



NAture Insurance value: **A**ssessment and **D**emonstration

NAIAD Case Studies:
Chapter 16
Denmark –
Copenhagen DEMO



NAture Insurance value: **Assessment and Demonstration**

1. INTRODUCTION AND CHARACTERIZATION

Urban flooding is an increasing hazard risk and expected to aggravate with climate change. The restoration of an urban river (RUR), which is the restoration of a currently piped river back to its natural environment, as a Nature-Based Solution (NBS) is explored to both mitigate urban flooding and create synergies with urban planning including climate change adaptation plans, leading to quantitative and qualitative co-benefits.

The City of Copenhagen initiated its climate adaptive measures in earnest after the climate summit, COP15, in Copenhagen in December 2009; on 25 August 2011, the City Council adopted the Copenhagen Climate Adaptation Plan. This plan sets the framework for the implementation of climate adaptive measures in the City Administration area. The Cloudburst Management Plan is an offshoot of the Copenhagen Climate Adaptation Plan, which before the disastrous flooding events in 2011 mainly had focus on flooding related to storm surge, but then accelerated measures to mitigate urban flooding as a result of cloudburst events. The Cloudburst Management Plan adopted in 2012 outlines the methods, priorities, and measures recommended for the area of climate adaptation including extreme rainfall. With this Plan, decisive steps forward have been taken to protect Copenhagen against high-intensity rain like the ones witnessed in August 2010 and especially in July 2011. Initiatives might include reopening streams, constructing new canals or establishing lakes and more green spaces, and using roads with high curbstones to lead the pluvial floodwater into confined spaces, notably surface water channels following a topographic gradient towards open waters (City of Copenhagen, 2012). Different NBS are already implemented as part of the City's cloudburst management plan, which will contribute to the RUR and are therefore included in this work. Such NBS relevant for the RUR NBS scenario includes green areas, retention areas, decoupled rainwater from roofs and blue surface water routing from street level flooding to the RUR recipient and are implemented in the hydrological model described later in this work.

It's important to stress that the restored urban river NBS (RUR) scenario described in this work, has not been political adopted and is currently not included in the cloudburst management or climate adaptation plan for the City of Copenhagen. The scenario therefore only served as an example of an NBS, which could be considered at a later time by the municipality.

The Copenhagen Demo site involves a test study of the benefits of implementation of the RUR based on a currently piped river or stream running through central parts of the city (See Figure 1 and Figure 2). The area along the piped river is 2-4 km long and covers an area of 80.000-120.000 m² depending on which solution chosen. The primary focus regarding analysis of the benefits related to restoring the river are mitigation of damages avoided from a rising groundwater table. Specifically, the shallow groundwater table in the Copenhagen area are located only a few meters below the groundwater surface. Therefore, it's tested, using a hydrological model, how future climatic changes will affect the shallow groundwater table in a part of the Copenhagen area.

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Furthermore, economic analyses have been carried out to assess the avoided costs by means of the Restored Urban River (RUR) NBS scenario. Avoided costs are considered as costs caused by groundwater flooding as a result of both cloudburst events by spilling over of excess water from street level and pushed up water from sewerage systems to subterranean building infrastructure (e.g. cellars) and a rising groundwater level.

A simple damage function has been set up to calculate the avoided costs for the river basin.

