MAURICE

Deliverable D.4.4.3

Indicators of climate change resilient urban drainage

Final version

03 2026

Activities from the Application form:

WP 4 Resilience to climate change impacts on urban groundwater quality through spatial planning elements
Activity 4.4 Joint solutions for implementing of CC resistant measures for urban groundwater in strategic plans
Deliverable 4.4.3 Indicators of climate change resilient urban drainage
Adopted booklet on »Sustainable urban drainage to restore urban water quality as a contribution to climate resilient interventions (elements of spatial regulation and their interrelation with urban drainage)«
Delivery period: Period 6, 31 - 36
Authors: Prestor, J., Biondić, R., Pestotnik, S., Plantak, L., Viršek, S., Loborec, J., Leskovar, K., Meaški, H., Grčić, I.…

Note:

The original document was prepared in the Slovenian language. This document represents an English translation provided for the purposes of international cooperation within the Interreg / EU programme. In the event of any ambiguity, discrepancy in interpretation, or doubt regarding the content, the Slovenian language version shall prevail as the reference version.

Interreg CENTRAL EUROPE Co-funded by the European Union

MAURICE

Table of content

List of symbols and abbreviations

A - Land area (m^2)
A_{imp} - Impervious land area (m^2)
BA – Paved external surfaces (m^2)
BF - built-up area factor
OLA – Open living areas (m^2)
dQ_{pon} - Share of stormwater runoff that can be infiltrated into groundwater
dQ_{pz} - Share of stormwater runoff that can be discharged under special requirements
LSF - Open living areas factor
SSI - Sealed surface index
USI - Unsealed surface index
FAR - floor area ratio
FP - Factor of paved external surfaces
FP-L - Factor of paved living surfaces
FP-T - Factor of paved transport, utilities and technical surfaces
BF - built-up area factor
GA – green areas, GAF – green area factor
BS – Building plot (m^2)
BP-S – Sealed part of the building plot (m^2)
BP-U – Unsealed part of the building plot (m^2)
$q_{0(r,D)}$ – Initial specific inflow from a rainfall event with return period r (years) and duration D (minutes), i.e. design rainfall intensity (l/s/ha)
q_{min} – Minimum specific inflow from rainfall (l/s/ha)
P-L - paved external surfaces intended for living (m^2)
$P\text{-}L_{paved}$ - embanked or paved, directly on the ground or above the underground space (m^2)
$P\text{-}L_{gab}$ - green area above building = e.g. intensively/extensively greened roof of an underground space arranged at the angle of the natural terrain (m^2)
P-T - Paved outdoor areas for transport, utilities and technical purposes (m^2)
$P\text{-}T_{util}$ - Utilities surfaces = embanked or paved, directly on the ground or above the underground space (m^2)
$P\text{-}T_{trans}$ - Transport surfaces = embanked or paved, directly on the ground or above the underground space (m^2)
$P\text{-}T_{tech}$ - Technical surfaces = e.g. external storage area, external disposal area, etc. (m^2)
BA – built-up area (m^2)
BA_{main} - Build-up area under the main building (m^2)
GA - Green areas (m^2)
BA_{assoc} - Build-up area under the associated ancillary buildings (m^2)
Ψ - Runoff coefficient
Ψ_m - Mean runoff coefficient
$\Psi_{m,tip}$ - Typical mean runoff coefficient

INTRODUCTION

The economic aspect is crucial for the sustainability of urban drainage, so it is necessary to consider the real costs from the generation of stormwater to its final discharge into the environment.

Stormwater management is based on the historical design and practice of urban drainage and is evolving towards a more appropriate distribution of responsibilities between individual investors and the community.

Stormwater planning is directly linked to the safety of people and property. In economics, the aim is to achieve the optimal balance between investment costs and regular maintenance and the required level of safety.

Options for stormwater drainage are primarily determined by natural conditions; therefore, the economic viability and sustainability of urban drainage improve as planning aligns more closely with these natural factors.

Adaptation to natural conditions begins with spatial planning and regulatory elements. Climate change adaptation measures are only truly implemented when they are incorporated into the spatial plan.

This report presents key indicators that demonstrate the climate resilience of the drainage system within a spatial planning unit and, importantly, how it can be most effectively improved.

A. SUSTAINABLE URBAN DRAINAGE

In stormwater management, there is an increasing awareness that stormwater runoff should, wherever possible, be avoided or reduced at its source. If this is not feasible, temporary retention of rainwater is necessary to mitigate runoff, protect drainage systems from overload, and limit their dimensions. Designing and sizing economically sustainable retention facilities requires maximum innovation in adapting the planned activity, architecture, and spatial layout to the natural conditions of each individual plot.

Potential impacts of climate change can significantly influence project design. Current rainfall projections show a very high degree of variability. When planning retention, the increase in local heavy downpours is particularly important, as this may require larger retention volumes. However, due to significant regional variability and high uncertainty in rainfall forecasts, it is not advisable to set a general additional safety factor for climate change. The safety factor should be determined rationally based on a risk assessment of the consequences for each planned intervention. It is also necessary to anticipate the possibility of later expansion of retention areas and reduction of stormwater volumes by introducing permeable surfaces.

When planning and sizing drainage systems, priority should be given to all options for decentralised stormwater management to reduce discharge into the public sewer system. The increased frequency of heavy rainfall, combined with the expansion of impervious surfaces, is increasingly overloading public sewer systems. Many cities and municipalities now completely or partially prohibit stormwater discharge from private properties into public sewers, and stormwater may not be discharged onto public traffic surfaces.

Good stormwater management involves opening up areas, reducing sealing, increasing permeability, promoting evaporation and transpiration, as well as retention, purification, and infiltration (the “sponge city” principle), which should be considered as early as possible in construction projects.

