ATENAS

# COOK BOOK

## Models and modelling for identification of hot-spot areas

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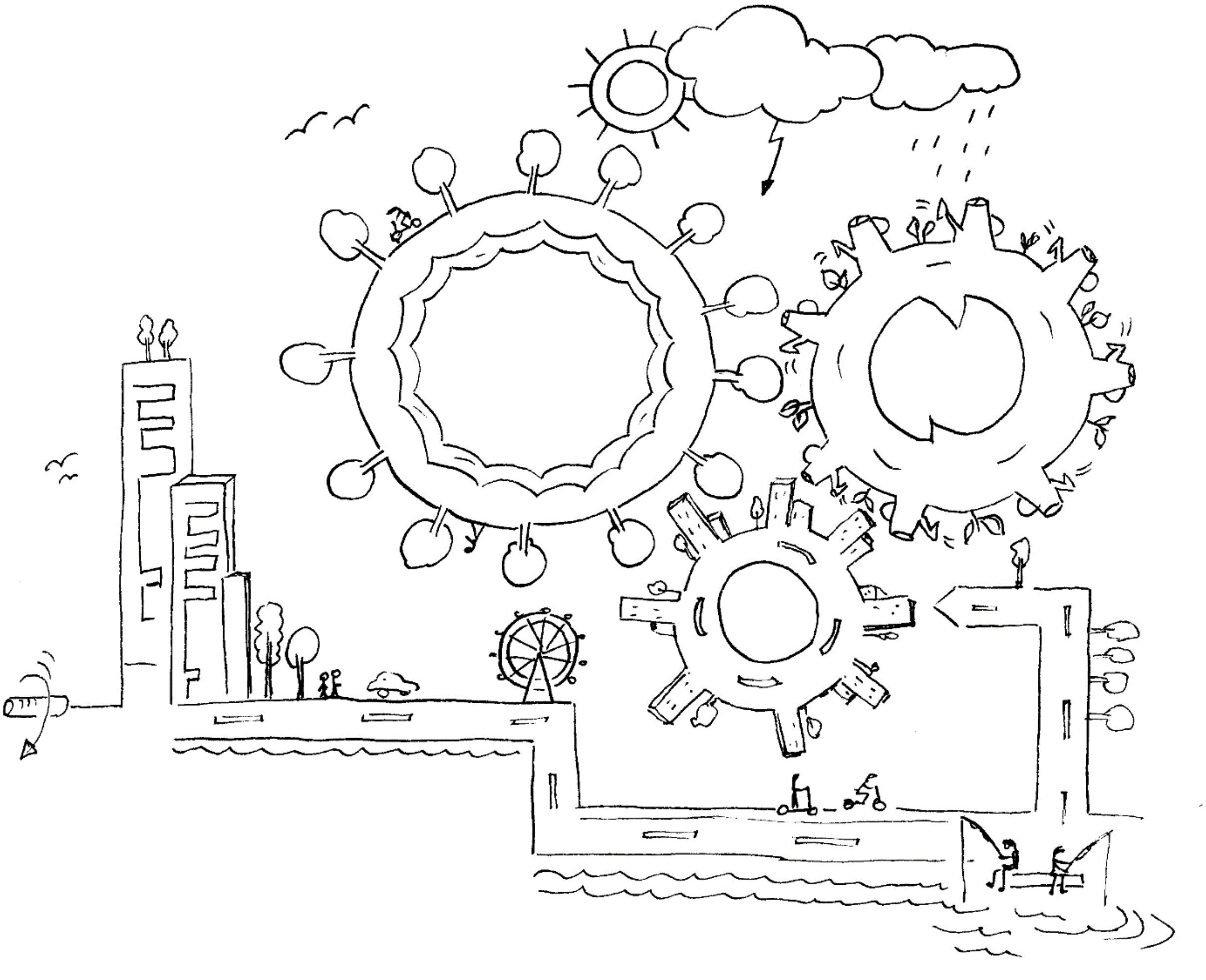

Graphics:
*Agnieszka Butterworth*

# Why do we need models and why there is so many of them?

**Models are critical if you want to answer questions:**

- how to quantify opportunities and risks?
- where to best locate NBS?
- what type of NBS do I need?
- how many of them is needed?
- are we able to solve the problem entirely?
- how grey, green and blue infrastructures interact and what is their synergic effect on health of humans and nature?

The task in front of us when planning actions in urban areas, is to: identify the main problems, check on opportunities we can use, try to estimate the scale of the challenge, and if possible to quantify it to properly chose and dose the remedy.

As NBS rely on nature, first of all we need to understand under which pressures nature operates, and if possible those pressures should be at least decreased. In urban context this might start from very minor but consistent impact like trampling, storing of materials, car parking, through improper site management (biomass removal, frequent cutting of greenery, species selection, invasive species) ending with exposition to UHI, water shortages or flooding, erosion, etc. (Figure 1).

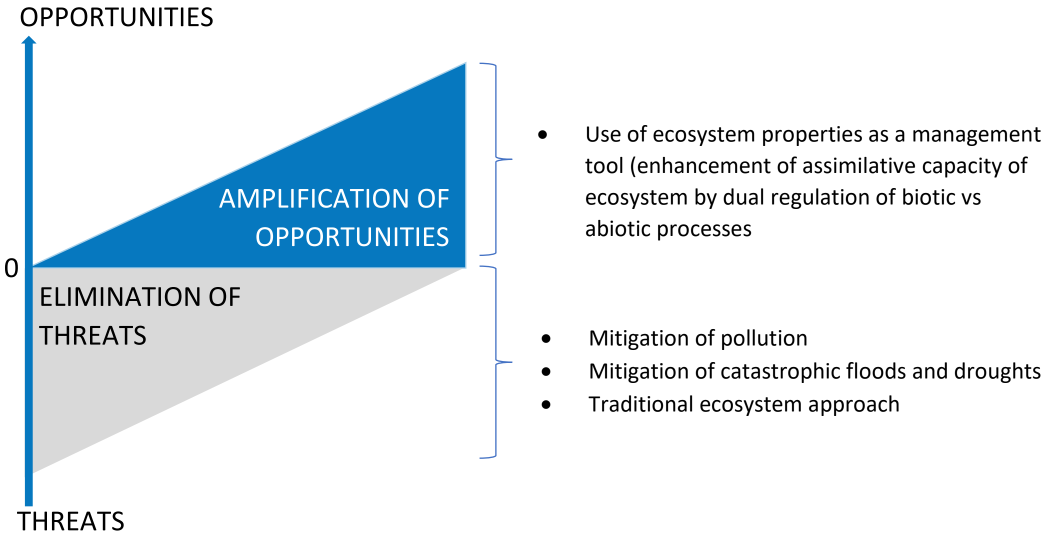

**Figure 1**. Operational framework for NBS context analysis[1]

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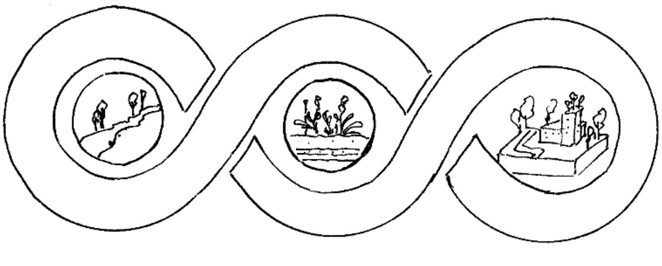
[1] Zalewski M. 2000. Ecohydrology. The scientific background to use ecosystem properties as management tools toward sustainability of water resources. Guest Editorial, Ecological Engineering, 16: pp. 1–8.

The threat may be also constituted by persistent use of technology and mechanistic approach ignoring properties and functions of ecosystems and needs of nature in general. What more, features of socio-economic system, like resource / nature management systems, policy and law in general, human attitudes, knowledge gaps, or simple lack of awareness and care may also be classified as a threat.

Among opportunities, we can surely list: presence, amount, quality of greenery, water bodies independent of their status as there is always a space for upgrading and improvement, knowledge of water cycle, especially run off generation and accumulation zones, people willingness to pay for values of nature, cultural context of places, finally interest of the locals and decision makers in particular actions for nature.

In this part of the ATENAS CookBook we present to you a few models used by the project:

1. **InVest Urban - ecosystem cooling effect model (applied in Łódź)**
2. **IRIP – indicator of intense pluvial runoff (applied in Lyon and Łódź)**
3. **SWMM - Storm Water Management Model (applied in Vantaa)**
4. **Green Area Factor (applied in Łódź and Vantaa)**



Graphics:
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# 1. InVest Urban – city cooling by ecosystems

## Shortly about

InVest Urban is a model developed by the Natural Capital Coalition. This is a global hub at Stanford University supporting collaboration among academic partners including the Chinese Academy of Sciences, the Royal Swedish Academy of Sciences, the Stockholm Resilience Centre, and the University of Minnesota together with core implementing partners including The Nature Conservancy and World Wildlife Fund.

It advances science and create actionable tools to bring the values of nature into decisions.

InVest Urban concentrates on the Urban Heat Island (UHI) effects and influence of vegetation on urban heat mitigation. Vegetation can help reduce UHI effect by providing shade, modifying thermal properties of the urban fabric, and increasing cooling through evapotranspiration.

## What data does it use?

- **Land Use/Land Cover** (raster): Map of LULC for the area of interest.
- The resolution should be small enough to capture the effect of green spaces in the landscape, although LULC categories can comprise a mix of vegetated and non-vegetated covers (e.g. “residential”, which may have 30% canopy cover).
- **Shade** (ratio, *conditional*): The proportion of area in LULC class that is covered by tree canopy at least 2 meters high.
- **Albedo** (ratio, *conditional*): The proportion of solar radiation that is directly reflected by this LULC class.
- **Building intensity** (ratio, *conditional*): The ratio of building floor area to footprint area.
- **Evapotranspiration** (raster, units: mm): Map of evapotranspiration values.
- **Area of Interest** (vector, polygon/multipolygon): A map of areas over which to aggregate and summarize the final results.
- **Maximum Cooling Distance** (number, units: m): Distance over which green areas larger than 2 hectares have a cooling effect; recommended value: 450 m.
- **Reference Air Temperature** (number, units: °C): Air temperature in a rural reference area where the urban heat island effect is not observed.

- **UHI Effect** (number, units: °C): The magnitude of the urban heat island effect, i.e., the difference between the rural reference temperature and the maximum temperature observed in the city.
- **Air Blending Distance** (number, units: m): Radius over which to average air temperatures to account for air mixing; recommended value range for initial run: 500 m to 600 m.

Optional data for running Energy Savings Valuation:

- **Buildings** (vector, polygon/multipolygon, *conditional*): A map of built infrastructure footprints.
- **Energy Consumption Table** (CSV, *conditional*): A table of energy consumption data for each building type.
- **Average Relative Humidity** (percent, *conditional*): The average relative humidity over the time period of interest.