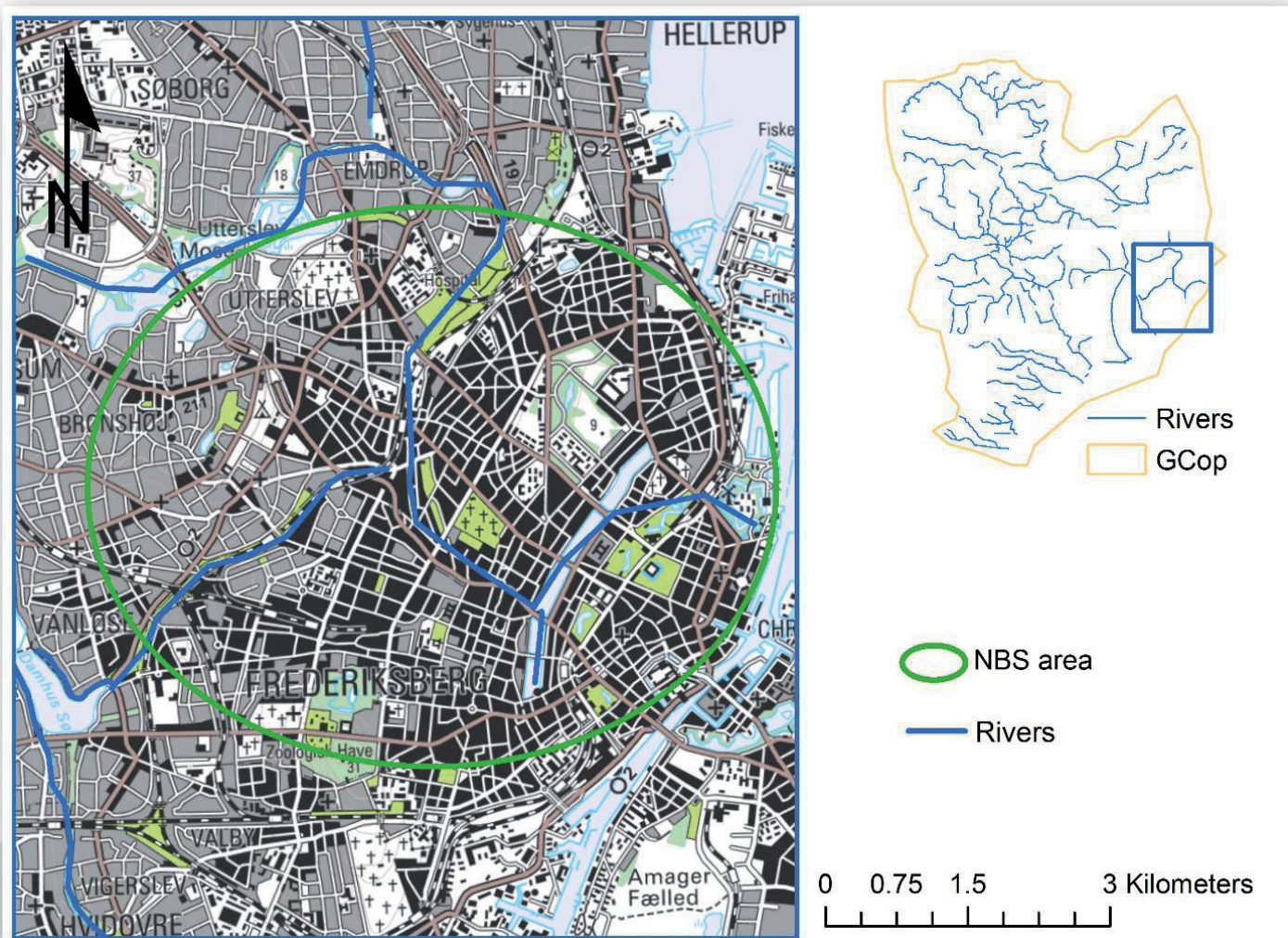


Figure 1. Focus area, area where NBS are implemented (green circle). In the NBS area the streams are presently in pipes in the subsurface. In the NBS scenario, the streams are restored to a blue/green water infrastructure

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Figure 2. Bispeengbuens motorway ramp, expected to be removed to create place for residential and green areas, road tunnels and climate adaptation solutions.

METHODOLOGY APPLIED

The methodology used in this study builds on simulating shallow groundwater with a hydrological model, which show that the groundwater table under the current conditions and future conditions (see Table 1. **No se encuentra el origen de la referencia.**) may rise above surface and become surface inundation and adds to the stormwater flooding from e.g. cloudburst events. The methodology is also described in chapter 3, Part II.

The avoided damage is calculated by analysing the area in which shallow groundwater level exceeds a certain threshold value where damage to cellars is probable and for which we have estimates depending on the type of built environment for that particular location. The threshold value of 2.0 m has been determined from averaging know cellar depths (data provided by city of Copenhagen) and expert judgement on expected shallow groundwater level in the NBS catchment area (Figure 1).

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HYDROLOGICAL MODEL

The hydrological effects of the restored urban river and the ability to divert not only rainwater but also groundwater in contact with buildings and critical infrastructure are simulated with a hydrological model. The hydrological model (MIKE SHE/HYDRO) is a physically based fully integrated groundwater surface water model covering the primary aquifer for the Greater Copenhagen area and large parts of Northern Zealand. The set-up of the physical environment and geology hydrological model is described in detail in D6.1 (Pengal et al., 2017), D6.2 (van der Keur et al., 2018) and D6.3 (LeCoent et al., 2019). Groundwater levels are calculated for 9 numerical layers but only the most upper groundwater table is relevant for the estimation of damage level to urban buildings (see Figure 3).

The hydrologic model has been calibrated against discharge of the piped river to an open water recipient, but due to the fact that the urban river NBS is not yet implemented, no calibration for the anticipated urban river has been possible. However, the applied model is physically based, i.e. physical processes in the integrated groundwater and surface water environment are state-of-the-art represented. Regarding the physical properties of the urban river NBS, assumptions have been made including the exact position and depth of the restored river, groundwater-surface water interactions (e.g. groundwater - river leakage), groundwater well extractions and how cloudburst management climate adaptation measures are connected to the urban river, all of them add to assessment uncertainty.

The spatial scale of the model area is in the order of magnitude 5 x 5 km for the entire urban area which is shared by the municipalities of Copenhagen and Frederiksberg (shown in Figure 1) and includes the Bispeengen motorway ramp which in the considered scenario is replaced by road tunnels, residential and green areas and space for climate adaptation, Figure 2.

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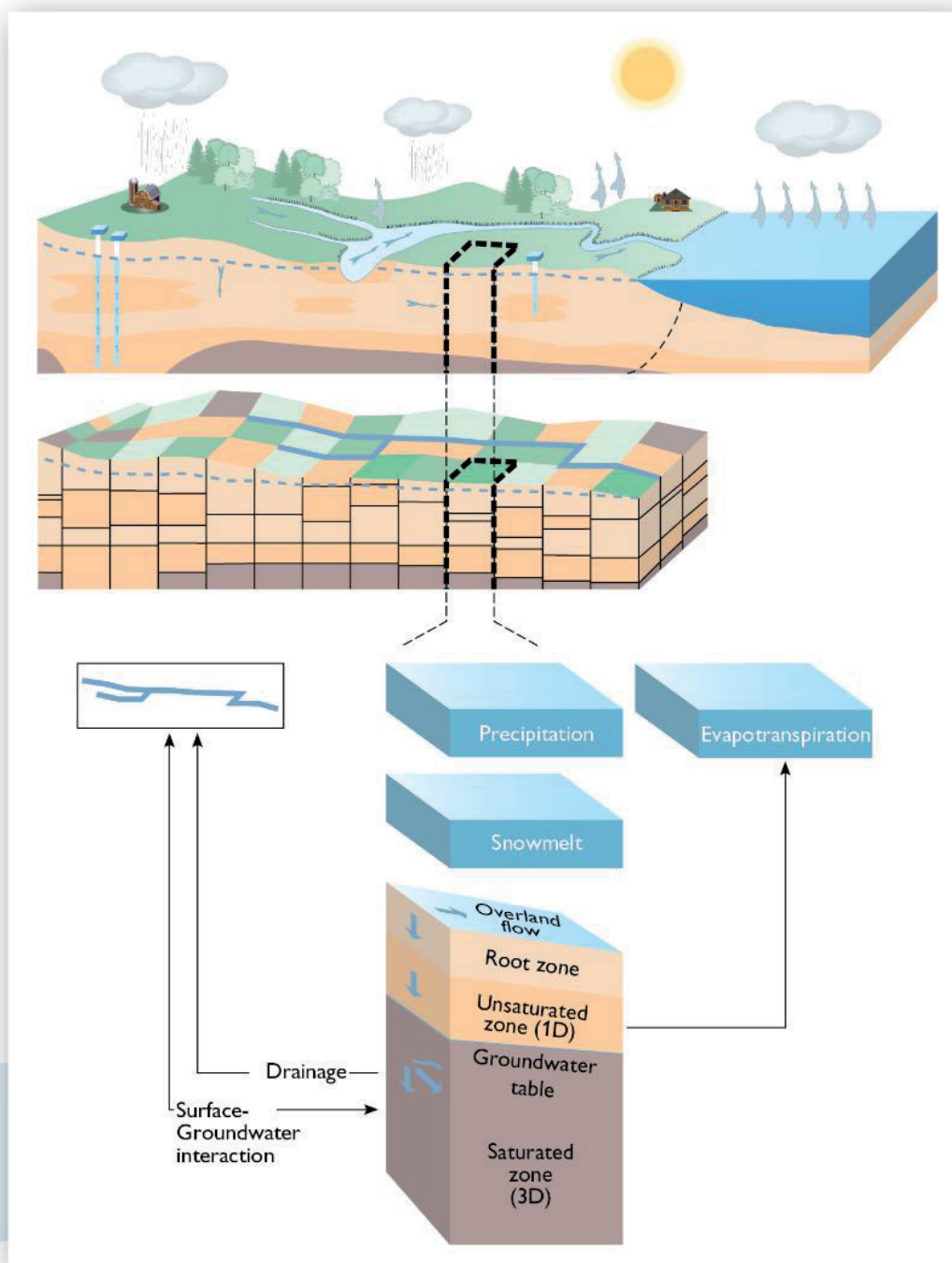