1. CLIMATE-RESILIENT INTERVENTIONS

1.1. Strengthening infrastructure resilience

The planning of climate-resilient interventions follows the guidelines set out in the Technical guidance on the climate proofing of infrastructure for the period 2021–2027 (2021/C 373/01) [i]:

1. Strengthening climate resilience involves integrating climate change mitigation and adaptation measures into the development of infrastructure projects.
2. Interventions comply with the Paris Agreement and EU climate objectives, adhere to the “energy efficiency first” principle, and follow the “do no significant harm” principle.
3. Adaptation measures for infrastructure projects focus on ensuring an adequate level of resilience to climate change impacts, including acute events such as more intense floods, heavy rainfall, droughts, heatwaves, wildfires, storms, landslides, and hurricanes, as well as chronic events such as projected sea-level rise and changes in average precipitation, soil, and air humidity.
4. Areas with low and decreasing seasonal rainfall are increasingly exposed to risks of drought, soil subsidence, and wildfires.
5. Areas with higher seasonal rainfall, possibly combined with faster snowmelt and heavy showers, are more frequently exposed to flash floods and erosion.
6. Drought – technologies and methods for capturing rainwater must be introduced.
7. Flood regimes and extreme rainfall events – several key questions must be addressed to define climate adaptation issues:
   a) Will the proposed project be at risk due to its location in a river floodplain?
   b) Will it alter the capacity of existing floodplains to naturally manage floods?
   c) Will it change the water retention capacity within the catchment area?
   d) Are embankments stable enough to withstand floods?
   e) Will the project be threatened by rising shallow groundwater levels? [ii]
   f) Which infrastructure (e.g., existing or planned road sections, water supply, energy) is at risk due to its location in flood-prone areas?
   g) Does the network capacity suffice to manage potential extreme rainfall?
   h) Does the design of drainage systems prevent drained water from being directed into lower-lying areas?
   i) Will the proposed public plan/ programme reduce or enhance the capacity of ecosystems and floodplains to naturally manage floods?
   j) Will the proposed public plan/ programme reduce or increase the exposure of vulnerable groups (e.g., older people, those in poor health or young people, individuals whose income, livelihoods or cultural heritage depend on natural resources, and those with socio-economic characteristics limiting adaptive capacity) or sensitive receptors (e.g., critical infrastructure) to flooding or impacts on cultural heritage?

1.2. Examples of alternative options and measures related to climate change adaptation

It is necessary to consider design modifications that accommodate higher water levels and groundwater tables, such as construction on stilts or elevated structures.

Infrastructure exposed to flooding or critically flood-prone should be protected by:

- installing automatically rising flood barriers that use the lifting force of approaching floodwater;
- installing backflow valves in drainage systems to protect interior spaces from flooding caused by wastewater backflow;
- improving drainage, dewatering and drying pf structures and installations.

It must be ensured that all existing or planned critical infrastructure is protected against future flood risk.

In high-risk areas, arrangements for the supply of goods and services that could be disrupted by flooding should be considered.

Flood resilience should be enhanced through the application of sustainable drainage systems (SuDS).

The extent of permeable and green areas, as well as areas designated for temporary flooding during extreme events, should be increased in new public plans and programmes.

The reduction of flood storage capacity in flood-prone areas must be prevented.

ANNEX F – Recommendations to support climate resilience strengthening, F.1. Support framework at national, regional and local levels (information on precipitation and climate, such as showers, rainfall events, and Blue Spot mapping models).

2. REGULATION ELEMENTS

2.1. Regulation elements and stormwater drainage

The organisation of a building plot is closely linked to drainage from two main perspectives: the potential for stormwater infiltration and its pollutant load. For this reason, this chapter summarises and systematically presents the subunits, their names, and designations used in spatial planning for the organisation of a building plot (Figure 1, Table 1).

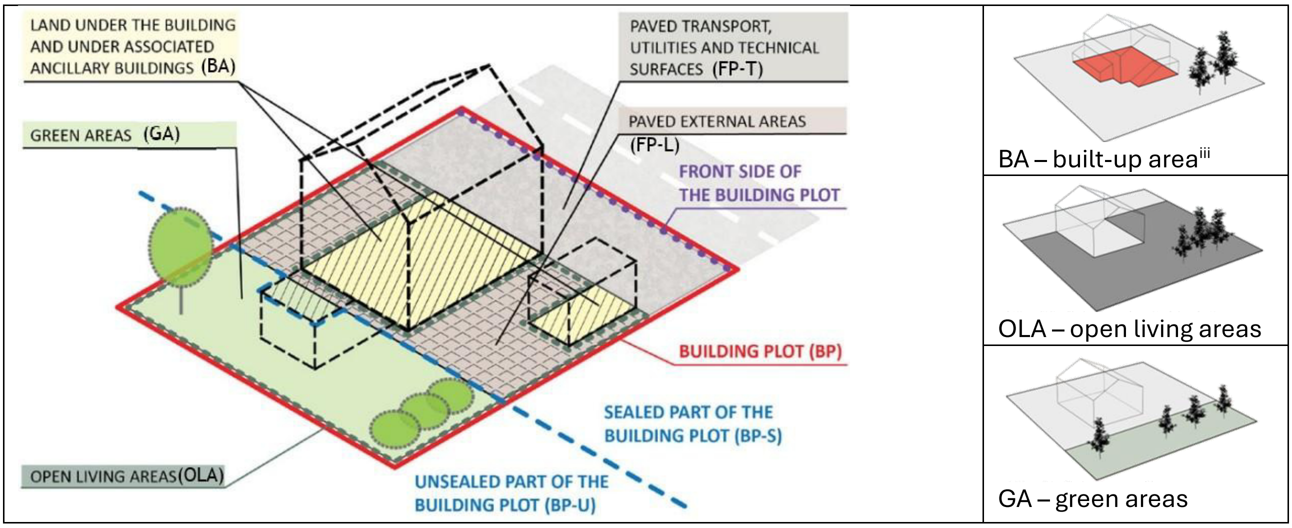

Figure 1.Schematic representation of the detailed division of the covered and vegetated areas of a building plot into subunits, illustrated with the example of a residential building (adapted from: Ministry of Natural Resources and Spatial Planning.)

