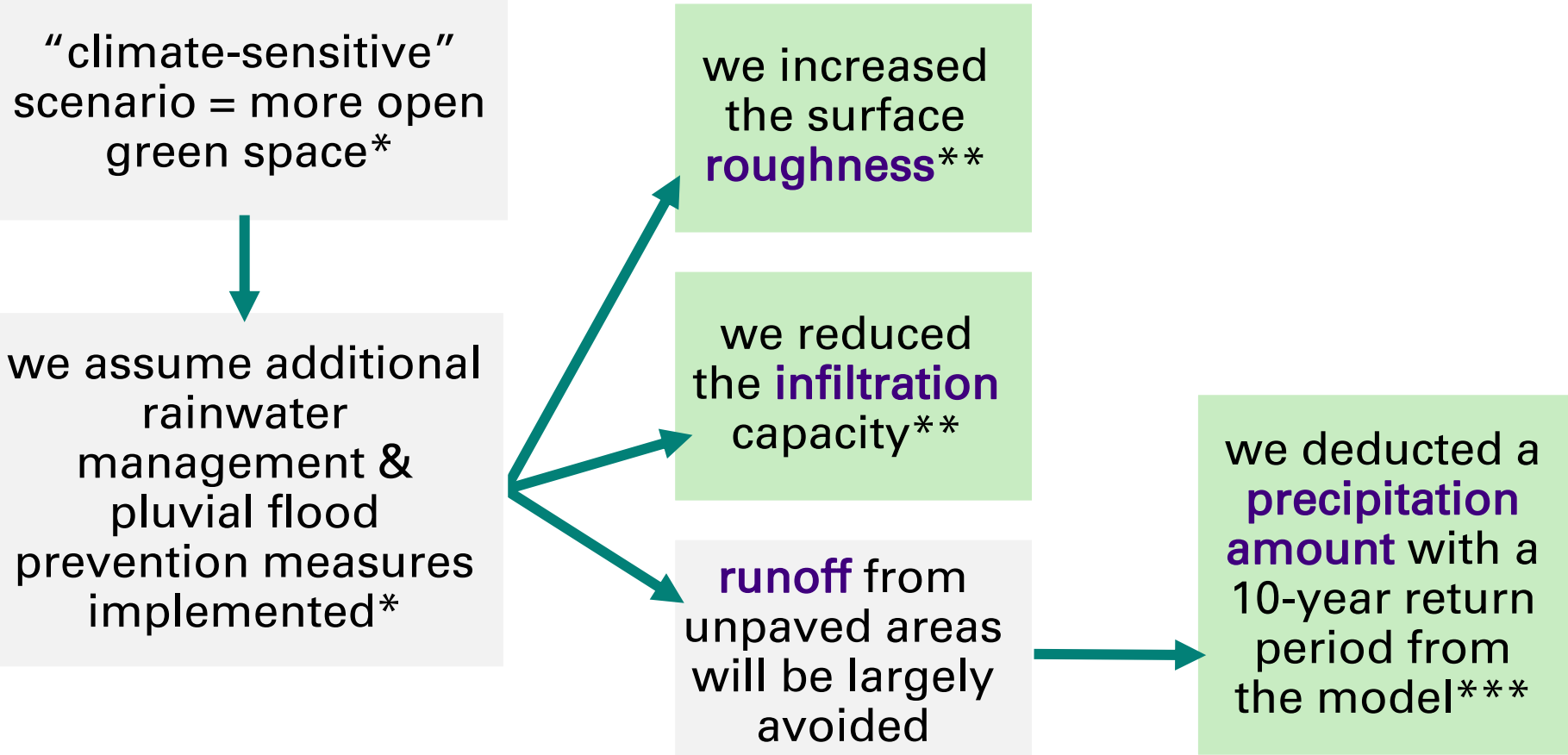


Figure 2: Map of the appropriate gross residential density for new developments for each municipality according to the Stuttgart Region's regional spatial plan.