Figure 3. Concept of hydrological model. The unsaturated zone is simulated in 1D, whereas the saturated zone is simulated in 3D, and overland flow in 2D. From vandmodel.dk

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SCENARIOS

In the analysis two different type of scenarios are considered:

- a scenario with and without the RUR – NBS in which the 'without RUR NBS' scenario is the 'Business-as-Usual (BAU);
- and the climate scenarios: the reference climate, 1981-2010 and the future climate 2071-2100 using the RCP8.5 projection (Collins et al., 2013). The scenarios are also shown in Table 1 and Table 2 .

Overall hydrological restored Urban River NBS scenarios	
Business as Usual scenario (BAU)	Restored Urban River scenario (RUR)
The present situation with a piped urban river and no cloudburst management plan projects implemented.	The piped urban river is restored and interaction with groundwater enabled. A flow rate of 300 l/sec is targeted to sustain a stable and ecological flow. The restored urban river is fed through the three water sources shown in Figure 3 (hydraulic contact, groundwater pumping and decoupled water).

Table 1. The BAU and RUR scenarios

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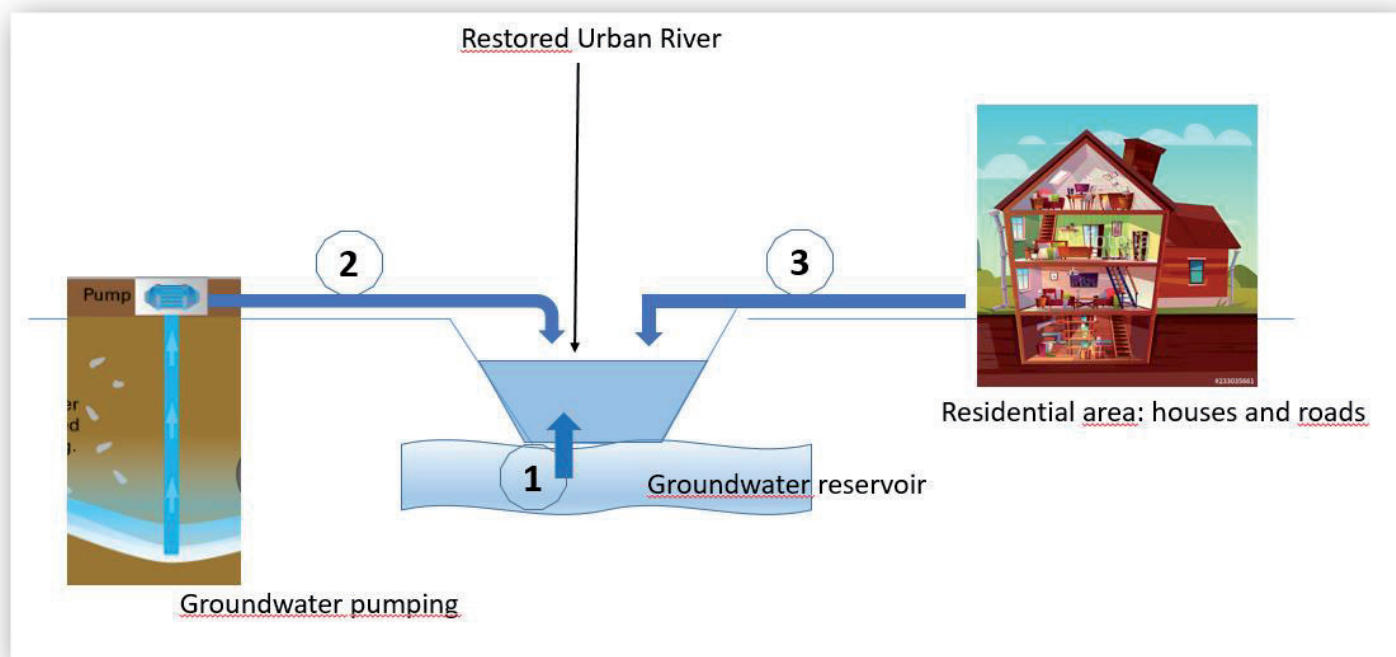


Figure 4. Water sources to the restored urban river NBS: (1) from groundwater through hydraulic contact with the river; (2) groundwater pumping, shallow and deep; (3) decoupled water from residential areas (e.g. roofs) and other paved areas (e.g. roads).