Table 1. Subunits of a Building Plot (adapted from: Ministry of Natural Resources and Spatial Planning. (2024). Manual for Building Plots. Retrieved from

https://www.gov.si/assets/ministrstva/MNVP/Dokumenti/Graditev/prirocnik_gradbene_parcele.pdf)

BP	Building plot [m^2]
Sub-units of the building plot of a building:	
BP-U	Unsealed part of the building plot = external areas of the building plot which maintain direct contact with the geological subsoil and thus the ability to retain, drain and sink water, and allow for the planting of tall vegetation, and may also be used for outdoor living [m^2]
GA	Green areas [m^2]
BP-S	Sealed part of the building plot = areas which are built up with buildings (including underground parts of buildings, balconies, eaves, canopies) and associated ancillary buildings or are arranged as paved external areas. [m^2]
BA	Build-up area (land under the building and under associated ancillary buildings) [m^2]
P	Paved external surfaces [m^2]
P-T	Paved outdoor areas for transport, utilities and technical purposes [m^2]
P-L	Paved living surfaces intended for outdoor living [m^2]
OLA	Open living areas [m^2]

The entire building plot is organised with a detailed subdivision into subunits at four levels (Table 2). Such a division is necessary in particular from the perspective of the universal applicability of the prepared expert background documents.

From a drainage perspective, the key division occurs at the first level, separating the covered and vegetated parts of the plot (BP-S and BP-U). The vegetated part of the plot (BP-U) allows for the preservation of natural stormwater infiltration and provides a surface for the infiltration and retention of stormwater runoff from the covered part of the plot in the most nature-based way possible.

Subunit Z (built-up surface – see Table 1) determines from which surface on the plot runoff will occur and the quantity of generally clean roof stormwater.

Subunits U (hardened outdoor surfaces – see Table 2 and Table 4) indicate the volumes of stormwater with varying pollutant loads that need to be considered.

Table 2. Hierarchical scheme of building plot organisation (adapted from: Ministry of Natural Resources and Spatial Planning. (2024). Manual for Building Plots. Retrieved from

https://www.gov.si/assets/ministrstva/MNVP/Dokumenti/Graditev/prirocnik_gradbene_parcele.pdf).

BP							
BP-S							BP-U
BA		P					
		P-T			P-L		
BA_{main}	BA_{assoc}	$P\text{-}T_{trans}$	$P\text{-}T_{util}$	$P\text{-}T_{tech}$	$P\text{-}L_{paved}$	$P\text{-}L_{gab}$	GA

Table 3. Connections between the subunits of a building plot.

$BA = P\_L + P\_T$	Paved external surfaces [m^2]
$PB\_S = BA + P\_L + P\_T$	Sealed part of the building plot [m^2]
$BP\_U = BP - BP\_S$	Unsealed part of the building plot [m^2]
$OLA = BP\_U + P\_L = BP - BA - P\_T$	Open living areas [m^2]

Table 4. Additional subdivision of building plot subunits

Additional subdivision of building plot subunits	
BA_{main}	Build-up area under the main building (m^2)
BA_{assoc}	Build-up area under the associated ancillary buildings (m^2)
$P\text{-}L_{gab}$	green area above building = e.g. intensively/extensively greened roof of an underground space arranged at the angle of the natural terrain (m^2)
$P\text{-}L_{paved}$	Embanked or paved, directly on the ground or above the underground space (m^2)
$P\text{-}T_{trans}$	Transport surfaces = embanked or paved, directly on the ground or above the underground space (m^2)
$P\text{-}T_{util}$	Utilities surfaces = embanked or paved, directly on the ground or above the underground space (m^2)
$P\text{-}T_{tech}$	Technical surfaces = e.g. external storage area, external disposal area, etc. (m^2)

2.2. Planning stormwater quantity for drainage

The amount of stormwater that will run off from a plot depends on its layout, the runoff coefficients of individual subunits, and the impervious surface area.

$$A_{imp} = A \cdot \Psi_m = \Sigma\,(A_i \cdot \Psi_i)$$

- A_{imp} — Impervious surface area of the land (m^2)
- A — Total land area (m^2)
- Ψ — Runoff coefficient
- Ψ_m — Average runoff coefficient

The proportions between the subunits of the building plot and the design of their surfaces can vary greatly. Therefore, the range of possible stormwater quantities that will run off from the land is also very wide (Figure 2).