Simulation of the scenarios in the 2D surface runoff model

Urban expansion that involves building on and sealing surfaces changes the terrain and surface properties (e.g. flow paths, obstacles and depressions), and thus changes rainwater runoff of flow characteristics (i.e. usually runoff amounts and flow rates increase). The exact location and design of new urban development has a significant impact on the small-scale flood situation. However, the scenarios in this research are defined using generic parameters not exact plans. Thus, it as a methodological challenge to translate the scenarios into our surface runoff model, which we solved based on assumptions described in Figure 3 below.



*in the new developments, when compared to the “business-as-usual” scenario.
**in accordance with the green space parameter (in both scenarios we reduced the infiltration capacity, but to a lesser extent for the climate-sensitive scenario).
***as opposed to the amount with a 3-year return period that is otherwise deducted to account for the sewer network and decentralized rainwater management.
Figure 3: Overview of how we translated generic assumptions into percentage changes to the parameters in our model for the “climate-sensitive” scenario.

Thus, only the surface properties were adjusted in accordance to the green space parameter, the elevation model was not adjusted. The surface runoff model was run for an exceptional heavy rainfall event (average rainfall = 54.6 mm, rainfall duration = 60 min, with 60 min follow-up time, precipitation statistics: KOSTRA DWD 2010R).

Simulation of the scenarios in the local climate analysis

The local climate analysis of the region identifies areas with different climate conditions such as urban overheating compared to the surrounding area and local cold air currents and their effects on temperature and thermal comfort. Simulations for a typical hot summer day and a typical cold winter day in an autochthonous weather situation were carried out using the microscale climate model PALM-4U with a resolution of 100 m x 100 m. Basis of the calculations are the following parameters:

- terrain elevation
- land use
- building height
- building density
- degree of soil sealing

As these parameters were used to describe the two land-use scenarios, **the simulation method did not have to be adjusted, only the parameter values were adjusted to simulate the affect of the urban expansion scenarios on the local climate.**

Results

The results of the surface runoff model show that in the “business-as-usual” scenario, the new development results in faster flow speeds (Fig.4) and greater water depths in lower-lying areas (Fig.6). In contrast, in the “climate-sensitive” scenario, the new development tends to cause less deterioration in the situation and can even lead to an improvement if water retention measures are specifically implemented in the newly developed area (Fig.6). Thus, the results emphasize that **urban expansion has an impact on the pluvial flood hazard in existing settlement areas.**

The results of the climate analysis show no significant affect of the simulated urban expansion on near-ground air temperature during the day. However, the calculations show that **at night, development on previously undeveloped areas predominantly leads to an increase in near-ground air temperature. In areas of cold air outflows, the influence can be particularly seen in the lee of the simulated development areas** (Fig.5).