## What information the model delivers?

Based on shading, evapotranspiration and albedo data the model calculates the cooling capacity index. It provides information on how vegetation types (or non-vegetated areas) absorb or reflect heat.

The model allows also to obtain complementary information – cooling capacity based on intensity of buildings. On contrary to vegetation which lowers the temperature, buildings amplify it.

INVEST cooling shows also a map of Heat mitigation index (HMI) that estimates the cooling capacity of urban greenspaces on all land cover classes in the study area by taking into account the cooling capacity of larger urban parks extending beyond their boundaries.

Further the model shows Air Temperature Estimates for cities, what means air temperature without air mixing thus actual air temperature in each pixel of the area.

All those information can be used to monetize climate regulation services of greenery in terms of calculation of:

- Value of Heat Reduction Service presented as estimates of energy savings and work productivity based on global regression analyses or local data
- Work Productivity: the model converts air temperature into Wet Bulb Globe Temperature (WBGT) to calculate the impacts of heat on people work productivity

## What is it useful for?

NBS provide multiple services both to humans and nature. Even when we focus only on water cycle and its regulation, it is of key importance to understand which areas in the city still maintain high potential for climate regulation. It means that they can themselves, if undisturbed, provide high resilience to droughts, by keeping high air humidity and lowering surface temperatures. All areas indicated good in heat mitigation are just ready-to-go NBS for increasing cities adaptive potential to climate change, what includes contribution to closing the water gap. In planning for NBS upscaling such areas should be preserved from land development, linked with other areas of similar role with green and blue infrastructure, and if needed new NBS should be implemented to strengthen the blue-green network.

In such case we can rely on the transfer of regulatory ecosystem services, in this case air cooling, increased humidity, and microclimate preservation, from areas of low building intensity (high natural capital) to areas of high building intensity, that endanger human well-being through heat waves as presented below (Figure 2).

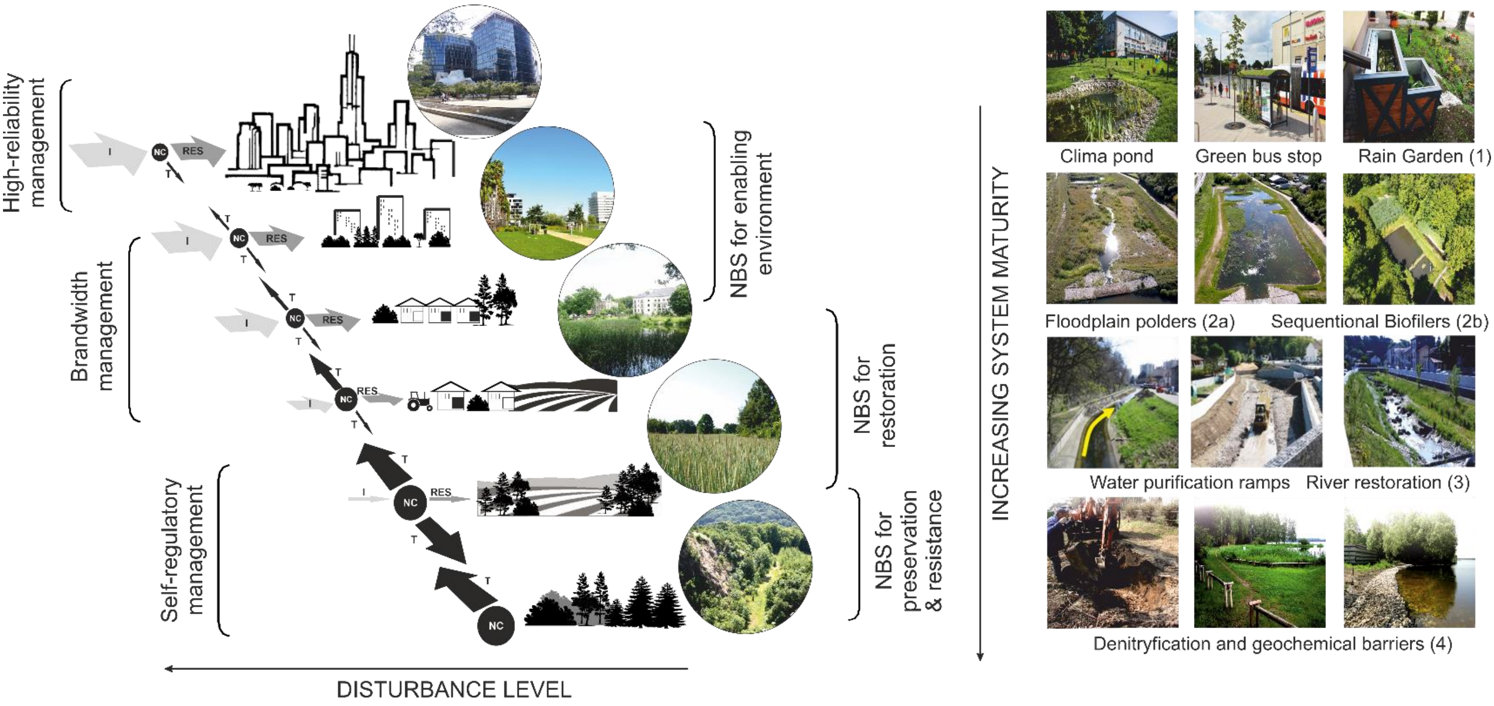

**Figure 2**. The desired transfer of regulatory services along urbanization gradient. In areas of high HMI (bottom of the figure) NBS implementation should be limited to protection of nature *status quo*; in intermediate disturbance areas NBS can support restoration of natural processes, in high building density areas NBS should be applied to enable and sustain any nature and its services

(1) FFP for LIFERADOMKLIMA project
(2) a – LIFERADOMKLIMA project, b – SWITCH project
(3) the Yzeron River project
(4) LIFE EKOROB project

IMPORTANT NOTICE

INVEST Cooling works at big scales – of the whole city or at least a district. Usually the data resolution don't allow to reach enough precision for small scale, furthermore the output of the model makes sense only if we are able to indicate differences between areas and the more different they are in terms of vegetation the stronger the differences are. In cities green patches are usually too small to have significant impact on UHI.

## ATENAS demonstration case

INVEST Cooling has been applied to ATENAS demo site of the City of Łódź (Poland). We intended to check which areas still remains important in terms of climate regulation, thus can mitigate heat waves and eventually provide protection against droughts. The map of cooling effect (Fig. 3) has been used to consult local land development plans, to prevent urban sprawl and to consider development of green infrastructure in the way increasing connectivity of heat mitigation areas and implementation of ecohydrological NBS (NBS improving water regulation) to sustain functions of nature.

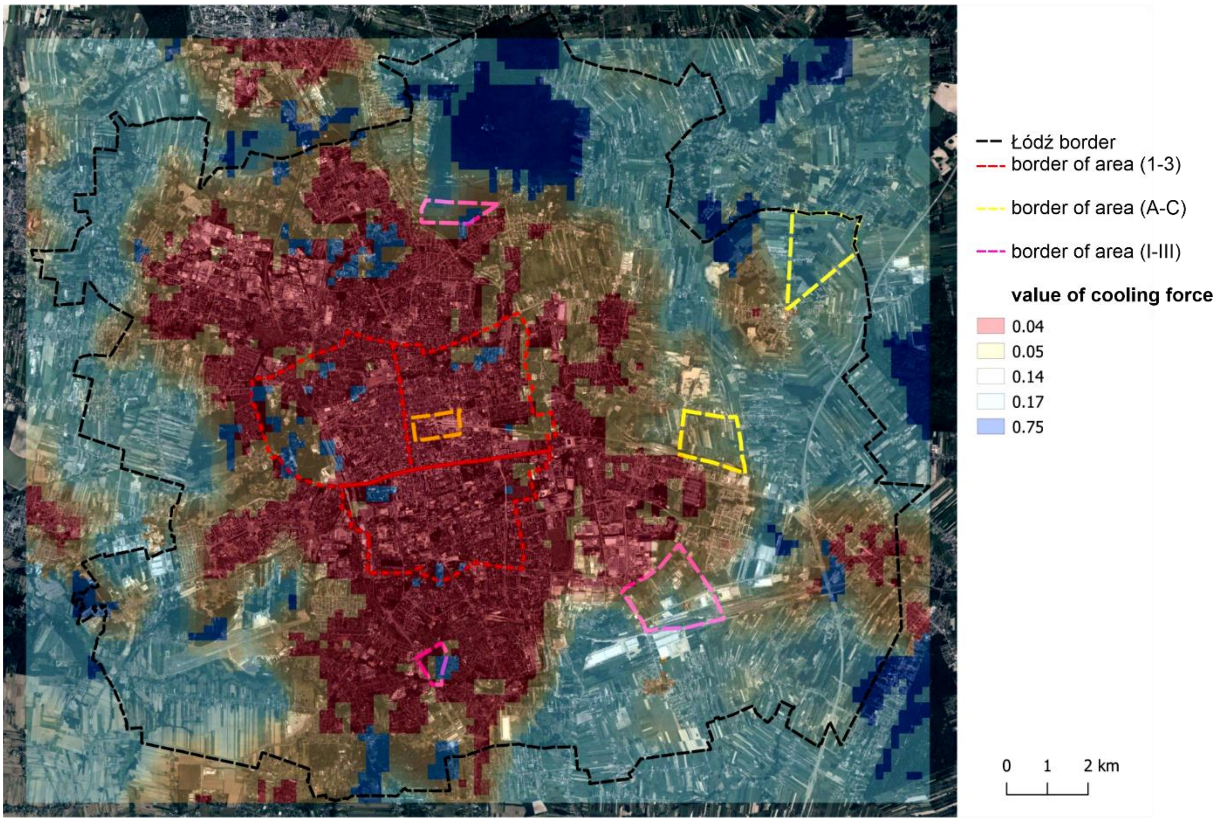

Figure 3. INVEST cooling map of the greenery cooling effect in Łódź, indicating areas greenish and blueish within the UHI that maintain their climate regulation potential

**Where to find the information about INVEST Cooling?**

The general website:

https://naturalcapitalproject.stanford.edu/software/urban-invest

About the model:

http://releases.naturalcapitalproject.org/invest-userguide/latest/en/urban_cooling_model.html

The urban cooling model publications:

https://naturalcapitalproject.stanford.edu/software/invest-models/urban-cooling

## 2. IRIP – indicator of intense pluvial runoff (applied in Lyon and Łódź)

### Shortly about

IRIP is a geomatic model based on scores calculated on factors favorable or unfavorable to runoff. This model was developed by INRAE to define the locations and types of prevention solutions to reduce the hazards related to intense runoff. These hazards are mainly related to erosive processes and liquid and/or solid submergence. The associated consequences are soil losses, pollution of aquatic environments, cuts in land transport routes and destruction of built elements. By construction, this model provides spatialized information in a watershed in the form of zones conducive to runoff generation, zones conducive to erosive runoff transfer and zones conducive to liquid and/or solid runoff accumulation. The knowledge of the distribution of these three processes in the catchment area informs on the organization of the surface flows which are associated with the runoff. It is thus possible to infer from the land uses the types of substances that are conveyed and stored downstream. It is also possible to infer ecological functions as for accumulation areas which are places of development of aquatic biocenoses and in particular wetlands, known to be natural systems with high metabolism and biodiversity.