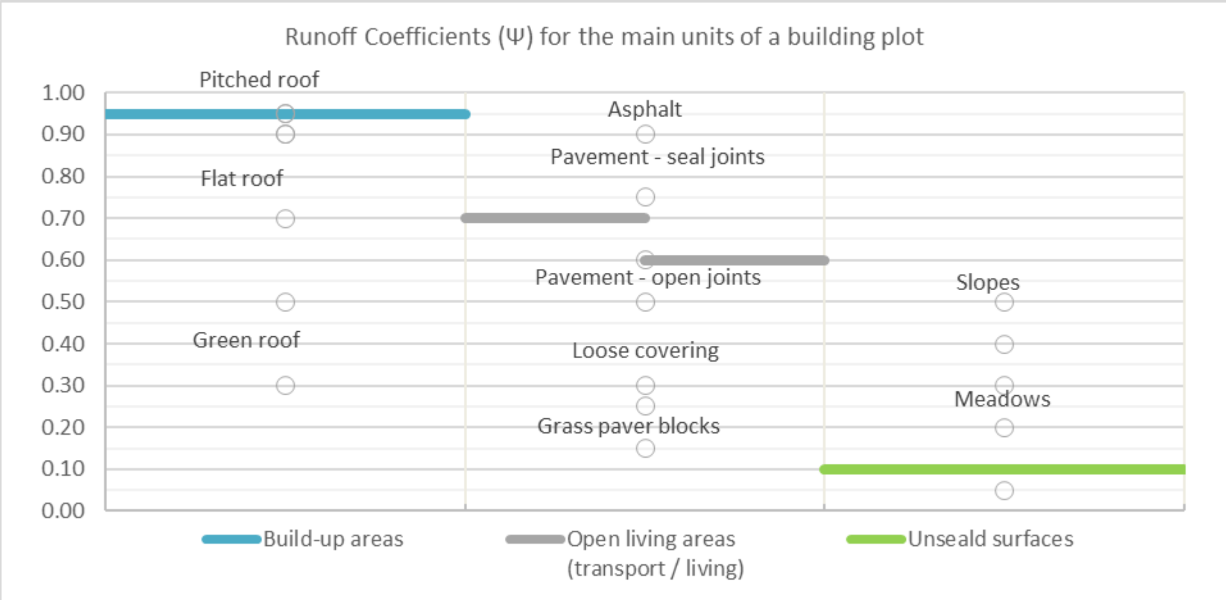

Figure 2. Comparison of typical runoff coefficient (Ψ) values for the three main units of a building plot (values summarised from DWA-A 138E).

The amount of stormwater runoff for plots with planned building plot organisation guidelines can be estimated using urban planning factors and the anticipated runoff coefficients relevant to the proposed interventions:

$$\Psi_m = BA \cdot \Psi_A + FP\_T \cdot \Psi_{P\_T} + FP\_L \cdot \Psi_{P\_L} + \mathrm{USI} \cdot \Psi_{BP\_U}$$

The values of runoff coefficients (Ψ) for various surface types or interventions are specified in standards (e.g. DWA-A 138E). When calculating the mean runoff coefficient for the area under consideration, the final layout of building plots is assumed, taking into account both the most and least favourable runoff coefficients applicable to individual sub-units of the plots. This approach yields a possible range of stormwater runoff volumes. More importantly, it provides a useful model for identifying which improvements in plot layout and in the runoff coefficients of individual surfaces offer the greatest potential for reducing stormwater runoff. An example of such an assessment (Table 5, Figure 3) shows the selection of the most and least favourable runoff coefficients and the calculated range of the runoff coefficient for the organisation of building plots, based on the guidance example presented in Table 6.

The presented calculation example shows a case with a significantly wider range of possible runoff coefficient selections compared to the distribution of subunit shares on building plots. In this case, optimisation is most sensible to carry out first by choosing the most favourable runoff coefficients.

Table 5. Example of selecting the least and most favourable runoff coefficients for the planned surfaces.

Runoff coefficient (Ψ)	BA	FP-T	FP-L	USI
Least favourable (Max)	0,95	0,95	0,7	0,2
Most favourable (Min)	0,4	0,5	0,3	0,05

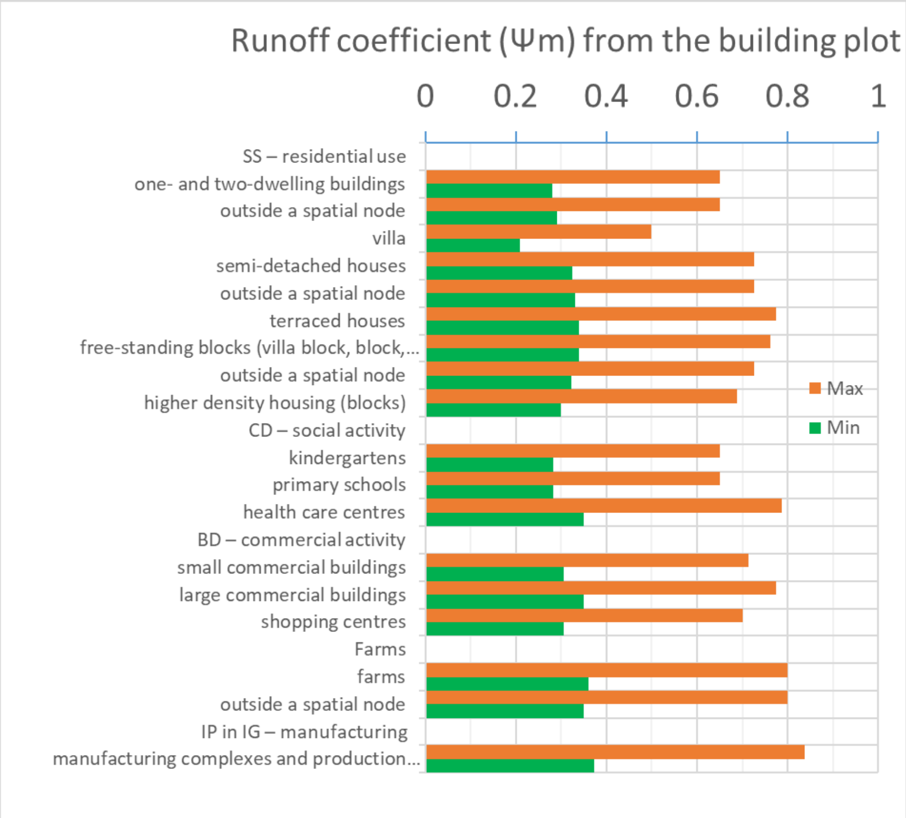

Figure 3. Calculated range of runoff coefficients for various building plots.

2.3. Planning stormwater quality for drainage

The basic classification of stormwater by quality is based on whether hazardous or other substances that could contaminate stormwater may be present on a particular unit or subunit of the building plot.

Stormwater that runs off unpaved, vegetated, and green areas, where there is no traffic or other activity that could release substances or pose a risk of contaminant discharge, is considered slightly or non-polluted. The same applies to roof water, except where roofing materials may leach substances or where the surrounding air is so polluted that it contaminates roof surfaces and precipitation before it reaches the ground. Slightly or non-polluted water also includes hardened outdoor living surfaces if they are green areas above a structure.