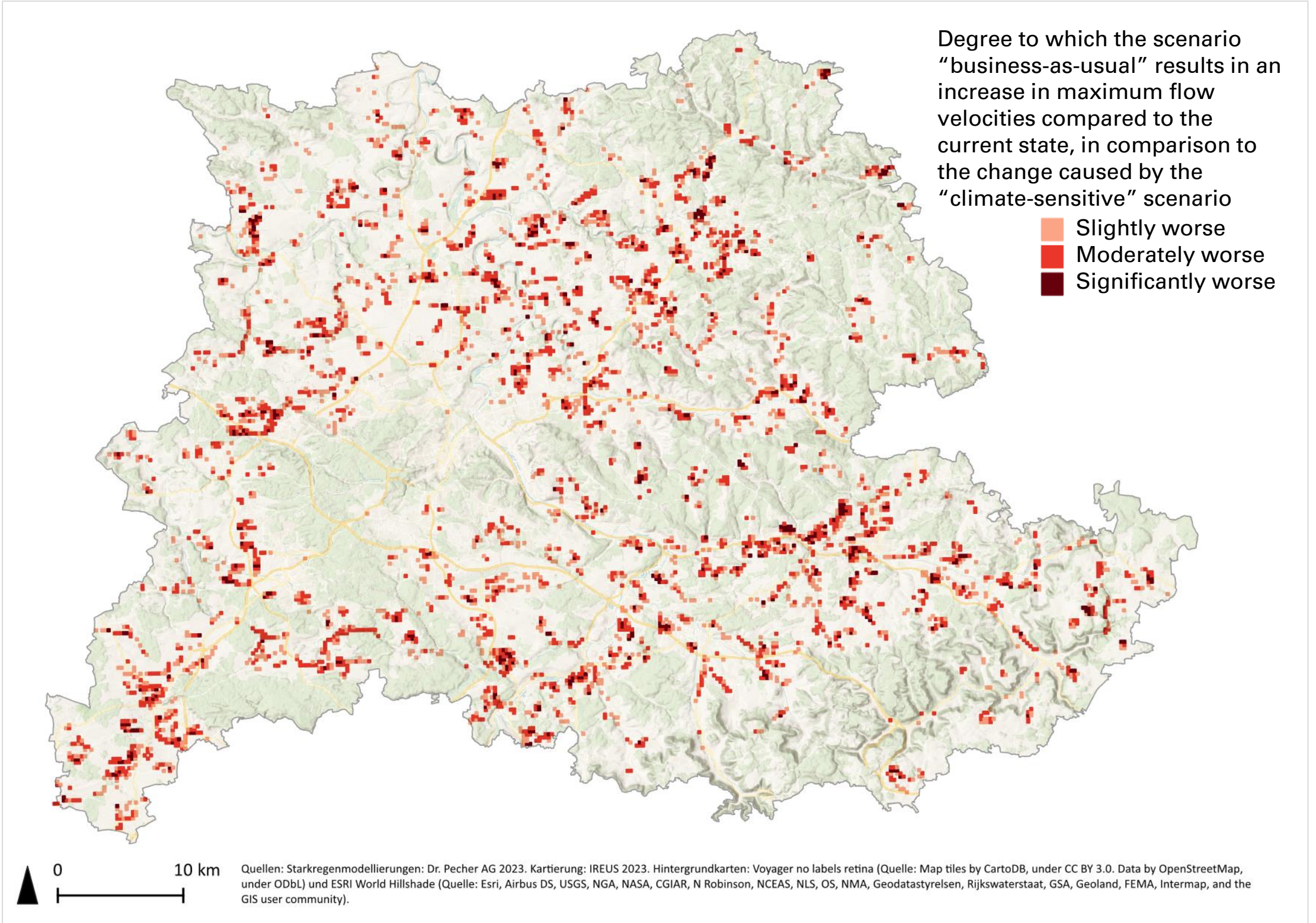


Figure 4: Map of the Stuttgart region (full spatial extent of the results) showing the difference between the two scenarios (“business-as-usual” and “climate-sensitive”) in terms of flow velocity. Results of heavy rain modeling for the “business-as-usual” scenario compared to the current state.