### How the model contributes to ATENAS objectives?

The ATENAS project is particularly interested in the conditions of success or failure of the use of NBS in urbanized areas to manage urban runoff. These NBS are designed according to priority objectives which are essentially to reduce the risks linked to runoff (pollution, flooding) and to manage the rainwater resource locally by infiltration (groundwater recharge) and or evapotranspiration (coolness island). Secondary objectives can be the creation of biodiversity in the city and the reduction of risks related to hydrological extremes. This last point is part of the actions necessary to adapt the urban system to the effects of climate change. These effects are the intensification of short rains and the lengthening of rain-free periods. Thus, the buffering capacity of NBSs under urban influence should be considered from both aspects: flood limitation and storage/purification of excess runoff when it occurs.

## What data does it use?

- **DEM, DTM:** Topographic information is the gravity engine of runoff. It is available most of the time in the form of a digital terrain model. It is preferable to use a digital surface model that takes into account the presence of buildings. They are often raster files (square mesh) with resolutions useful for IRIP ranging from 1m to 25m. The coarse resolution (25m) allows to quickly obtain a mapping of areas with strong hazards (IRIP scores >=3) for the Production, Transfer and Accumulation maps. Crossing these hazards with a vulnerability map allows to define risk areas where a 5m or 1m modeling allows to better position the NBSs.
- **Land use:** The land use allows to define the types of uses which will be favourable or not favourable to the appearance of a runoff in case of rain. It is also an indicator of the types of substances that can be carried by intense runoff. For example, it is a way to assess the connection between agricultural areas and small streams potentially impacted by agricultural inputs and suspended solids.
- **Top soil hydraulic characteristics:** These characteristics are necessary. They can be deduced from the USDA pedo-transfer functions (sand-silt-clay texture triangle). The four essential characteristics that condition runoff and erosion of soils are: battance, erodibility, and for the first 30 centimeters of soil, the infiltration rate (Ks) at soil saturation and the soil water storage capacity (%WC). These four characteristics are used to create a runoff and erosion suitability map (MixMap). The MixMAp map can be compared to statistical rainfall amounts of a given return period (10, 20, 30, ... years) over the durations of 1 hour and 24 hours. The 1-hour duration is an indication of the average intensity of a heavy rainfall, which is compared to the infiltration rate (Ks). If the rainfall intensity exceeds the infiltration rate, there is excess infiltration runoff. The 24-hour rainfall is compared to the amount of water that can be stored in the top 30 cm of soil (%WC). If the rainfall exceeds the amount of water that can be stored, then runoff occurs due to over-saturation.
- **Linear transportation networks** (road and rail) are vector data that must be overlaid for the model to take into account, in the form of runoff generation or runoff detour zones.

## What information the model delivers?

IRIP produces 3 spatialized information maps with scores ranging from 0 to 5. In the rasterized space of the watershed, a score of 5 in a raster mesh of the watershed indicates that all factors of intense runoff are favourable. This then expresses a high potential for realization in case of sufficient rainfall.

A score of zero indicates that none of the factors are favourable to runoff for this grid cell. Depending on the case, this may indicate a mesh that is favourable to infiltration.

- The production map shows the areas most likely to generate runoff during heavy rainfall. This map also shows the areas of production of suspended solids that are stripped from bare soil by the impact of raindrops. This shows areas where NBSs can limit runoff and soil loss downstream.
- The erosive transfer map shows areas where soils are likely to be washed away by the effect of flow velocity. If there are crossings with transportation networks, this may indicate the risk of destabilization of the network. This map is conditioned by the production map for 1 out of 5 factors.
- The accumulation map indicates the locations of solid and/or liquid deposits. It provides information on the potential of wetlands and therefore of places favorable to the development of transient storage NBSs. This map is also conditioned by the production map for 1 factor out of 5 (Figure 4).

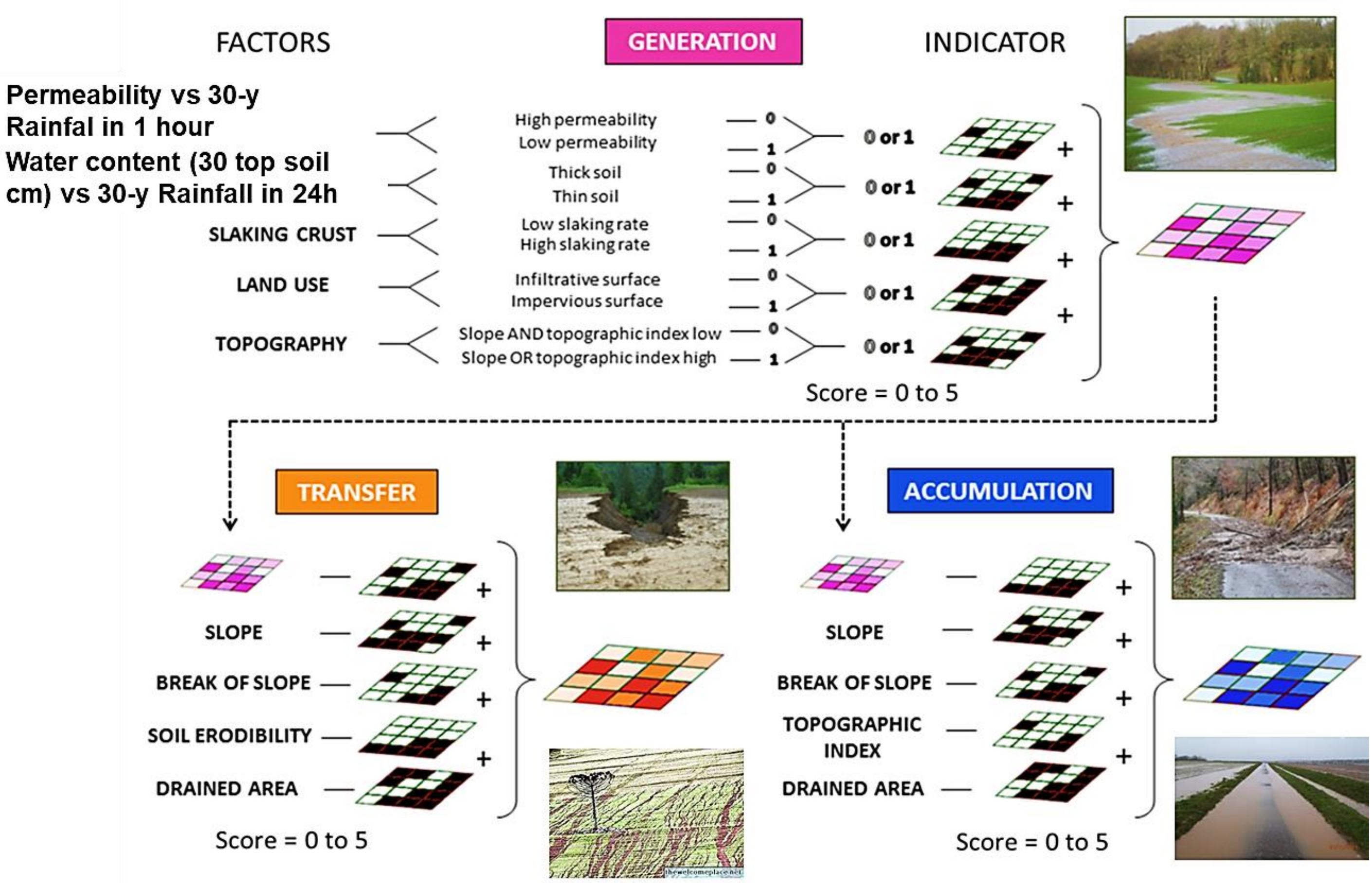

**Figure 4**. The scheme of IRIP output information

## What is it useful for?

The IRIP model allows us to consider the feasibility of NBS. Indeed, these solutions are constrained by the time required by natural processes to biotransform the substances. This implies sufficient land area to treat for several days the volumes of water and substances carried by runoff events. This is a strong constraint to the feasibility of NBS in dense urban areas. Peri-urban areas offer more possibilities.

Before the runoff drains into the talweg and river, it is interesting to compare the runoff generation areas calculated by the IRIP model (Figure 5) with the accumulation areas that are connected downstream. A high ratio indicates a high accumulation capacity, and therefore a favorable area for the implementation of a NBS. But it also means that there is a need for sufficient land area to handle the volume produced by the runoff event.

By construction, the IRIP model detects slope variations to identify the trigger zones for erosive transfer and accumulation processes. Thus we have the "limits or edges" of these processes from upstream to downstream of a topography. In the case of a body of water, it is the concave breaks in the topography that will be detected, but not the water area itself (as shown in the following view).