The Restored Urban River (RUR) scenario receives water from several sources, which is shown in Figure 4:

1. groundwater through urban river interaction (hydraulic contact) with (shallow) groundwater resources;
2. pumped groundwater from areas within the urban river catchment that experience rising groundwater, including from areas where water is infiltrated locally (LAR/Sustainable Drainage Systems, SuDS);
3. decoupled water from roofs and paved areas which otherwise would have been routed to the combined drainage-sewer system (combined sewer system)

The damage levels are calculated as 30-year maximum groundwater level for the periods 1981-2010 (reference period) and 2071-2100 (future period) (See Table 1). The generated 30-year maximum values are spatially distributed in a 100 m x 100 m raster dataset relative to the surface. Then, the dataset is analysed for simulated values above the defined threshold of 2 m below surface, e.g. a number of raster grid cells with a 30-year maximum level above 2 m below surface. This dataset is then applied in GIS analysis to find areas above the defined groundwater thresholds for building damage with (RUR) and without (BAU) implementation of the NBS and with and without the hydrological effect of climate change (as prognosed by an 8.5 RCP scenario (IPCC)).



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ECONOMIC ANALYSIS

The scope of the economic analysis for the NAIAD Copenhagen NBS is to assess the avoided costs by means of the RUR NBS scenario under two climate scenarios with reference periods 1981-2010 and a future period 2071-2100. In Table 2; Error! No se encuentra el origen de la referencia. the scenarios are listed.

Vision	NBS scenario	Climate scenario	Period
1	BAU (no NBS)	Reference	1981-2010
	RUR (with NBS)	Reference	1981-2010
2	BAU (no NBS)	RCP8.5	2071-2100
	RUR (with NBS)	RCP8.5	2071-2100

Table 2. The scenarios conducted in this study.

Avoided costs are considered as costs caused by groundwater flooding as a result of both cloudburst events by spilling over of excess water from street level and pushed up water from sewerage systems to below ground building infrastructure (e.g. cellars) and rising groundwater level. Other costs as life cycle costs and opportunity costs as well as an assessment of co-benefits of the RUR – NBS scenario have not been included in the analysis.

The RUR scenario is compared to the BAU scenario with respect to shallow groundwater level and avoided damage is then calculated as the difference in affected area in which the shallow groundwater level causes damage. The damage caused (total damage) is estimated to 509 kr/m² (COWI 2014) and implemented in the adopted damage function. The damage function is expressed as:

$$[\text{BAU-RUR}] (\text{Area affected [m}^2\text{]}) \times \text{unit cost [DKK/m}^2\text{]}$$

where Area affected is the cellar affected by flooding and unit cost is a constant (estimated unit damage, [DKR/m²]). In this study the total damage is set to 509 DKK/m², which is a value derived from an analysis by COWI (2014) for the Danish assurance umbrella organisation "Forsikring og Pension" (Danish Insurance and Pension). The unit damage key numbers were estimated from reimbursed compensation from insurance companies for the period 2006 to 2012, including the catastrophic cloudburst event in July 2011, (Figure 6).

The principle is demonstrated in Figure 5.

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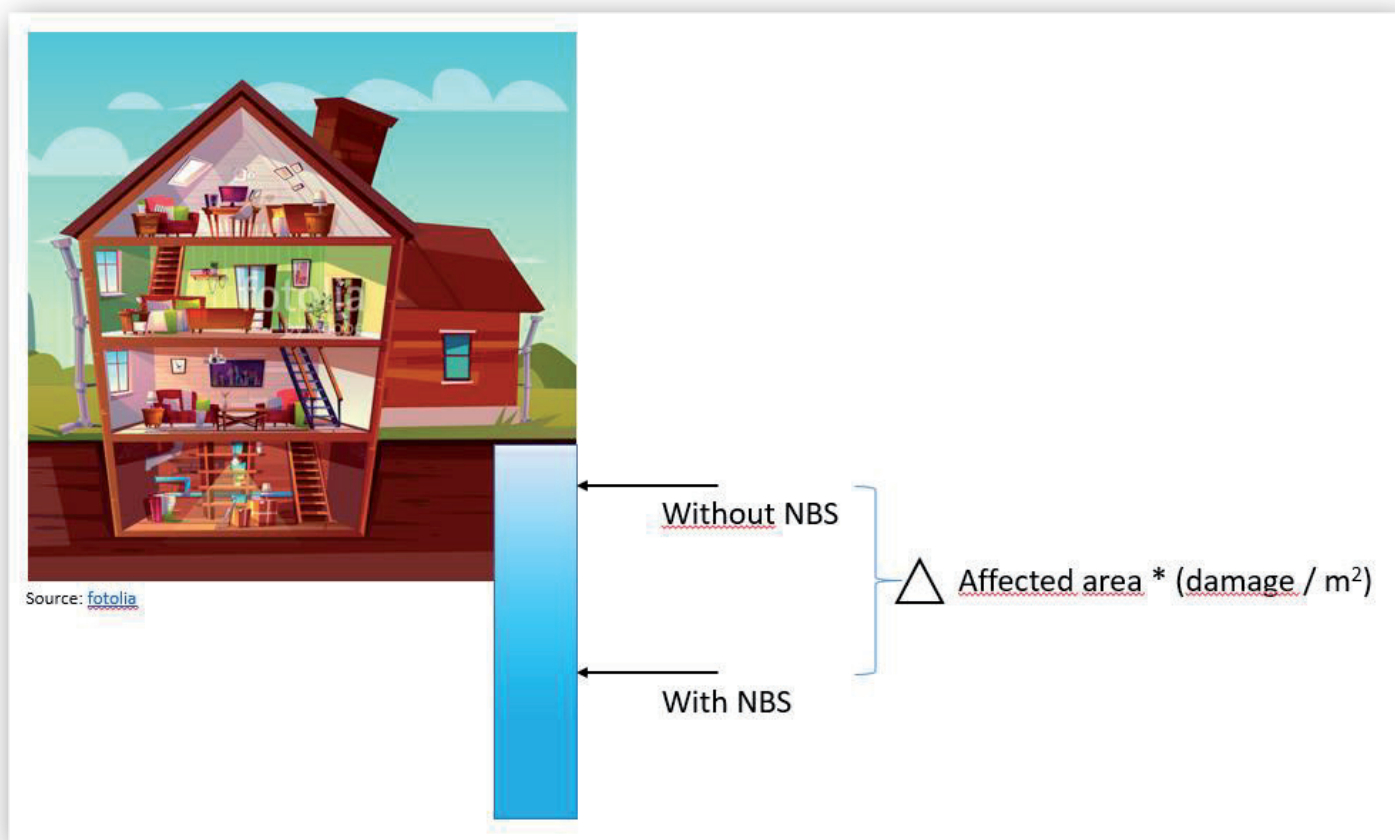


Figure 5. Avoided damage is calculated from the difference in area in which dwellings and businesses are affected by high shallow groundwater causing subsurface damage, i.e. cellars, and (in case the groundwater level rises above ground surface) inundation damage.