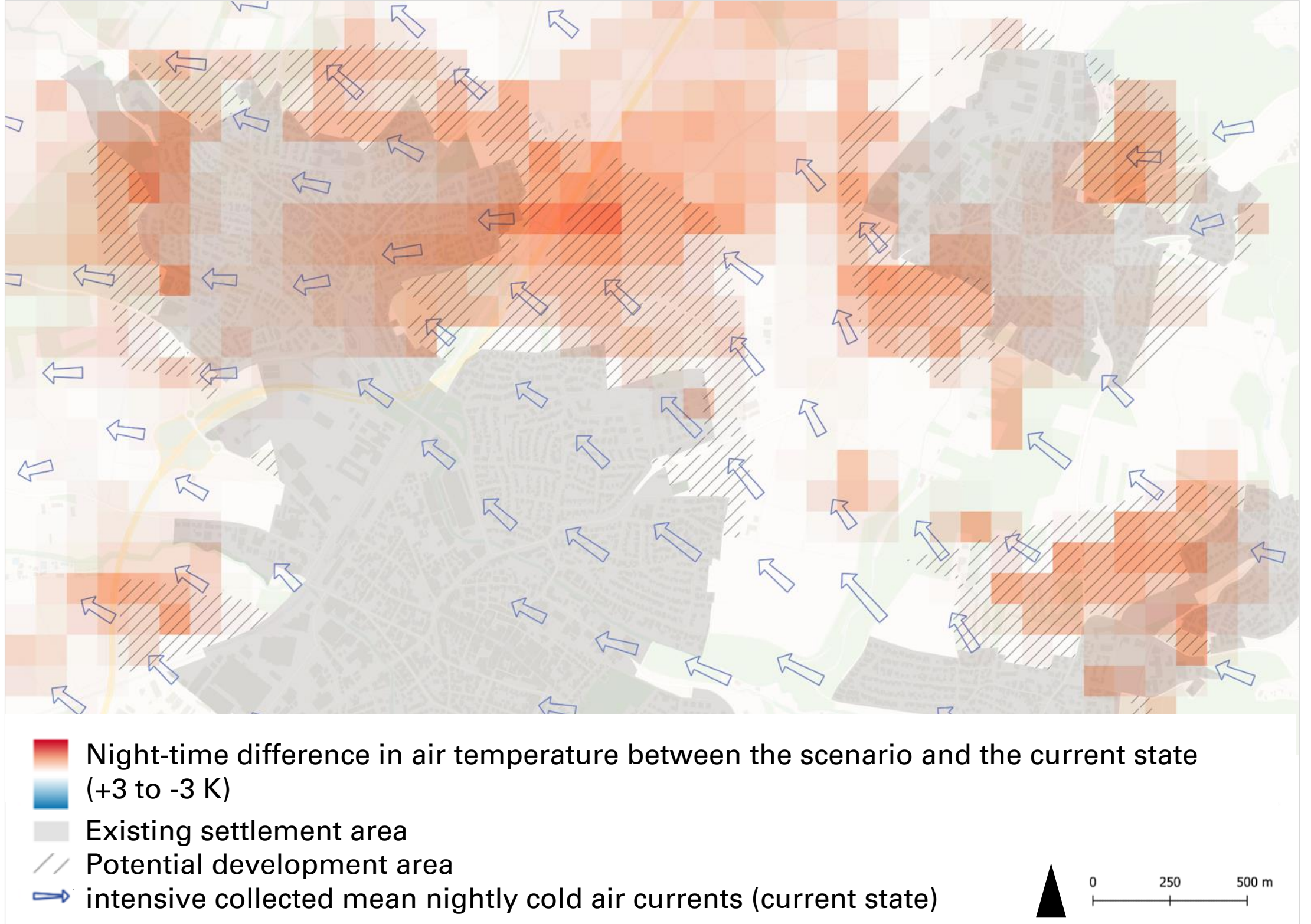


Figure 5: Night-time difference in air temperature between the urban expansion scenario and the reference situation (map excerpt). A distinction between the “business-as-usual” and “climate-sensitive” scenarios was not possible for the climate analysis (analysis data: B. Brecht, Lohmeyer GmbH, ISAP 2023).