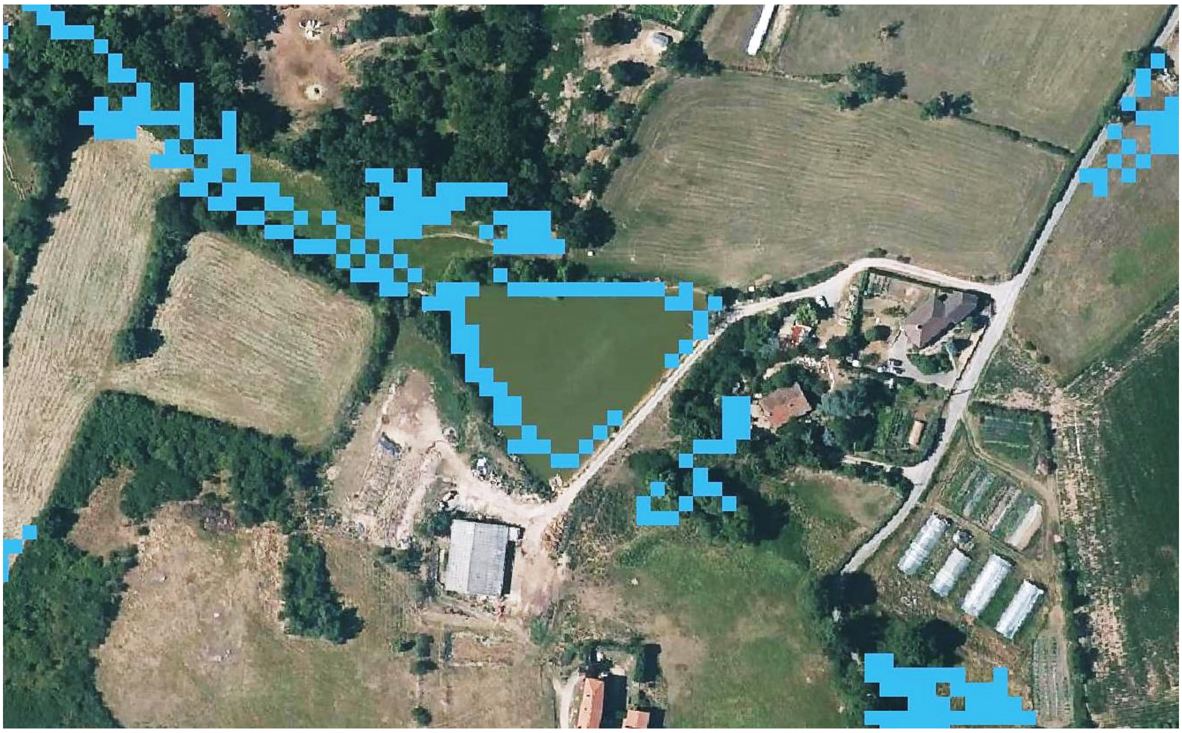

**Figure 5**. IRIP run off accumulation map

### IMPORTANT NOTICE

The IRIP model uses surface topography. Its use is directly relevant in unbuilt environment for medium to heavy rainfall that can be interpreted according to the scores >= 4 and >= 3. In urban areas, rainfall of medium intensity is managed by the artificial network. But this is generally not the case for intense rainfall which saturates the artificial networks (scores >= 3). In this case the urban runoff follows the surface topography. As this situation becomes more frequent with climate change, the search for accumulation zones becomes relevant to position NBSs on the surface runoff pathways, including in highly urbanized areas.

The maps produced by IRIP result from the combination of factors conducive to the different manifestations of the runoff process. Each map carries specific information that can be reworked in post-processing with respect to a specific issue related to runoff management.

The IRIP model has an interface in English if you use this regional language or a QUERTY keyboard.

## ATENAS demonstration case

Examples of using IRIP maps to define the "best" location for NBS implementation. There are two main situations:

- Upstream of any vulnerable area.

The objective is to reduce the amount of downstream runoff, avoid urban flooding and improve water quality, infiltration or gentle discharge downstream, but in a separate sewer system to feed the river further downstream, provide an air cooling effect and a functional biodiversity site. In addition, NBS reduces the impact of downstream pollution from intense urban runoff on natural water bodies further downstream, particularly small peri-urban and/or seasonal urban rivers.

- Downstream of any area where polluting runoff is generated from upstream.

The goal is to prevent exposed downstream aquatic ecosystems from experiencing waves of pollution from intense runoff on bare agricultural soils, particulate matter, fertilizer and pesticide loading.

These two cases are illustrated by the following image taken from the Ratier river watershed located in the periurban area of Lyon city (France) (Figure 6).

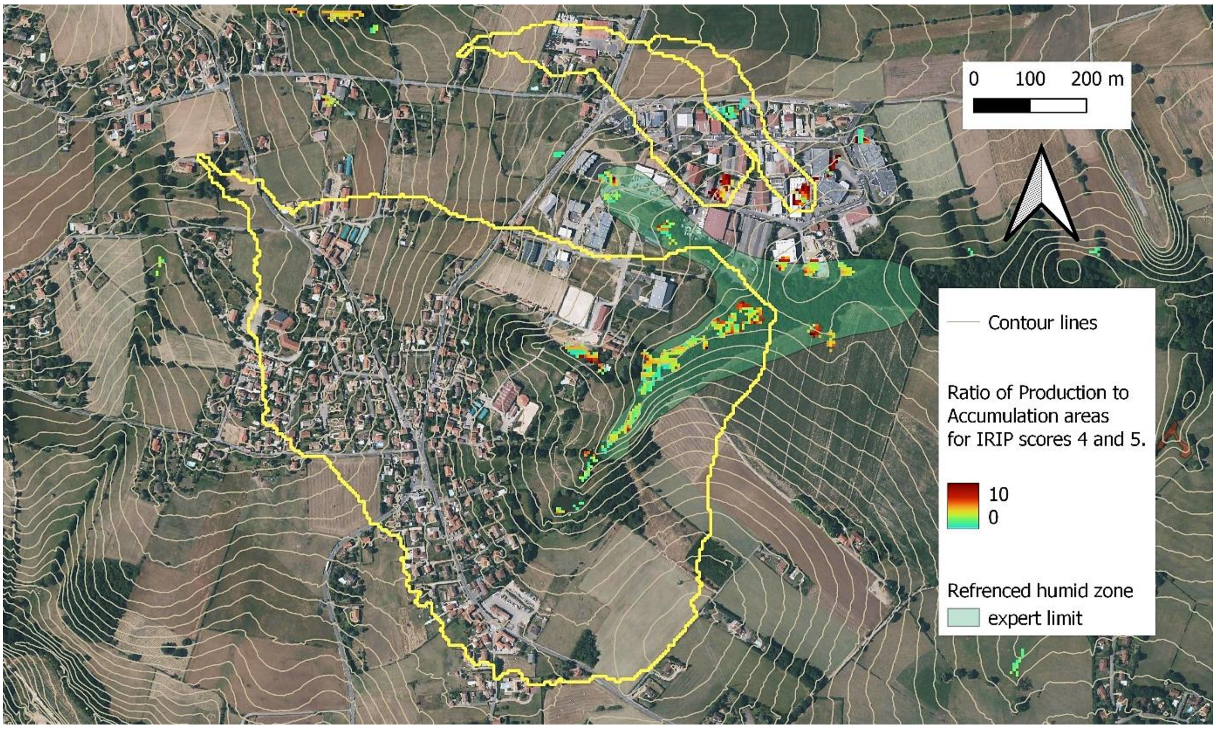

**Figure 6**. The legend indicates that the green, orange and red pixels (5m X 5m) have ratios that vary from 1 to 10. The yellow boundaries are those of the sub-watersheds that feed the high ratio pixels

The largest sub-watershed drains a moderately dense urbanized area, as well as agricultural and forested areas in its southwestern part. The high ratio pixels appear in the downstream valley which is also referenced as a wetland by regional experts. This illustrates the case of a natural NBS that purifies runoff. However, care must be taken not to exceed its natural capacity. NBS with objective of runoff energy dissipation and pre-treatment would need to be inserted in the upstream areas not yet built.

The two small sub-watersheds delineate areas of runoff contribution whose outlets are urbanized areas with high ratios. The solution is to develop NBS upstream of the urbanized area, in the agricultural part. If the place is too limited upstream, it is possible here to ensure drainage towards the wetland located downstream, but by ensuring a pre-treatment zone with a NBS which ensures the settling of part of the suspended solids. The objective is to protect the natural wetland from excessive inputs.

Regarding the ATENAS demonstration site.  This in-stream NBS is the result of an experimental field pilot developed in previous research projects. The objective was to prove the concept and then to build a full-scale NBS. This was done during ATENAS project. The main idea of this NBS is to restore and even increase the self-purification capacity of small seasonal rivers impacted by the urbanized environment. These small rivers receive the overflows of combined sewers (CSOs) during medium to intense rainfall events. This NBS was placed on the Ratier River which drains a 30 km$^2$ watershed in the western peri-urban area of the city of Lyon (France). The figure 7 below shows that the ecological status of the Ratier river is classified as poor from its upstream. This is due, on the one hand, to the fact that the river receives pollution produced by upstream urbanization and by direct runoff from agricultural land. On the other hand, the river flows in this area on bedrock and does not benefit from a protective tree corridor against agricultural runoff. As indicated in the figure legend, sandy deposits appear further downstream and seem to contribute to the improvement of the ecological quality of the Ratier River, despite the increase in the number of CSO points. The IRIP production map confirms the huge runoff contribution to this downstream part of the Ratier river catchment. The ATENAS demonstration site was located at the very downstream end of the Ratier River, in the area where four CSOs follow each other and where sandy deposition is moderate. The objective is to increase the sandy deposit in order to increase the self-purification capacity of the river at this location.

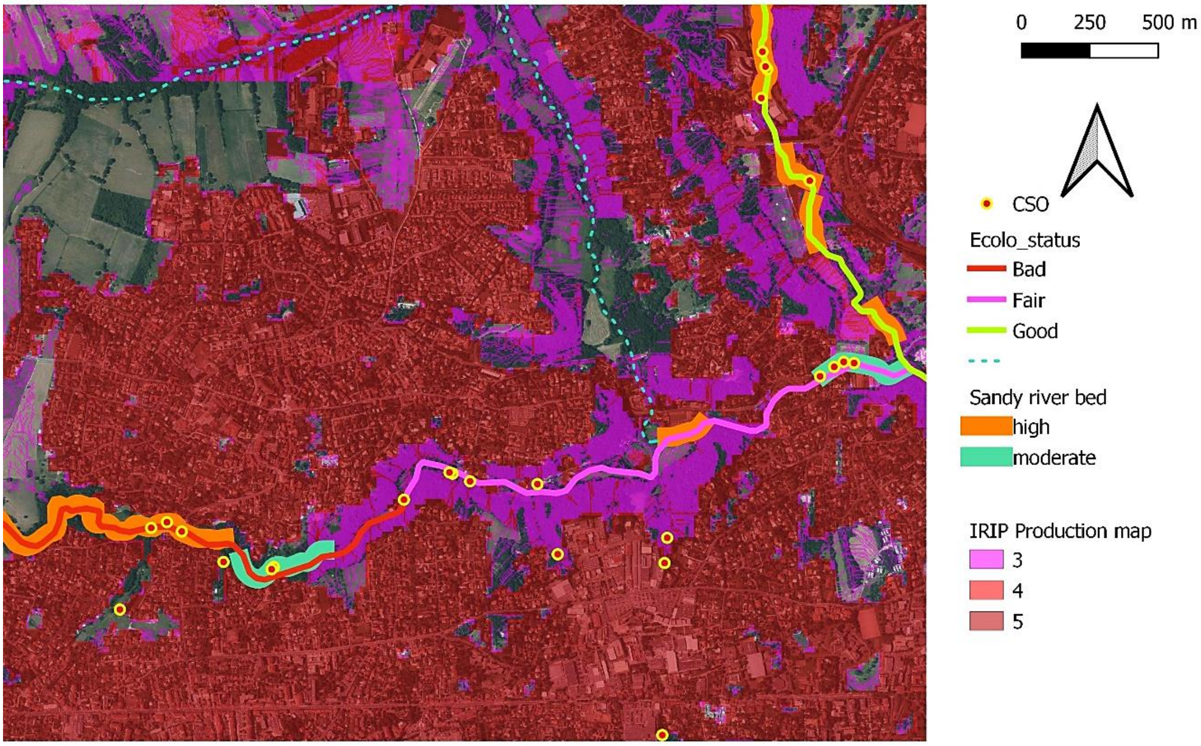

**Figure 7**. IRIP map of run off generation areas (including sewage leaking) and related status of waterbodies

## Where to find the information about IRIP model?

https://fr.wikipedia.org/wiki/IRIP

IRIP Wiki version to be updated soon and translated in English

The model is a plugin for QGIS 3.10. It is available for free on request at with a tutorial in English.