Damages to cellars and other subsurface infrastructure as a result of elevated groundwater levels due to cloudburst events, but also prolonged rainfall, or both in combination, can be distinguished in two main damage types, which in combination can show cascading effects, reinforcing each other:

(A) water damage due to (i) fast increased street level inundation and spilling over to lower areas, like cellars, via doorsteps, staircases to cellars or other low thresholds, as well as (ii) water pushed up from floor drains and toilets (in case no backflow blocker has been installed). Both types are the result of fast 'catastrophic' rain events.

(B) slowly rising groundwater as a result of prolonged rainfall, changed (decreased) water abstraction patterns (water savings), and repaired sewage and drainage channels that also functioned as shallow groundwater drainage, all of which exacerbate the effects under (A) as drainage capacity to remove surface water is decreased.



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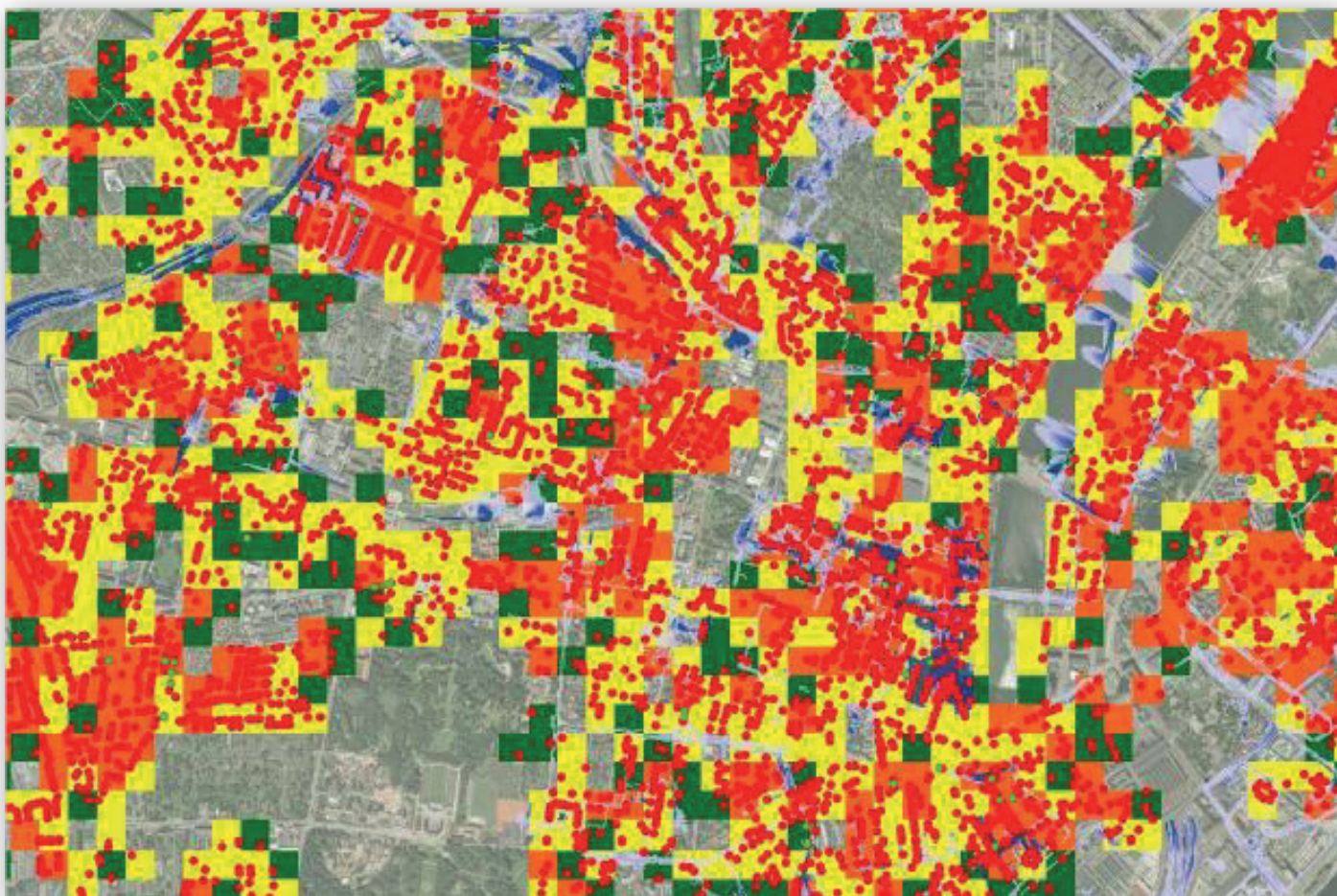


Figure 6. Insured compensation for the July 2011 cloudburst event aggregated for damage due to inundation, groundwater or both (COWI 2014). Spatial resolution is 100 m x 100 m. Red and green cells indicate high and low insured damage compensation respectively (yellow cells are medium). The red and green dots represent actual addresses where damage (high and low respectively) occurred.

The hydrologic model simulates the effect of (B) whereas mainly (A), and to an unknown extent (B) are previously only considered in the damage functions. This means that the calculated 'avoided damage' is considered to be a minimum avoided cost.

The avoided damage is calculated by analysing the area in which shallow groundwater level exceeds a certain threshold value where damage to cellars is probable and for which we have estimates depending on the type of built environment for that particular location. The threshold value of 2.0 m below surface has been determined from averaging known cellar depths (HOFOR, 2008) and expert judgement on expected shallow groundwater level in the RUR catchment. Groundwater may rise to this level where it interferes with the drainage and sewer system, usually combined, and where it may cause water being pushed up to cellar or street level.