Infiltration of slightly or non-polluted stormwater is generally not expected to cause groundwater contamination or adversely affect its quality. Therefore, infiltration may be carried out into the subsoil, for example, using a soakaway or infiltration trench, provided that the base of the infiltration facility is at least 1 metre above the highest groundwater level.

Stormwater from working surfaces and roads in commercial and industrial areas with significant air pollution, as well as from surfaces such as heavy vehicle parking areas or aircraft aprons at airports, is highly polluted. Such water is generally unsuitable for infiltration, even through biologically active soil, as pollutants would accumulate in the soil and eventually destroy its biological activity. To determine the appropriate drainage method for these waters, the pollutant load or contamination level of the drained surfaces must be specified in detail (e.g. DWA-A 138E, Table 1, p. 14). In addition, soil characteristics at the site are important, as different soils can have very different retention capacities. It is useful to define infiltration criteria based on soil properties, particularly their thickness and grain size, i.e. granulometric composition (VSA[iv]).

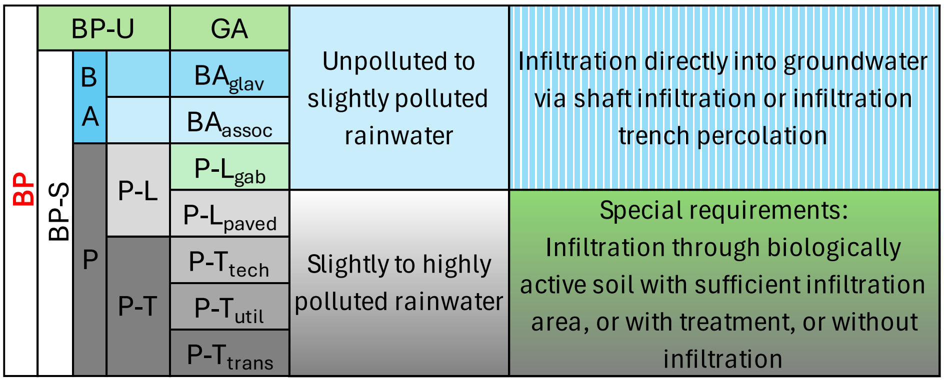

Figure 4. Basic approach to infiltration based on the pollutant load of stormwater runoff from a building plot unit.

The proportions of stormwater runoff that can be infiltrated into the subsoil or discharged under special requirements can be estimated from the planned urban planning factors and runoff coefficients.

$$dQ_{inf} = (USI \cdot \Psi_{BP-UR} + BA \cdot \Psi_{BA} + FP\_L_{gab} \cdot \Psi_{P\_L_{gab}})/\Psi_m$$

$$dQ_{sr} = (FP\_L_{paved} \cdot \Psi_{P\_L_{paved}} + FP\_T \cdot \Psi_{P\_T})/\Psi_m$$

dQ_{inf}	Share of stormwater runoff that can be infiltrated into the subsoil
dQ_{sr}	Share of stormwater runoff that can be discharged under special requirements

An example calculation of the shares of stormwater for infiltration into the subsoil and for discharge under special requirements is shown in the table (Table 6).

As a rule, waters with different levels of pollution should be drained separately; otherwise, stricter discharge requirements must be applied.

Table 6. Example calculation of stormwater runoff shares for infiltration and discharge under special requirements.

SS – residential use	BF	FP_T	FP_L	USI	Runoff coeff. (Ψ_m)	Infiltration into subsoil	Special drainage requirements
Runoff coefficient (Ψ)	0.95	0.95	0.7	0.2			
one- and two-dwelling buildings	**40**	**20**		**40**	0.65	71%	29%
outside a spatial node	30	30		40	0.65	56%	44%
villa	**20**	**20**		**60**	0.50	62%	38%
semi-detached houses	**40**	**30**		**30**	0.73	61%	39%
outside a spatial node	35	35		30	0.73	54%	46%
terraced houses	**50**	**20**	**10**	**20**	0.78	75%	25%
free-standing blocks (villa block, block, tower block)	**40**	**25**	**15**	**20**	0.76	69%	31%
outside a spatial node	35	25	15	25	0.73	67%	33%
higher density housing (blocks)	**35**	**20**	**15**	**30**	0.69	72%	28%
CD – social activity							
kindergartens	**30**	**20**	**15**	**35**	0.65	71%	29%
primary schools	**30**	**20**	**15**	**35**	0.65	71%	29%
health care centres	**50**	**25**	**5**	**20**	0.79	70%	30%
BD – commercial activity							
small commercial buildings	**50**	**15**	**5**	**30**	0.71	80%	20%
large commercial buildings	**40**	**30**	**10**	**20**	0.78	63%	37%
shopping centres	**40**	**20**	**10**	30	0.70	73%	27%
Farms							
farms	50	30		20	0.80	64%	36%
outside a spatial node	60	20		**20**	0.80	76%	24%
IP in IG – manufacturing							
manufacturing complexes and production zones	**60**	**25**		**15**	0.84	72%	28%

The above example of surface area shares within a building plot is a recommendation from the Manual for the planning and organisation of building plots, prepared by the Urban planning institute of the Republic of Slovenia, the Ljubljana urban planning institute Ltd, and BD projektiranje Ltd. Municipalities define these shares in various ways; however, such a system can be transferred and applied at different planning levels. Below (Table 7), the definition of factors from the OPN MOL ID is presented for the case of Ljubljana, which differ considerably, particularly regarding the definition of "USI".

Table 7. Example calculation of stormwater runoff shares for infiltration and discharge under special requirements (case of the City of Ljubljana – MOL, 2023).