Make the request to: pascal.breil@inrae.fr

A free 30 minutes training on a test case allows to understand the different steps of realization of the three maps. A user's charter allows to join a group of users who address different issues of runoff management and allows to define the post-processing to be developed in a new version of IRIP.

# 3. SWMM - Storm Water Management Model (applied in Helsinki)

## Shortly about

Storm Water Management Model (SWMM) developed by United States Environmental Protection Agency (EPA). It is used for planning, analysis, and design related to stormwater runoff, combined and sanitary sewers, and other drainage systems.

## What data does it use?

SWMM is used for single event or long-term simulations of water runoff quantity and quality in primarily urban areas—although there are also many applications that can be used for drainage systems in non-urban areas. SWMM provides an integrated environment for editing study area input data, running hydrologic, hydraulic and water quality simulations. SWMM requires and takes advantage of stormwater network data. Other required datasets include e.g. elevation model and land cover.

## What information the model delivers?

According to USA EPA, SWMM allows for viewing modelling results in a variety of formats. These include color-coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses. The model delivers calculations of time series of runoffs in different types of rain events and data on over-flowing of stormwater wells.

## What is it useful for?

SWMM modelling is useful for many kinds of purposes. It can be used to evaluate grey infrastructure stormwater control strategies, such as pipes and storm drains, and is a useful tool for simulating cost-effective green/grey hybrid stormwater control solutions. In NBS planning, SWMM modelling can provide detailed analysis of runoff and water quality if the source data is sufficient. If measurement data is available to calibrate the model, it is possible to validate the model and improve accuracy.

## SWMM in Atenas demonstration case

In Atenas project, we conducted a case study in Malmi (Figure 8), which is a sub-centre in Helsinki Metropolitan Area. The City of Helsinki aims to develop Malmi station neighbourhood to an attractive centre through urban infill. The renewal of the area offers opportunities to the application of NBS. We examined different ways to apply NBS to urban stormwater management in Malmi by formulating five NBS scenarios. The impacts of scenarios were calculated by using green factor tool for districts and stormwater modelling. Because the regional green factor is a relatively new method, stormwater modelling using the SWMM network model was performed to support and validate the green area for districts. Modelling evaluated the impact of the scenarios and their NBS on runoff and flooding.

The SWMM modelling area is bordered by the railroad and smaller streets. Stormwater runs primarily from north-west to south-east and go under the railway in a pipe. The land use is intensive close to railway station, medium density in high-rise residential blocks and lower density in park areas in the north-west (Figure 9). Stormwater modelling required detailed GIS work to delineate the catchment, define the land cover, flow directions and stormwater networks.

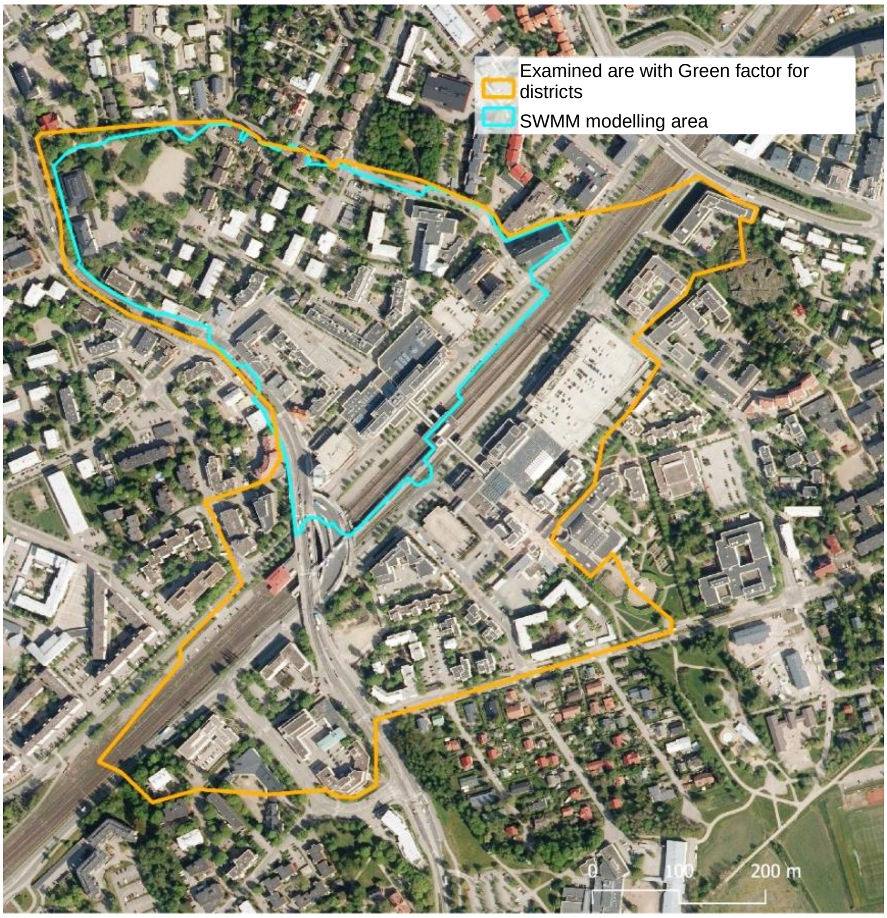

**Figure 8**. ATENAS case study are in Malmi neighbourhood in Helsinki

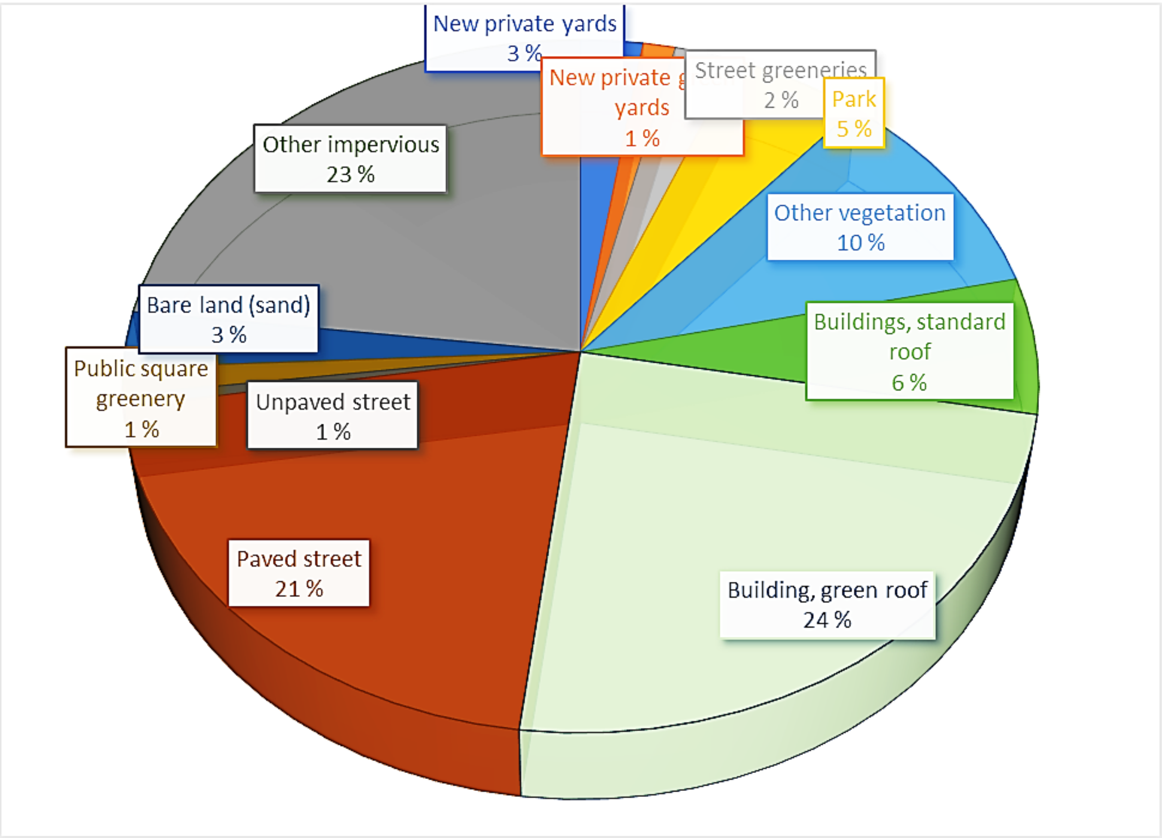

**Figure 9**. Land use of the modelled area

Based on detailed data on buildings, topography, land cover, vegetation and the drainage system, it was possible to analyse how rainwater runs from roofs, yards, pavements and green areas after different types of rain events. The stormwater network data included pipelines, rainwater gullies, wells, culverts, pumps and other parts of the stormwater system. In the examined area, stormwater pipelines were located underground. The stormwater network data was sensitive, and for security reasons, it was not allowed to be shown in any published maps.

The stormwater pipeline network needed first to be trimmed by excluding extra pipelines that didn't connect to trunk lines.  Trunk stormwater pipelines were then carved to the elevation model. Depressions in the topography were filled to enable the calculation of flow direction. On the basis of flow direction, it was possible to define drainage basins. The size limit of drainage basins was 0.1 ha to create sufficiently small sub-catchments that could be linked to different land cover alternatives. The whole modelled basin was delineated by setting an outlet in the culvert passing underneath the railway. The delineation of basin was polished manually based on the location of buildings and stormwater sewers.

In the stormwater modelling, small sub-catchments were classified based on land cover. Each sub-catchment was given a single land cover type based on present situation and scenarios that were elaborated together with city planners. The creation of a topologically consistent data required a considerable amount manual work, because of the complexity of the source data. The delineation of sub-catchments was simplified to make it easier to create the model with SWMM programme, while preserving the areas of different land cover types in sub-catchments (Figure 10).