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In that case it adds to the stormwater flooding from e.g. cloudburst events. The applied threshold of 2.0 m below surface above which unit damage per square meter does not change. This assumption is in reality an underestimation, due to that the damage value probably will change with level higher above the threshold value, therefore the avoided damage calculated in this way must be regarded with caution and represents a minimum value (best case). Hence, the rule is damage = 0 if depth < 2m and damage = constant if depth > 2m.

Cellar depth shown in Figure 7 is calculated as an overall average depth for all 100 m by 100 m model grids for which an occupation percentage of 7.5 % is applied. For example, for a 100 m by 100 m grid amounting to 10,000 m² there is a building which is at risk for being flooded as a result of rising groundwater level, or spill over water from the street level. This building is assumed to have a cellar surface of 0.075 * 10,000 m² = 750 m², which is the value used for calculating damage for cellar flooding.

To estimate the cost of damages the calculation looks like this:

$$\text{Damage} = (\text{number of pixel}) \times 750 \text{ m}^2 \times 509 \text{ kr/m}^2$$

for both the RUR and BAU scenarios.

The avoided damage is the difference between the two scenarios:

$$\text{Avoided damage} = \text{BAU_damage} - \text{RUR_damage}.$$

Other avoided costs with respect to the implementation of the restored urban river RUR scenario are costs associated with climate adaptation alternatives and grey solutions. Alternatives to the opening of the urban river and its tributaries include cloudburst tunnels and retention basins, the costs of which have been estimated (EY and Moe 2019). Before the release of the cloudburst management plan there also was the option of upgrading the traditional combined sewer system in Copenhagen which appeared to be a very costly solution (EY and Moe 2019) as compared to alternative climate adaptation solutions. Therefore, avoided costs associated with upgrading and operating the traditional sewer solutions are not considered in this analysis for the urban river RUR NBS scenario.

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Figure 7. The pink dots represent data points for which there is cellar depth attributed to the building location data (source: HOFOR water utility, 2008). The lower part represents the Frederiksberg Municipality for which no data is available, but where the average depth for the Copenhagen part (1.78 m) is assumed

2. RESULTS

No se encuentra el origen de la referencia. shows the simulated change between the future groundwater levels with and without implementation of RUR. As expected, and intended, the shallow groundwater level rise is reduced in case a RUR-NBS is implemented (the blue pixels have lowest groundwater level).

Within the catchment area of RUR NBS (see ¡Error! No se encuentra el origen de la referencia.) for the future climate, the area with GW damage is reduced from 1,620,000 m² (162 cells x 10,000 m²) to 1,060,000 m² (106 cells x 10,000 m²), which equals a reduction of 35 %.

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This means that the avoided damage under the conditions of future climate can be calculated from the reduced number of cells for which the cellar area is 750 m² per cell. Therefore, the avoided damage is $(162-106) \times 750 \text{ m}^2 \times 509 \text{ DKK/m}^2$ is equal to DKK 21,378,000.

Likewise, for the reference period, the area is reduced from 1,460,000 m² to 930,000 m² (not shown) which results in a somewhat lower avoided cost of DKK 20,232,750.

Vision	NBS scenario	Climate scenario	Period	Avoided cost [DKK]
1	BAU (no NBS)	Reference	1981-2010	20,232,750
	RUR (with NBS)	Reference	1981-2010	
2	BAU (no NBS)	RCP8.5	2071-2100	21,378,000
	RUR (with NBS)	RCP8.5	2071-2100	

Table 3. Avoided cost of the two overall scenarios (Table 1)

UNCERTAINTIES

This methodology to assess avoided damage is conducted under a number of sources of uncertainties. The hydrologic model has been calibrated against discharge of the piped river to an open water recipient, but due to the fact that the urban river NBS is not implemented no calibration for the anticipated urban river has been possible. However, the applied model is physically based, i.e. physical processes in the integrated groundwater and surface water environment are state-of-the-art represented. Nevertheless, assumptions have been made including the exact position and depth of the restored river, groundwater-surface water interactions, groundwater well extractions and how cloudburst management climate adaptation measures are connected to the urban river, all of them add to assessment uncertainty.

Another source of uncertainty is the missing information on cellar depths for the municipality of Frederiksberg for which the assumption of similarity with data from Copenhagen has been made, i.e. the average depth for the Copenhagen part of 1.78 m has been assumed for the Frederiksberg part, which is probable. The model setup and overall approach however represents a credible tool which can be updated when new information becomes available.

To calculate the avoided damage, data on insured damage reimbursements for the period 2006 to 2012 were crucial. Reported damage from citizens to insurance companies has been analysed by a consultant (COWI 2014) for which available damage data from the insurance companies to the built environment has been aggregated as 'water damage'. As a result of this, damage to cellars from both surface water overflow and sewerage system could not be distinguished from each other and were aggregated at the scale of residential buildings (DKK 509/m²).

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This value does not consider whether flooded area and buildings include businesses for which the damage costs may be higher. Also, the unit damage cost of DKK 509/m² does not vary with depth over the threshold value (2 meter), which represent an uncertainty and means the estimated avoided damage is a minimum value.

In addition, groundwater flooding damage as a result of sewer overflow probably also causes damage to the structure of buildings, not taken into consideration in the simple damage function used, which is why the estimated value of damage, a bit more than DKK 20 million, alone for this reason among others, probably is much higher.

When calculating the cost of avoided damages, a value of 7.5 % for the affected area (e.g. cellars) is used. This value is a premise based on the best qualified assessment and is also subject to a certain uncertainty. The affected area is likely higher, which means the calculated cost of avoided cost is higher than shown.