2. SScv – Predominantly residential use					
Building typologies	Building typologies / function	BF (max)	LSF (min)	GAF (min)	FAR (max)
V	Tower block, block	/	30 %	Ø	1,2
V	Slab buildings	70 %	20 %	Ø	/
V	Terraced houses	70 %	20 %	Ø	/
VS	Residential buildings	40 %	30 %	Ø	1,2
NV	Residential buildings	40 %	35 %	Ø	/
3. SSse – General one- and two-dwelling buildings residential areas					
Building typologies	Building typologies / function	BF (max)	LSF (min)	GAF (min)	FAR (max)
NA	One- and two-dwelling buildings	40 %	30 %	Ø	/
NA	semi-detached houses/ per dwelling unit	40 %	30 %	Ø	/
ND	One- and two-dwelling buildings	40 %	30 %	Ø	/
NB	Terraced houses	50 %	25 %	Ø	/
NB	Atrium house	60 %	20 %	Ø	/
All types except NB	Non-residential buildings	40 %	Ø	25 %	/

Additional vegetated ground is defined in Article 32 of the OPN MOL ID (MOL, 2023), which states that vegetated ground represents 100% of FZP (calculated only for non-residential uses) and at least 50% of FBP (calculated for residential uses). An additional condition for FBP is that a minimum of 15 m^2 of open living space per planned dwelling must be provided, with at least half of the required area consisting of vegetated ground.

2.4. The importance of regulation elements in drainage planning within a spatial planning unit

Table 8. The significance of land use and urban indicators for stormwater drainage planning.

Element	Value range on BP	Significance for stormwater drainage
Residential buildings (SS) $\Psi_{m,type}$ = 0,59 Social activity (CD) $\Psi_{m,type}$ = 0,60 Commercial activity (BD) $\Psi_{m,type}$ = 0,64 Farms (K) $\Psi_{m,type}$ = 0,72 Manufacturing (IP in IG) $\Psi_{m,type}$ = 0,76	Ψ_m = 0.78-0.21 Ψ_m = 0.79-0.28 Ψ_m = 0.78-0.31 Ψ_m = 0.80-0.35 Ψ_m = 0.84-0.37	The final state for stormwater drainage represents the highest load for industrial use and the lowest for residential buildings. For all land uses, the runoff coefficient allows a wide range of potential reductions in load.
Unsealed surface index (USI)	15 % - 60 %	USI > 20% enables infiltration at a ratio of rA = 5, thus allowing infiltration of the most polluted stormwater.
Sealed surface index (SSI)	40 % - 86 %	SSI > 80% prevents infiltration of the most polluted stormwater.
Built-up area factor (BF)	20 % - 60 %	The share BF + USI represents the proportion of non-polluted water (BF + USI > 65% means that at least two-thirds of stormwater will be slightly polluted).
Factor of paved external surfaces (FP)	20 % - 40 %	Share of surfaces where infiltration through biologically active soil must be considered.
Factor of paved living surfaces (FP-L), e.g. courtyards, terraces, paved recreation areas	5 % - 30 %	A very important share of surfaces for reducing the runoff coefficient.
Factor of paved transport, utilities and technical surfaces (FP-T) that supporting the operation of the building	20 % - 35 %	Indicative share of polluted surfaces requiring treatment (oil separator, biologically active soil, sufficient infiltration area, etc.).
Green area factor (GAF) Without SS	15 % - 35 %	Important share of surface reducing the overall runoff coefficient of the plot and enabling increased evapotranspiration.
Open living areas factor (LSF) Only for SS	30 % - 65 %	Reduces the runoff coefficient and increases infiltration potential.
Sealed part of the building plot (BP-S)	40 % - 86 %	A large share of BF compared to BP-S (BF/BP-S > 0.5) means that most stormwater will be slightly polluted.

3. PLANNING DRAINAGE FOR THE FINAL DEVELOPMENT STATE

3.1. Regulation elements

Planning within a spatial planning unit begins with defining land use, urban indicators, and building dimensions.

At the same time, it is possible to calculate the expected quantities of clean and polluted stormwater for a given rainfall event, with the selected safety margin against flooding.

The quantity of clean stormwater (roof water and water from open living surfaces) can be infiltrated into the subsoil without treatment.

Stormwater from open traffic and utility surfaces can be infiltrated without additional treatment if infiltration occurs on open vegetated or biologically active surfaces. The area of this surface must be at least 1/15 of the sealed surface. For more heavily polluted open traffic surfaces, the ratio should be 1/5 of the sealed surface.

Using the Infiltration Capacity Map, it is possible to determine whether special offsets will be required for infiltration systems.

It is also possible to identify whether special offsets will be needed between covered surfaces to prevent seepage of perched groundwater from compressible geological layers into foundation soils.

Based on this, the determination of regulatory elements is adjusted and improved to ensure optimal land use and investment safety.

3.2. Possible drainage outlets

- Infiltration

Using the Infiltration Capacity Map, it is possible to predict whether discharge and overflow will fully or partially infiltrate, and to determine the required retention volumes.

- Surface discharge

For surface discharge, retention must be planned if increased runoff would affect neighbouring plots. Retention should limit runoff to $q_{0(1,15)}$ and provide overflow for rainfall events with a return period exceeding 10 years.

- Discharge into a surface watercourse

Information from the operator is required regarding the permitted discharge volume into a surface watercourse. If no specific hydraulic or ecological definition of permitted discharge exists, retention should limit runoff to $q_{0(1,15)}$ and provide overflow for rainfall events with a return period exceeding 10 years. If this limit is not acceptable, a restriction of q_{min} = 10 l/s/ha of sealed surface is proposed, or in extreme cases, q_{min} = 2 l/s/ha.

- Discharge into a stormwater sewer

Information from the operator is required regarding the permitted discharge volume into the sewer. If no specific hydraulic definition of sewer capacity and permitted discharge exists, retention should limit runoff to $q_{0(1,15)}$ and provide overflow for rainfall events with a return period exceeding 10 years. If this limit is not acceptable, a restriction of q_{min} = 10 l/s/ha of sealed surface is proposed, or in extreme cases, q_{min} = 2 l/s/ha.