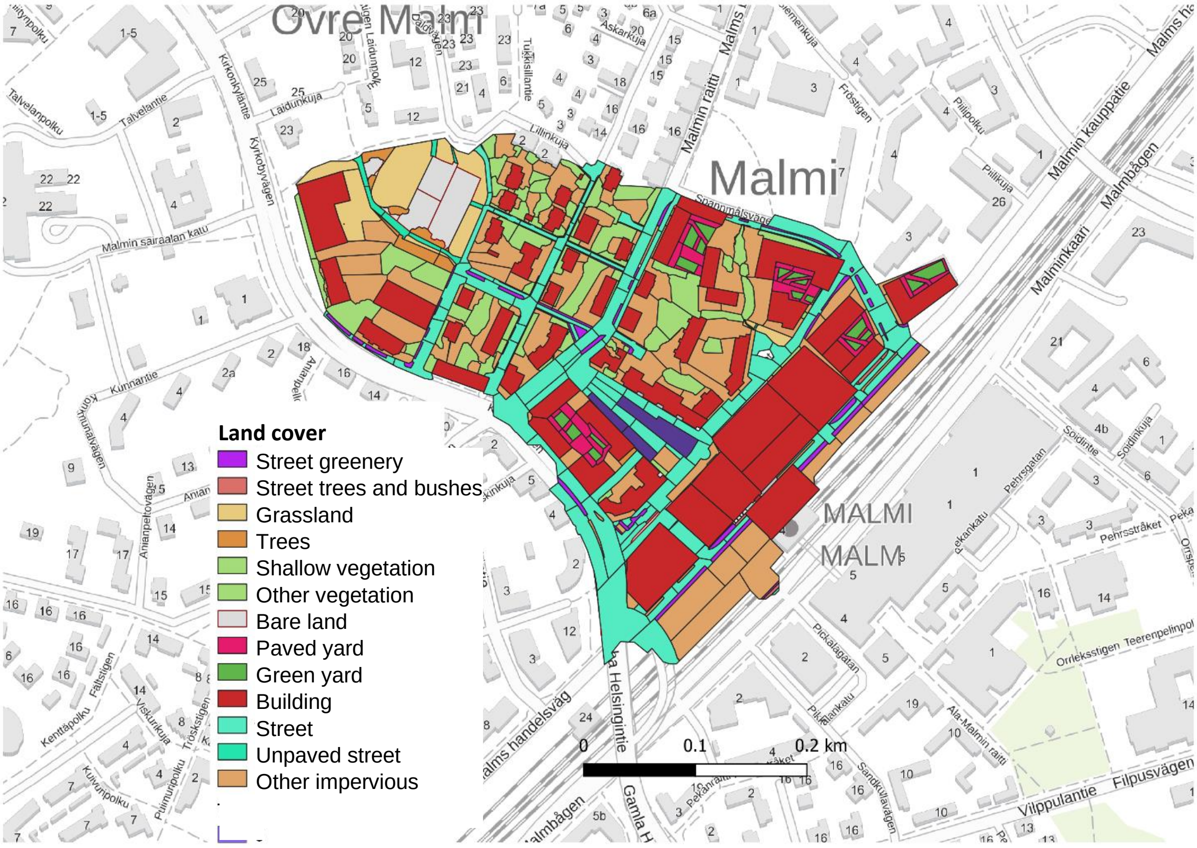

**Figure 10**. Modelled area and the land cover of sub-catchments.

To every small sub-catchment we calculated slope and aspect, flow path length and flow width based on sub-catchment polygon properties and slope raster. Flow width is a SWMM model parameter that defines the shape of the basin in relation to flow direction. The flow width was calculated by dividing the surface area of a sub-catchment by flow path length and correcting manually some areas to define the right flow direction.

The stormwater network data was created using the elevation data of pipelines and wells. Some of the data was missing or incorrect, so the elevation was estimated based on other network structures and elevation of the ground.

All compared scenarios included the same stormwater network. The differences between scenarios were defined by changing the land cover of sub-catchments to represent different types nature-based solutions (NBS) or low impact development (LID) structures. Part of the street greenery were changed to bio-retention cells, market square greeneries to rain gardens, building roofs to green roofs and green yards to bio-retention structures. The NBS in yard areas were defined on the basis of yard type. Permeable ground allowed infiltration to ground and groundwater, while decked surfaces had thinner bio-retention structures and all the water ran ultimately to stormwater sewer. Yards with permeable ground had also more diverse vegetation that had an effect on hydrological parameters.

The NBS/LID structures covered usually the whole sub-catchment, except for bio-retentions cells in the yard areas where they covered 20% of the green yard area and the rest was normal greenery. The hydrological parameters were defined for different types of soils, land cover and NBS/LID structures. The parameters were found in literature (e.g. *Holt et al. 2018*). Some parameters differed between the scenarios based on the yard type Table 1-4.

**Table 1**. Hydrological parameters of soil according to (*Niemi et al. 2019*)

| | |
|---|---|
| Saturated hydraulic conductivity | 24.965 |
| Suction head | 55.832 |
| Maximum moisture deficit | 0.35 |

**Table 2**. Manning n values, depression storages and slope values for different types of land cover according to Holt et al. (2018) applied in SWMM modelling

| **Land cover** | **Manning n** | | **Depr. st.** | | **slope** |
|---|---|---|---|---|---|
| | Sce 1 | Sce 2 | Sce 1 | Sce 2 | % |
| Impervious area | 0.014 | | 0.5 | | |
| Street greenery | 0.168 | | 5 | | |
| Asphalt | 0.011 | | 0.42 | | |
| Gravel | 0.03 | | 2.49 | | |
| Vegatation | 0.667 | | 4.13 | | |
| Roofs | 0.01 | | 0.5 | | 6.3 |
| Stone pavement | 0.02 | | 0.7 | | |

| | | | | | |
|---|---|---|---|---|---|
| Yeard stone pavement | 0.02 | | 0.7 | | 1 |
| Yard lawn/vegetation | 0.168 | 0.238 | 5 | 4.22 | 1 |
| Square lawn/vegetation | 0.238 | | 4.22 | | |
| Forest/lawn | 0.3 | | 6 | | |
| Other vegetation | 0.667 | | 4.13 | | |
| Gravel | 0.03 | | 2.49 | | |

**Table 3**. Parameters for green roofs according to *Holt et al.* (2018)

| | | Sce 1 b | Sce 2b & c | |
|---|---|---|---|---|
| **Parameter** | **LID structure** | **Value** | **Value** | **Unit** |
| Berm height | surface layer | 30 | 30 | mm |
| Vegetation volume fraction | surface layer | 0.1 | 0.15 | |
| Manning’s Roughness Coefficient, n | surface layer | 0.168 | 0.6 | |
| Slope | surface layer | 8 | 8 | % |
| Thickness | soil layer | 100 | 200 | mm |
| Porosity | soil layer | 0.4 | 0.4 | |
| Field capacity | soil layer | 0.29 | 0.29 | |
| Wilting point | soil layer | 0.02 | 0.02 | |
| Conductivity | soil layer | 37.9 | 37.9 | mm/h |
| Conductivity slope | soil layer | 40 | 40 | |
| Soil suction head | soil layer | 61.3 | 61.3 | mm |
| Thickness | drainage mat | 3.8 | 3.8 | mm |
| Void ratio | drainage mat | 0.41 | 0.41 | |
| Manning’s Roughness Coefficient, n | drainage mat | 0.01 | 0.01 | |

**Table 4**. Parameters for yard greeneries (bio-retention without infiltration on decked surfaces in Scenario 1 and with infiltration to permeable ground in Scenario 2) according to *Lehikoinen* (2015) and street greeneries (rain garden) and square greeneries (bio-retention cells) according to *Tuomela* (2017), see also *Holt et al.* (2018)

| **Parametre** | **LID structure** | **Decked yard** Sce 1 | **Permeable ground** yard Sce 2 | **Street and square greenery** Sce 2 |
|---|---|---|---|---|
| Berm height | surface layer | 20 | 20 | 200 |
| Vegetation volume fraction | surface layer | 0.1 | 0.18 | 0.15 |
| Manning's Roughness Coefficient, n | surface layer | 0.3 | 0.6 | 0.6 |
| Slope | surface layer | 1 | 1 | 1 |
| Thickness | soil layer | 100 | 300 | 700 |
| Porosity | soil layer | 0.4175 | 0.4175 | 0.52 |
| Field capacity | soil layer | 0.153 | 0.153 | 0.15 |
| Wilting point | soil layer | 0.08 | 0.08 | 0.08 |
| Conductivity | soil layer | 60.96 | 60.96 | 119.4 |
| Conductivity slope | soil layer | 10 | 10 | 3.26 |
| Soil suction head | soil layer | 134.493 | 134.493 | 48.26 |
| Thickness | drainage mat | 50 | 150 | 300 |
| Void Ratio | drainage mat | 0.5 | 0.5 | 0.5 |
| Seepage rate | drainage mat | 0 | 1.016 | 1.016 |
| Clogging factor | surface layer | 0 | 0 | 0 |
| Flow coef | surface layer | 2.17 | 3.61 | 5.77 |
| Flow exp | surface layer | 0 | 0 | 0.5 |
| Offset height | surface layer | 0 | 150 | 150 |

Stormwater modelling was carried out in a way that describes the scenarios from the viewpoint of stormwater management. SWMM programme is widely used both in Finland and internationally. There are however uncertainties related to the modelling. The model was not calibrated with an occurred rain event, because validation data was lacking. This was the reason for not examining the present situation in detail but concentrating on comparing the scenarios. To compensate the lack of validation data, land cover was described in detail and modelling parameters were chosen carefully. Equivalent modelling has been taken place and the parameters found were considered proper.

There are uncertainties related to dealing with nature-based solutions in the model. Parameter values, location of NBS structures and lack of optimization cause uncertainty. Particularly, the effectiveness of bio-retention structures depends on the thickness of different layers and infiltration parameters. Bio-retention structures along streets were not optimized in a way that runoff peaks from them would occur at different times, evening out the flood peak. The parametrisation of NBS causes rather considerable uncertainty in the results.

The processing of over-flowing water in the model is a noteworthy issue in the modelling results. In the Malmi case model, it was assumed that over-flowing water is removed from the system, which affects the total amount of runoff in the scenarios with a lot of over-flowing.

The parameters defined for different types of land covers in NBS/LID structures had some impact on modelling results. It was also important how much of water runs through NBS/LID structures.

The results of the modelling highlighted differences between scenarios in runoff peaks, total runoff and over-flowing from stormwater gullies. In runoff peaks, the differences started to level out, the more rare and extreme the rain event was. It was noteworthy that in the scenario where the stormwater structures were more diverse, the impact on the runoff peak was greater than the sum of its parts. Diversification of stormwater structures could thus produce more runoff delay than green roofs or street structures alone. The results of SWMM stormwater modelling correlate with the values of the green are factor, especially in less severe rain events (once every 2 and 10 years recurring rain storms) (Figure 11).