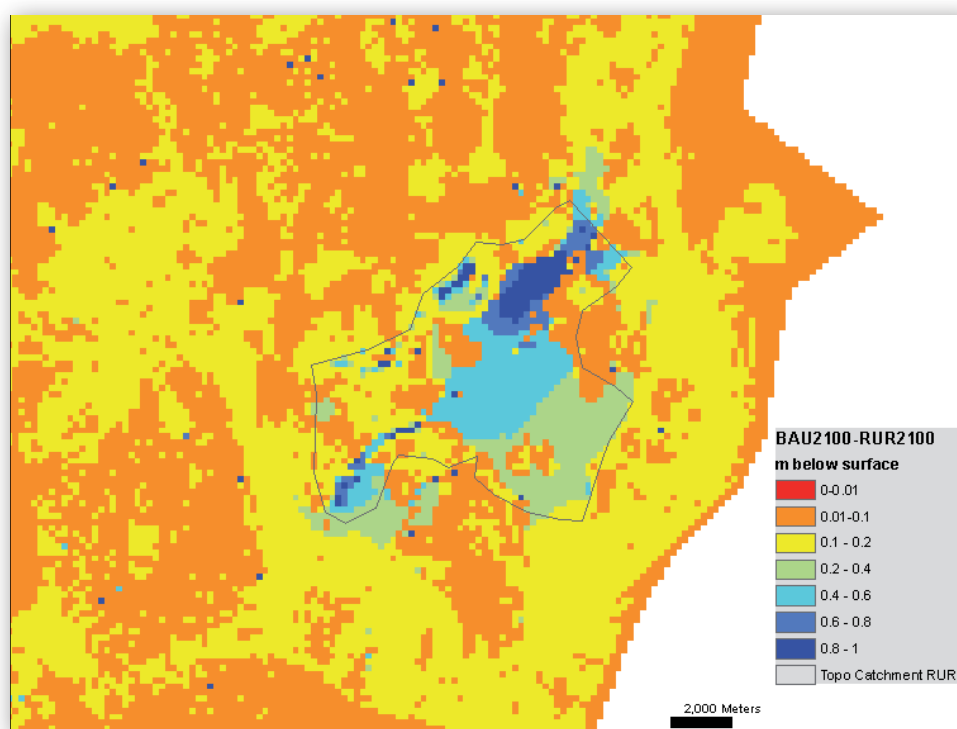


Figure 8 Difference in groundwater max levels with and without implementation of NBS (RUR) for the period 2070-2100 simulated the RCP 8.5 emission scenario (mean ensemble member)

All this adds substantially to the overall uncertainty, but again the conceptual approach can be improved with new and improved data. Therefore, improved and more data, especially for the development of accurate damage functions are needed to reduce the overall uncertainty.

A way to take such uncertainties in considerations is the use of a Bayesian Belief Network (BBN) in which uncertainty is explicitly dealt with. A BBN approach developed for use in a GIS environment and in combination with the methodology presented here is anticipated and under preparation (see chapter 3).

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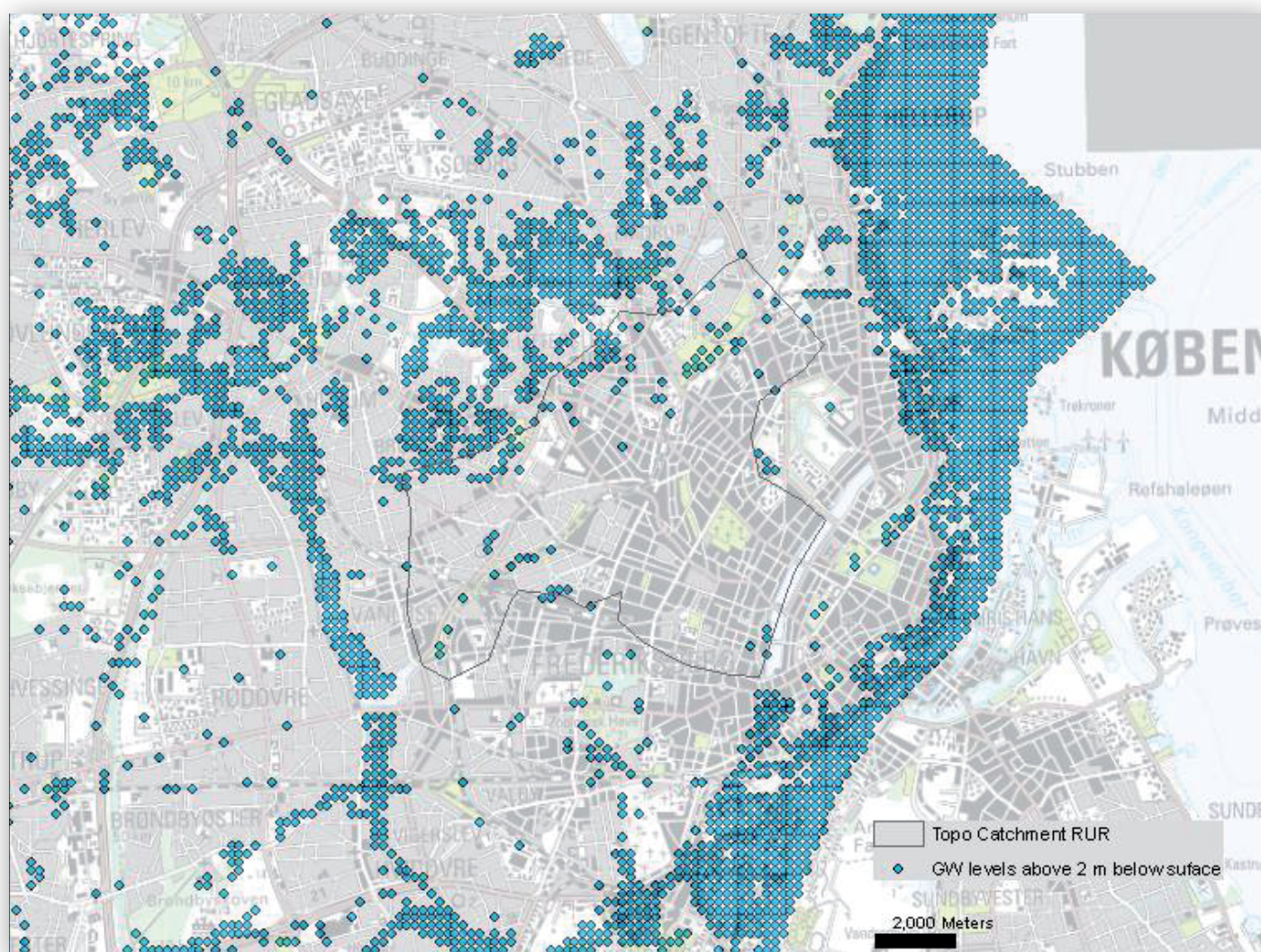


Figure 9. BAU scenario of flood risk areas with groundwater max levels above 2 m below surface (threshold for GW damage) for the period 2070-2100.