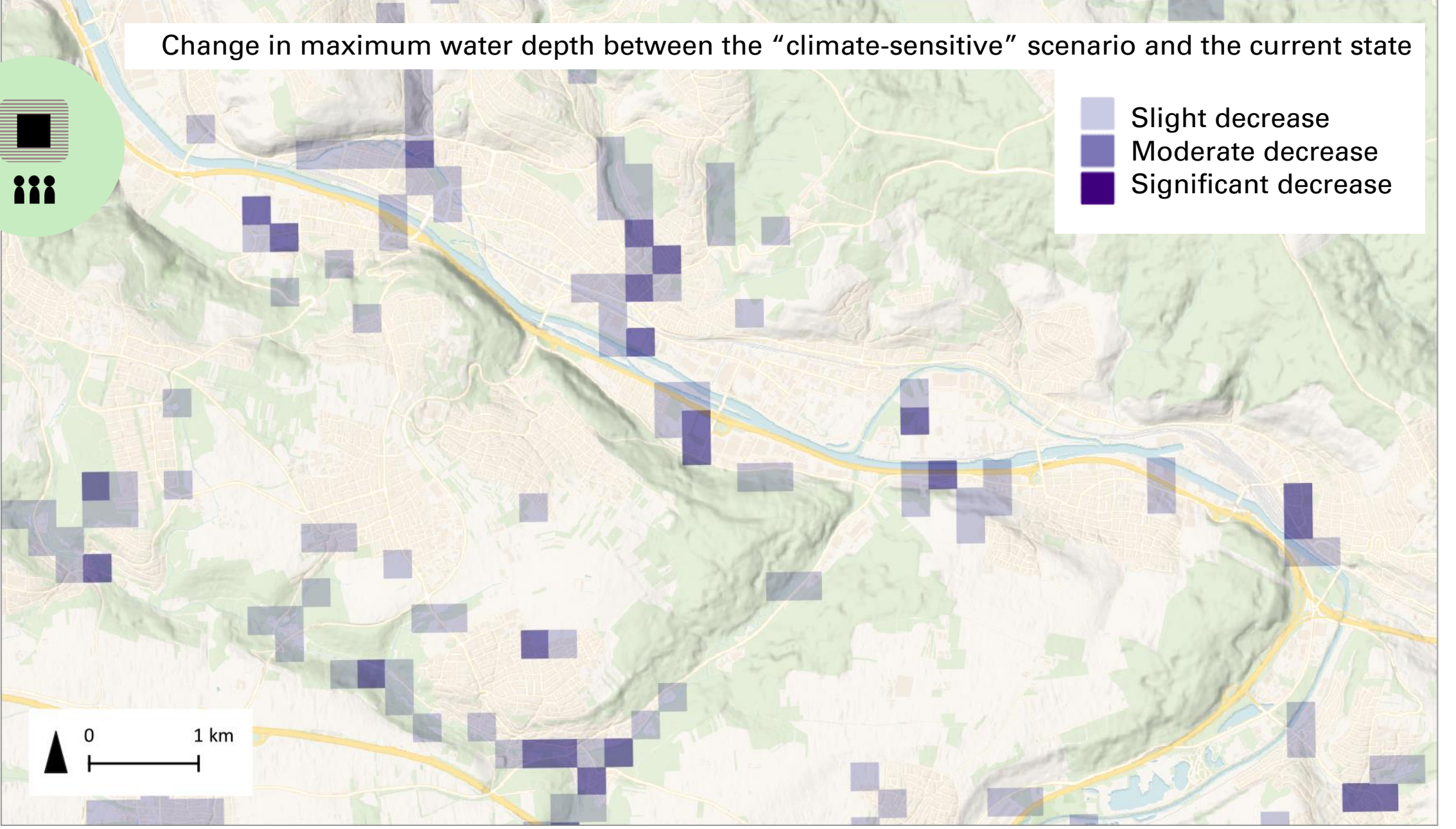
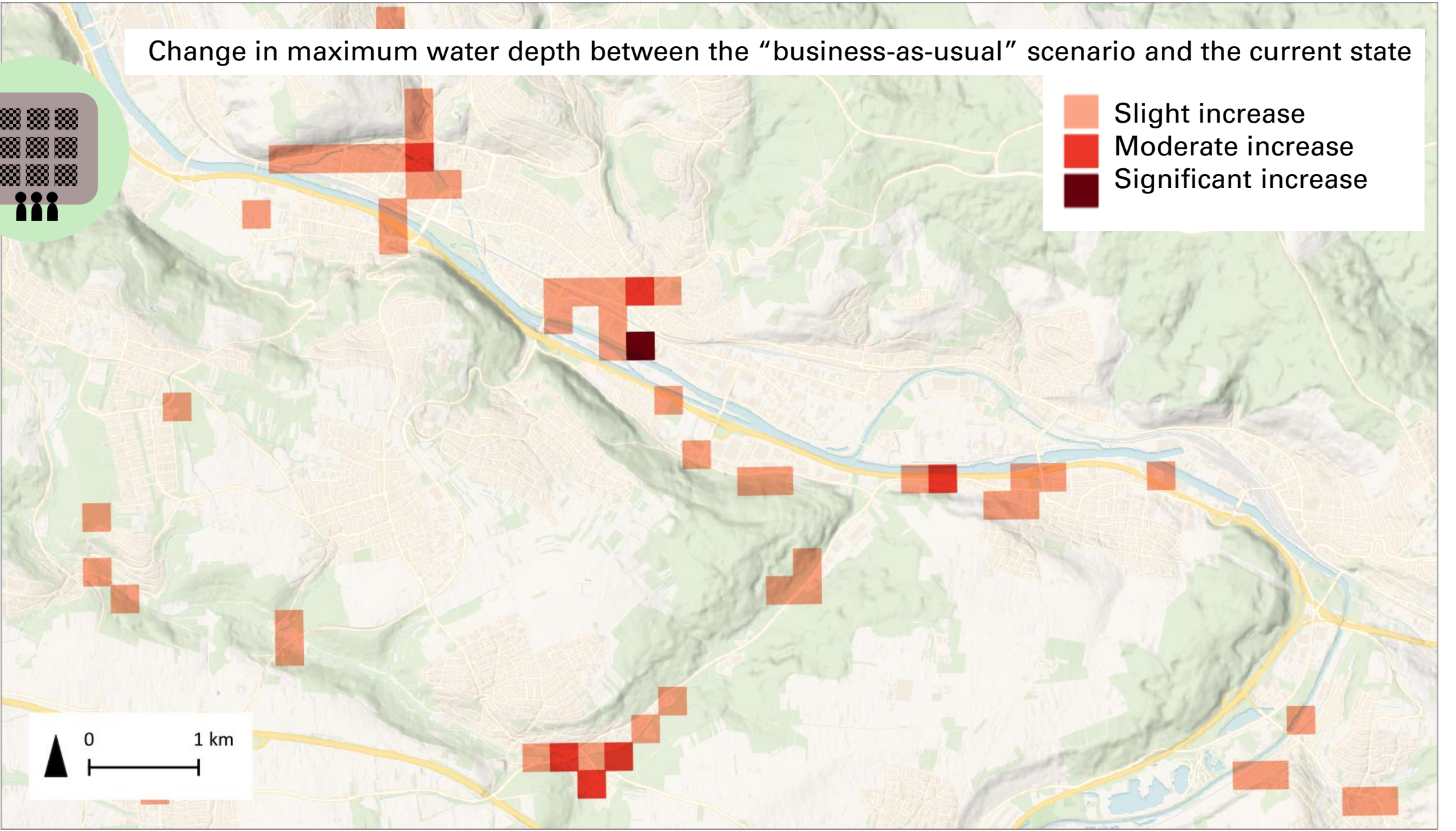