- Discharge into a combined sewer

If interventions are planned that will generate stormwater runoff, and no stormwater sewer exists or is planned, a discharge of at least q_{min} = 2 l/s/ha of sealed surface and overflow for rainfall events with a return period exceeding 10 years must be ensured. If this cannot be guaranteed due to sewer load, the interventions are not permissible.

- Discharge into a planned stormwater sewer

If the stormwater sewer is still in the planning stage and temporary substitute measures are foreseen by the community, project solutions must be designed to allow proper connection after sewer construction. Retention, discharge, and overflow must already be dimensioned for the planned capacity and prepared as required by the operator for connection after construction. If these boundary conditions are not yet known, a discharge of at least q_{min} = 2 l/s/ha of sealed surface and overflow for rainfall events with a return period exceeding 10 years must be ensured.

3.3. Sealed surface of the land

The sealed surface of the land is optimised to:

- save space,
- reduce drainage costs,
- reduce the need for stormwater treatment or infiltration through a biologically active layer, and
- introduce blue-green infrastructure into living and working environments.

B. BENCHMARKING ANALYSIS OF DRAINAGE RESILIENCE

4. ANALYSIS OF ADVANTAGES AND OPPORTUNITIES FOR IMPROVEMENT

The analysis of the advantages of a specific planning unit and its higher drainage resilience to climate change can be conducted from three perspectives:

1. How the drainage was planned,
2. What solutions exist for stormwater runoff and retention, and
3. How infiltration and stormwater discharge are arranged.

A planning unit achieves significant advantages and good climate resilience (see Table 9) when:

1) Drainage was planned at the conceptual design stage with the involvement of various experts (e.g., hydraulic engineer, hydrogeologist, architect, arborist), and when solutions exceed minimum requirements;
2) At least 80% of sealed surfaces are unpolluted, roofs also provide retention and do not discharge into the sewer system, and building flood safety is ensured for at least 25 years;
3) At least 80% of stormwater is retained within the natural water cycle, the overall runoff coefficient $\Psi_m < 0.3$, and stormwater is partially reused both outdoors and indoors.

5. INDICATORS OF DRAINAGE RESILIENCE

5.1. Drainage planning - seeking the best solutions

Finding effective solutions is closely linked to the effort invested, the time allocated, and the exchange of opinions on risk. Timely agreement among stakeholders on the acceptability of impacts indirectly leads to better consideration and greater resilience of the investment itself.

5.2. Runoff and retention - environmental load and safety

Recommended urban planning indicators can achieve over 60% unpolluted surfaces even with relatively high runoff coefficients for building plots. By reducing the proportion of open traffic surfaces in favour of increasing vegetated, built-up, and open green living areas, and by lowering the runoff coefficient of open traffic, utility, or working surfaces, the share of unpolluted surfaces can significantly increase towards 80%.

Priority should be given to finding solutions for roof surfaces so that they are fully drained (discharge and overflow) through infiltration, whether via surface discharge, into a surface watercourse, or a combination of these methods. Particularly in cases of clayey top layers and wetlands, roofs should also serve a retention function.

According to standard SIST EN 752-2, sewers in urban centres and industrial areas are designed for flood safety with a 1-in-30-year return period, and sewer overflows should occur only for rainfall events with a 5-year return period. If drainage in the planning unit is designed so that there are no sewer overflows for rainfall events with a return period of up to 5 years, the minimum standard requirement is met, and good building safety is ensured for at least 25 years.

5.3. Infiltration and discharge - maintaining the water cycle

At the design stage, arrangements can be made to achieve at least 60% clean sealed surfaces. Infiltration of clean water is easier to ensure than infiltration of polluted water. If at least clean water is discharged through retention-infiltration depressions and trenches with overflows designed specifically for areas with permeability of approximately $k \approx 10^{-6}$ m/s, at least 80% of stormwater returns to the water cycle.

An overall runoff coefficient for the planning unit of $\Psi_m < 0.8$ can be achieved by following recommended urban planning indicator values (Figure 6).

With careful planning for space-saving and reduced drainage costs, an overall runoff coefficient of $\Psi_m < 0.6$ can be achieved.

With targeted planning of blue-green infrastructure, an overall runoff coefficient of $\Psi_m < 0.4$ is possible.

Water reuse also means returning stormwater to the water cycle through infiltration, provided it is implemented according to modern standards. Even more effective is water reuse that reduces consumption and extraction from water sources. If reuse replaces water consumption inside buildings– water that is essential and would otherwise be used– this represents the greatest contribution to climate resilience.

Table 9. Assessment of indicators of climate resilience for stormwater drainage in a planning unit (adopted after VSA, 2025).

Planning & design of drainage measures	2	1	0
Consents	Optimized impact	Minimum requirements	No
Reconciliation with experts	Different fields experts	One field experts	One expert
Timeliness of planning	Conceptual design/initiative	Building permitting	After building permitting

Runoff and retention	2	1	0
Share of clean water surfaces of A_{imp}	≥ 80 %	60 - 79 %	<60 %
Roofs	Retain water /no sewage	No sewage	Sewage
Safety of buildings	30 years	10 years	5 years

Infiltration and drainage	2	1	0
Managed in natural water cycle	≥ 80 %	60 - 79 %	40 - 59 %
Surface runoff coefficient of the area	< 0.3	0.3 - 0.4	≥ 0.4
Rainwater use	Inside and outside	Outside	No

C. TOOLS

Excel spreadsheet for calculating the runoff coefficient and the shares of clean and polluted water for the final development state.