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3. NAS EFFECTIVENESS

The RUR NBS scenario clearly shows that restoring (opening) a piped urban river to its natural position (see Figure 10) has an effect on the groundwater level. The simulations show that the restored river will act like a drainage channel for both cloudbursts induced surface water flooding and a rising groundwater levels and thereby avoid groundwater flooding and subsequently damage to subterranean structures.

Calculations show that by restoring the urban river to its natural position, 35 % of the catchment area for the RUR NBS scenario (Figure 8) will remain below the applied threshold of 2 m, where no damage will occur (Figure 9), compared to the BAU scenario.

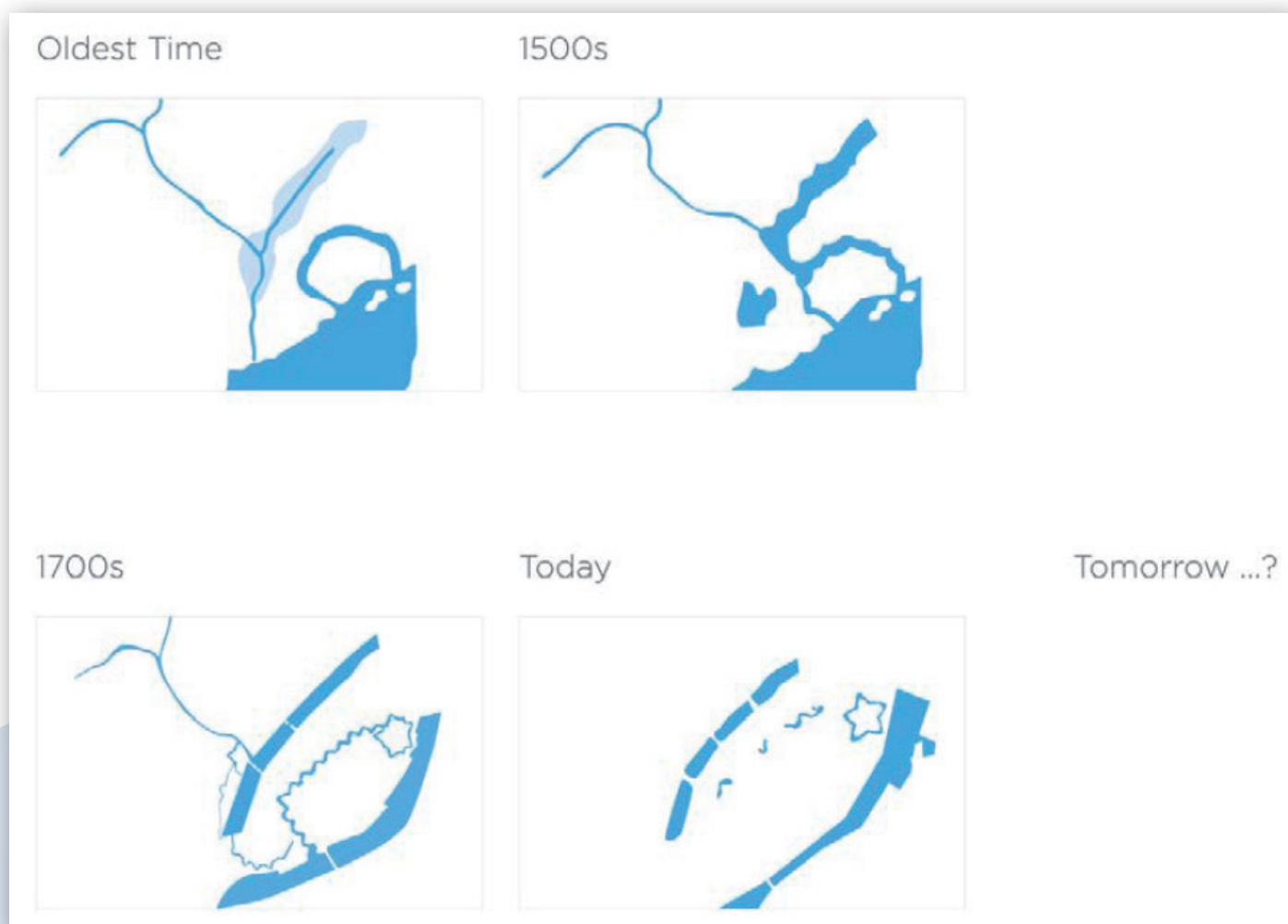


Figure 10. Map of the evolving of surface waters during time. The RUR is an attempt to restore the previous conditions

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Economic analyses show that the avoided costs by restoring the urban river will be at least 20 million DKK for the catchment area of the RUR scenario, and probably higher considering the overall uncertainty.

Besides the direct benefits of lowering the risk of groundwater flooding by restoring the urban river, there is also many others additional benefits or co-benefits associated with the RUR scenario. The converting of the area from an area with a heavy traffic (see Figure 2) to a greener and more quiet and ambient place, will expect to increase the well-being of residents in terms of better health because of less air pollution, outdoor facilities and the opportunity for more exercise. The temperature will be reduced during the summertime, due to the cooling effect of the greenery and reduction of concrete and asphalt. Other co-benefits are increase in real estate prices which will provide a higher tax revenue; businesses can flourish and creates more jobs and crime will go down, due to the openness of the altered area.

About the NAIAD Project

'NAIAD' (Nature Insurance Value – Assessment and Demonstration) is an advanced, first of a kind, EU Horizon 2020 applied research programme focused on Nature Based Solutions (NBS) in risk management strategies, with a focus on water. NAIAD aims to operationalize the insurance value of ecosystems to reduce the human and economic cost of risks associated with water (floods and drought) by developing and testing - with key insurers and municipalities - the concepts, tools, applications and instruments (business models) necessary for its mainstreaming.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730497.



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