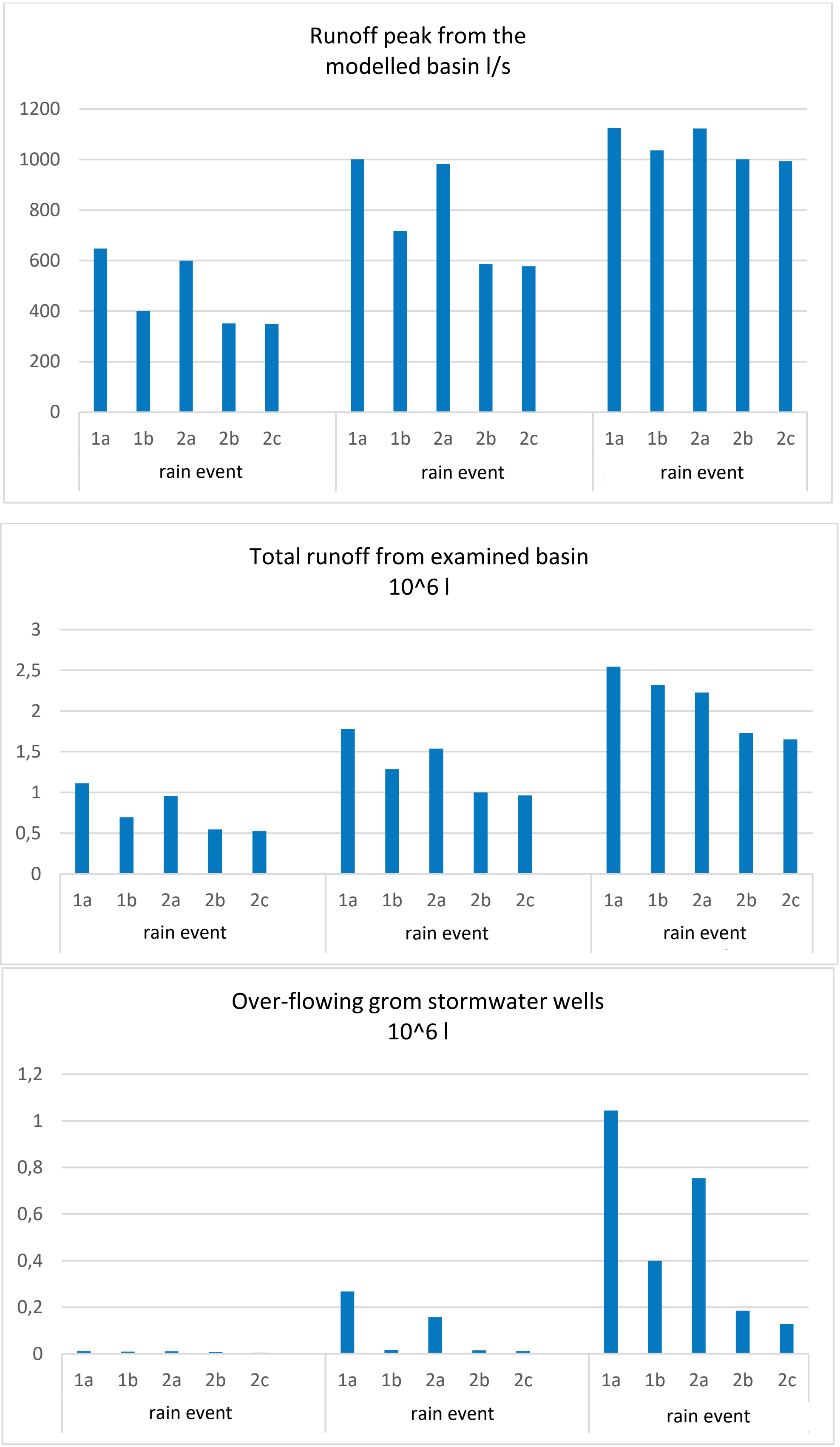

**Figure 11**. Results of SWMM modelling in Malmi case: peak runoff, total runoff and over-flowing of wells in five scenarios

## Where to find the information about SWMM model?

The general website:

https://www.epa.gov/water-research/storm-water-management-model-swmm

Summary on Wiki:

https://en.wikipedia.org/wiki/Storm_Water_Management_Model

Download webpage:

https://www.pcswmm.com/Downloads/USEPASWMM

# 4. Green area Factor (applied in Łódź and Vantaa) [2,3]

## Shortly about

The goal of the green factor (GAF) approach is to mitigate the effects of construction by maintaining a sufficient level of green infrastructure while enhancing the quality of the remaining vegetation. Calculation of the contribution of green surfaces to general surface allows to increase greenery of lots in a dense urban environment. The significance of green surfaces in the adaptation to climate change raises as the city structure becomes denser. They contribute to such ecosystem services like: city cooling, water cycle, nutrient cycle, soil formation and habitat maintenance.

## What data does it use?

GAF is a tool which requires only greenery maps (extracted from land use / cover) however usually high resolution information is needed, particularly when assessments are applied to small scale projects, e.g. a single lot or a building. The information comprises type of the greenery, its area within the case study, and set of limitation factors. The attractiveness of GAF comes from the fact that it can be applied to different scales (although not to really large ones) and it is relatively easy to calculate using a number of excel calculators delivered by several projects.

The type of land cover is then translated into the score according to the surface cover type proposed in a planning application. Scores range from 1 for semi natural vegetation, through to 0 for impermeable sealed surfaces.

The considered land covers types include:

- Semi-natural vegetation (e.g. trees, woodland, species-rich grassland) maintained or established on site
- Wetland or open water (semi-natural; not chlorinated) maintained or established on site
- Intensive green roof or vegetation over structure. Substrate minimum settled depth of 150mm
- Standard trees planted in connected tree pits with a minimum soil volume equivalent to at least two thirds of the projected canopy area of the mature tree

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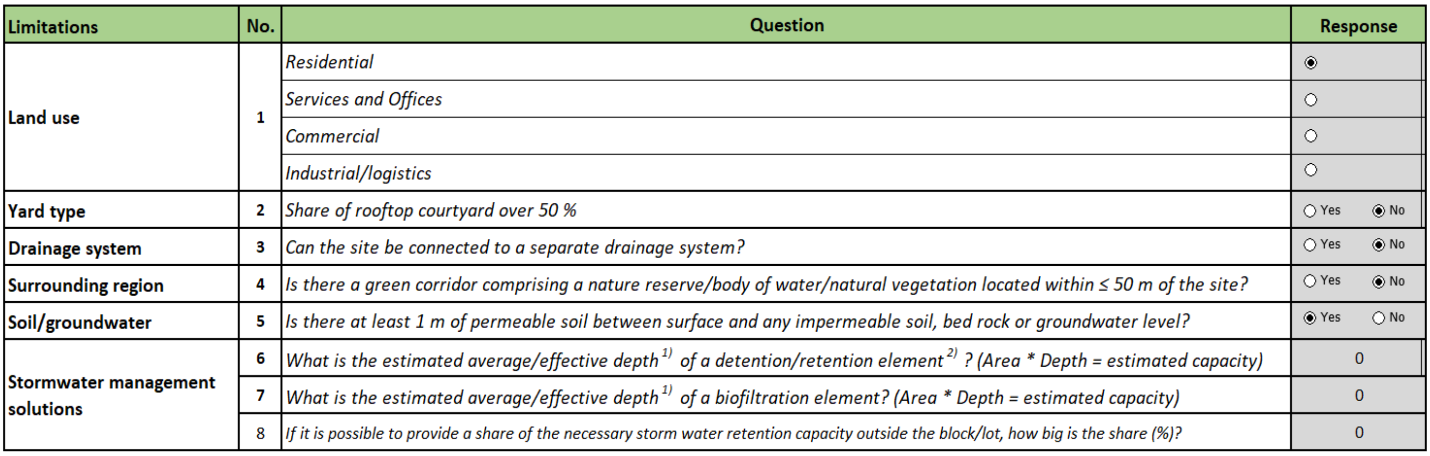
[2] https://www.integratedstormwater.eu/sites/www.integratedstormwater.eu/files/report_summary_developing_a_green_factor_tool_for_the_city_of_helsinki.pdf

[3] http://www.integratedstormwater.eu/content/green-area-factor-and-other-tools

- Extensive green roof with substrate of minimum settled depth of 80mm (or 60mm beneath vegetation blanket) – meets the requirements of GRO Code 2014
- Flower-rich perennial planting
- Rain gardens and other vegetated sustainable drainage elements
- Hedges (line of mature shrubs one or two shrubs wide)
- Standard trees planted in pits with soil volumes less than two thirds of the projected canopy area of the mature tree
- Green wall –modular system or climbers rooted in soil
- Groundcover planting
- Amenity grassland (species-poor, regularly mown lawn)
- Extensive green roof of sedum mat or other lightweight systems that do not meet GRO Code 2014
- Water features (chlorinated) or unplanted detention basins
- Permeable paving
- Sealed surfaces (e.g. concrete, asphalt, waterproofing, stone)

The tool considers also a limitation set:



| Limitations | No. | Question | Response |
|---|---|---|---|
| Land use | 1 | *Residential* | ● |
| | | *Services and Offices* | ○ |
| | | *Commercial* | ○ |
| | | *Industrial/logistics* | ○ |
| Yard type | 2 | *Share of rooftop courtyard over 50 %* | ○ Yes ● No |
| Drainage system | 3 | *Can the site be connected to a separate drainage system?* | ○ Yes ● No |
| Surrounding region | 4 | *Is there a green corridor comprising a nature reserve/body of water/natural vegetation located within ≤ 50 m of the site?* | ○ Yes ● No |
| Soil/groundwater | 5 | *Is there at least 1 m of permeable soil between surface and any impermeable soil, bed rock or groundwater level?* | ● Yes ○ No |
| Stormwater management solutions | 6 | *What is the estimated average/effective depth 1) of a detention/retention element 2) ? (Area * Depth = estimated capacity)* | 0 |
| | 7 | *What is the estimated average/effective depth 1) of a biofiltration element? (Area * Depth = estimated capacity)* | 0 |
| | 8 | *If it is possible to provide a share of the necessary storm water retention capacity outside the block/lot, how big is the share (%)?* | 0 |

## What information the model delivers?

GAF analyses several categories of surfaces: Preserved vegetation and soil, Planted and/or new vegetation, Pavements, Stormwater elements and Bonus elements. Based on the user’s choice of elements, the tool automatically calculates the weighted areas based on the built-in weighting system, their total sum and the derived Green Factor. Additionally the tool calculates an average runoff - coefficient of the lot based on built-in element-specific coefficients for each type providing a surface. Due to the variety and large amount of sources, as well as the partially different land-use types combined in one element, the runoff-coefficients should be seen as an estimation, and not as an exact definition.

Green-Area Factor shows you the contribution of surfaces actively providing ecosystem services to 0-service area. Setting certain desirable value for all the spatial developments allows to keep the climate adaptation standards at certain level.

## What is it useful for?

GAF allows you to translate into tangible and comparable scoring different land use / construction options in order to support optimization of choices. It enables comparison of run off of those options, and selection of certain combination of greenery types acting as nature-based solutions for water run off regulation. It is critically important as water retention or infiltration empowers number of ecosystem services, in particular regulatory ones, what is translated into human and nature well-being and health.