	Critical stormwater discharge rate	150	l/s/ha				**1**	**2**	**3**	**4**	Critical stormwater	150	l/s/ha	
	Building plot (BP)	1000	m^2				0.1	3	0.05	0.2				
		0.1	ha				Coef.	l/s/ha	P. $runoff_{min}$	P. $runoff_{max}$				
	Runoff coefficient	0.95	0.7	0.6	0.1									
							Permitted discharge (l/s)				Required overflow to the environment, w			
(% BP)	**SS – residential use**	**Roof**	**Traffic**	**Operational**	**Unsealed**	**Runoff koef.**	$q_{disc}1$	$q_{disc}2$	$q_{disc}3$	$q_{disc}4$	$q_{ro}1$	$q_{ro}2$	$q_{ro}3$	$q_{ro}4$
100	**one- and two-dwelling buildings**	40	20		**40**	0.56	1	1	1	3	8	8	8	6
100	outside a spatial node	30	30		**40**	0.54	1	1	1	3	8	8	8	6
100	**villa**	**20**	**20**		**60**	0.39	1	1	1	3	5	5	5	3
100	**semi-detached houses**	40	30		**30**	0.62	1	1	1	3	9	9	9	7
100	outside a spatial node	35	35		**30**	0.61	1	1	1	3	9	9	9	7
100	**terraced houses**	**50**	**20**	**10**	**20**	0.70	2	1	1	3	9	10	10	8
100	**free-standing blocks** (villa block, block, tower block)	40	**25**	**15**	20	0.67	1	1	1	3	9	9	9	7
100	outside a spatial node	35	25	15	**25**	0.62	1	1	1	3	9	9	9	7
100	**higher density housing** (blocks)	**35**	**20**	**15**	**30**	0.59	1	1	1	3	8	8	8	6
	CD – social activity													
100	**kindergartens**	**30**	**20**	**15**	**35**	0.55	1	1	1	3	8	8	8	6
100	**primary schools**	**30**	**20**	**15**	**35**	0.55	1	1	1	3	8	8	8	6
100	**health care centres**	**50**	**25**	**5**	**20**	0.70	2	1	1	3	9	10	10	8
	BD – commercial activity													
100	**small commercial buildings**	**50**	**15**	**5**	**30**	0.64	1	1	1	3	9	9	9	7
100	**large commercial buildings**	**40**	**30**	**10**	**20**	0.67	2	1	1	3	9	10	10	8
100	**shopping centres**	**40**	**20**	**10**	30	0.61	1	1	1	3	9	9	9	7
	Farms													
100	**farms**	50	30		20	0.71	2	1	1	3	9	10	10	8
100	outside a spatial node	60	20		**20**	0.73	2	1	1	3	9	10	10	8
	IP in IG – manufacturing													
100	**IP in IG – manufacturing complexes and production zones**	**60**	**25**		**15**	0.76	2	1	1	3	10	11	11	9

	Boundary condition for the permitted discharge
1	Default runoff coefficient under natural conditions
2	Default maximum permitted specific runoff from sealed surfaces
3	Default minimum runoff coefficient under natural conditions
4	Default maximum runoff coefficient under natural conditions

$q_{disc}1$	Permitted discharge (l/s) for the given boundary condition
$q_{ro}1$	Required overflow (l/s) for the given boundary condition

6. LITERATURE

Gérer ses eaux pluviales | Nantes, ville et métropole

i Tehnične smernice za krepitev podnebne odpornosti infrastrukture v obdobju 2021-2027.pdf O:\SimonaPestotnik\oMauriCE\Predpisi\Obrazec_Podnebna-presoja-climate-proofing.doc

ii Original: Will the project be a risk from raising levels of near-surface ground water?

Consider changes in construction design that allow for rising water levels and ground water levels (e.g. build on pillars, surround any floodvulnerable or flood-critical infrastructure with flood barriers that use the lifting power of approaching floodwater to automatically rise, set up backwater valves in drainage-related systems to protect interiors from flooding caused by backflow of wastewater). Improve the project's drainage.

iii https://www.gzs.si/Portals/Panoga-Gradbenistvo/BIM_Smernice%20za%20modeliranje.pdf)

iv https://vsa.ch/fr/fachbereiche-cc/assainissement-urbain/temps-de-pluie/

OFT/OFEV (éd.) 2018. Directive Evacuation des eaux des installations ferroviaires, str. 31, Annexe 5.

DWA, 2005. DWA-A 138E: Planning, Construction and Operation of Facilities for the Percolation of Precipitation Water. Hennef: DWA – German Association for Water, Wastewater and Waste. Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall (DWA). ISBN 978-3-937758-74-9.

MOL, 2023. Odlok o občinskem prostorskem načrtu Mestne občine Ljubljana – izvedbeni del (neuradno prečiščeno besedilo, NPB št. 22 - odločba US, november 2023). Ljubljana: Mestna občina Ljubljana. Dostopno na:

https://www.ljubljana.si/assets/OPN-MOL/NPB-Odloka-OPN_MOL_ID_NPB-st.-22-odlocba-US_november-2023_BeJ.pdf

Nikšič, M., Dražič, B., Konda, K., Bizjak Komatar, N., Solomun, J., Mušič, B. & Bevc Šekoranja, B., 2021. Načrtovanje in organizacija gradbene parcele stavbe: Priročnik. Uredili: Červek, J., Peršak Cvar, S. & Jerman, Z. Ljubljana: Ministrstvo za okolje in prostor, Direktorat za prostor, graditev in stanovanja. ISBN 978-961-6276-50-4. Dostopno na:

https://www.gov.si/assets/ministrstva/MNVP/Dokumenti/Graditev/prirocnik_gradbene_parcele.pdf

OFT/OFEV (éd.) 2018. Directive Evacuation des eaux des installations ferroviaires, str. 31, Annexe 5.

VSA, 2025. Checklist pour une gestion durable des eaux de pluie dans les quartiers – Dossier complet. Glattbrugg: VSA – Association suisse des professionnels de la protection des eaux (VSA). Dostopno na:

https://vsa.ch/wp-content/uploads/2025/04/1-Dossier_complet_gestion_durable_des_eau_de_plui.pdf