Figure 6: Results of pluvial flood modeling showing the difference in the maximum water depth of (top) the “business-as-usual” scenario compared to the current state and (bottom) the “climate-sensitive” scenario compared to the current state (excerpt of regional map).

Quellen: Starkregenmodellierungen: Dr. Pecher AG 2023. Kartierung: IREUS 2023. Hintergrundkarten: Voyager no labels retina (Quelle: Map tiles by CartoDB, under CC BY 3.0. Data by OpenStreetMap, under ODbL) und ESRI World Hillshade (Quelle: Esri, Airbus DS, USGS, NASA, NOAA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatasystemen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community).

Discussion

The results show the sensitivity of existing settlement areas to urban expansion and the effects and advantages of climate-sensitive development. We aimed to measure the effect of urban expansion on hazard exposure in a way that was relevant to regional planning. This focus on planning relevance drove our decisions about methodological approach, each of which had implications on the usability of the results (Table 1).

Approach	Disadvantage	Advantage
Region-wide spatial extent	Necessary generic assumptions mean results cannot be used to measure the exact impact of development	Relevance to regional planning & inclusion of transboundary effects (e.g. changes to runoff/airflows due to neighboring development)
Scenarios based on spatial plans	Publicising results has to be done with care due to political sensitivity	Relevance to actual current planning
Analysis of both heat & flooding	Difficult to define scenarios to suit parameters of both models	Simulations of the impact on both hazards comparable

Table 1: Reflection of the pros and cons of key aspects of our chosen methodological approach.

Key References:

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