Having the GAF set in planning documents (e.g. at a level of 0.6) enables keeping control over land development in order to secure climate adaptation standards, protection of water cycle and supporting habitats for biodiversity. It allows also maintaining the same requirements across different investments in different locations. GAF can also support protection of local greenery or help to substitute different blue-green elements with the others while keeping the net delivery of functions untouched.

### IMPORTANT NOTICE

The runoff-coefficients should be seen as an estimation, and not as an exact definition. Additionally, runoff-coefficients are time-dependent and therefore vary with rainfall amount and intensity, and usually also depend on the type of soil and its saturation. Using a single set of coefficients for all conditions thus holds risks of over- or underestimation.

The overall task of this tool is NOT to replace a proper stormwater assessment and management plan, but to give the lot planner the opportunity of a rough estimation on the potential need for detention.

## GAF in ATENAS demonstration case (Malmi)

In Finland, green coefficients have been used to define plot-specific green structures, but a broader view in the planning of green structures is lacking. The Malmi case study of the ATENAS project, together with WSP, has experimented with the use of the regional green factor for districts to determine the benefits of NBS in different scenarios of Malmi's infill construction.

The regional green factor measures the eco-efficient area of public areas in relation to the area of the whole area at different levels, such as stormwater management or pollination, and is suitable for assessing entire neighbourhoods or districts. Because the regional green factor is a relatively new method, stormwater modelling using the SWMM network model was performed to support and validate the green area for districts. Modelling evaluated the impact of the scenarios and their NBS on runoff and flooding (Table 5). At the same time, the aim was to find out how the green area factor for districts works as a tool for urban planning and what its benefits and limitations are regarding considering stormwater management.

In Malmi, different scenarios were created for the infill construction of the town, which varied the area and quality of green areas and NBS especially for stormwater management, such as green roofs and street biofiltration basins (Figure 12). To support the creation of the scenarios, a workshop was organized for the representatives of the City of Helsinki to identify guidelines for the development of the area and areas where NBS would bring additional benefits to the city structure.

**Figure 12**. Different scenarios for Malmi case study

**Table 5**. Description of different scenarios for Malmi case study

| Code | Description |
|---|---|
| 1a | ”Business as usual”: Development is highly based on gray infrastructure, amount of paved soil is high, street green is only for aesthetic reasons without innovative NBS, covered inner yards with parking underneath, vegetation homogenous and with low diversity in parks. New tram line is built which causes cuttings of street trees. |
| 1b | As 1a but some extensive green roofs with shallow growth substrate. |
| 2a | Greener and more innovative: earthbound yards, parking in designated buildings, stormwater solutions along streets, more varied and diverse vegetation in parks also supporting pollinators. New tram line is not built. |

| | |
|---|---|
| 2b | Same as 2a but with extensive green roofs with thick growth substrate. |
| 2c | Even greener version of 2b, some current parking areas converted to greenery and stormwater solutions. |

**Figure 13**. Green area factor for Malmi

The results of the green area factor for districts show that added NBS, such as green roofs, have a significant effect on the green area factor (Figure 13). The reason behind is the dense construction of the area, where in the current state there is not much space left for the green structures. In addition, it can be stated that the regional green coefficient succeeds in concretizing the multifunctionality of green structures and NBS, i.e. the ability to produce many different ecosystem services simultaneously. The benefits of different scenarios are easy to understand and to compare.

The results of stormwater modelling correlate with the values of the green are factor, especially in less severe rain events (once every 2 and 10 years in recurring storms) (Figure 14, Figure 15). For runoff peak, it was noteworthy that in the scenario where the stormwater structures were more diverse, the impact on the runoff peak was greater than the sum of its parts. Diversification of stormwater structures could thus produce more runoff delay than green roofs or street structures alone.

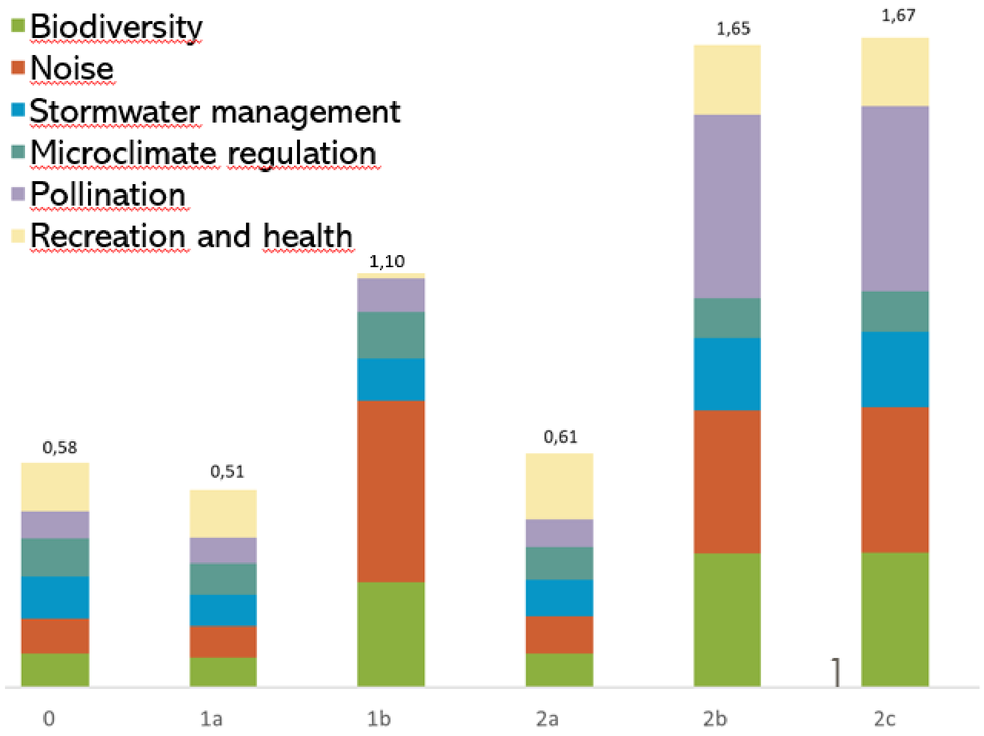


**Figure 14**. The green area factor results for the different scenarios, with the different colours indicating the importance of the separate components included in the factor

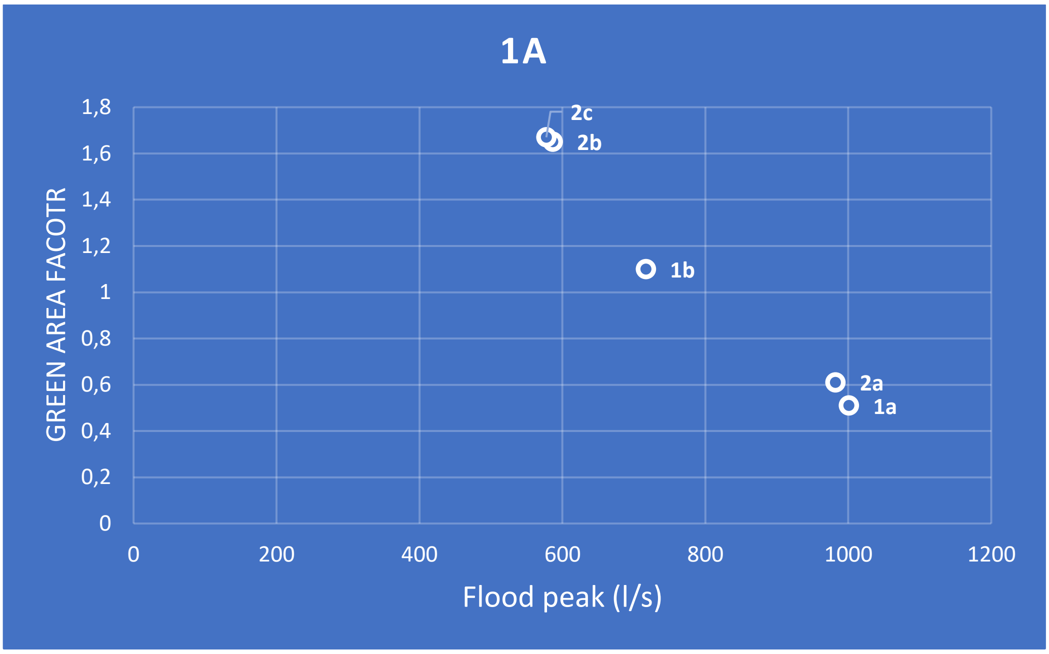


**Figure 15**. Comparison of the flood peak of 10a rain event to the green area factor. The flood peak correlates well with the green area factor, decreasing as the green are factor increases

GAF helped to compare scenarios according to diferent benefits that were enabled by protecting / actively introducing different types of blue-green infrastructure.

## Where to find the information about GAF model?

Access to general information about GAF from IWATER Interreg project:

http://www.integratedstormwater.eu

Helsinki tool guideline:

https://www.integratedstormwater.eu/sites/www.integratedstormwater.eu/files/final_outputs/helsinki_green_factor_tool_-_user_manual_final.pdf

Green area factor calculator:

https://www.balticwaterhub.net/tool/gaf

# 5. Reflections

The four models applied in ATENAS allows you to visualize some often different aspects of the managing water cycle gap in the city.

InVest focuses more on general potential of the area. InVest operates in big scales so at least the whole city scale, as it traces mutual interactions between areas heating-cooling, air movement and barriers, etc. Overview of a quality of greenery in terms of its metabolic activity (NDVI) allows it to delineate both natural and established areas which act as climate and water regulating NBS.

It is reasonable to have a closer look at cooling corridors and areas and to consider their protection in the first round and expansion towards the areas of lower cooling capacity. NBS may in this case create stepping stones enabling transfer of demanded ecosystem services from suppliers to recipients. However InVest will not answer the question about type and number of NBS needed to achieve the cooling effect.

IRIP helps to understand run off processes, thus tells where water that causes flooding comes from, the question could be put also differently - where the water can be harvested before it causes problem to infrastructure. As in majority of cities urbanization causes temporal shortage of water, especially under current climate change, every its source is important. At run-off generation zones water can be either infiltrated or stored. The run-off migration routes are the most tricky to deal with, but they indicate the connection between run-off sources and recipients. The latter indicated as run-off accumulation areas should be the second intervention areas. Usually counteracting flooding is more difficult at accumulation than at generation zones, however with no other option this one is also worth considering. IRIP shows you intensity of run off, and precisely its directions. However this is not a tool that helps to calculate accurately the amount of water we need to deal with NBS.

SWMM model is much more helpful here enabling precise calculation of amount of water available in particular locations under different land development scenarios, including introduction of different types of NBS. However SWMM is more data intense and may require more skills and knowledge from the applicant.

The fast overview of what could possibly be the effect of changing the land use by including stormwater NBS and greening of urbanscape can be made with Green-Area Factor. It is simple tool but well visualizing influence of NBS on run off coefficient. The weak point of GAF is its applicability to rather small scale projects and the fact that it provides more estimates that precise data on the run-off.

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