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BETTER WATER MANAGEMENT FO ADVANCING RESILIENT COMMUNITIES IN EUROPE

BEWARE

WATER, RESILIENCE AND TERRITORY

SOLUTION MANUAL

SUMMARY

I INTRODUCTION

Globally, climate change is leading to an increase in temperature and a change in rainfall patterns. This implies an increase in the frequency of extreme and catastrophic weather events. The consequences of these phenomena are exacerbated by an increase in land consumption that amplifies the effects of increased rainfall intensity, stressing drainage and hydrographic networks, both in urban and agricultural contexts, and endangering the health of communities, and food production, and the balance of habitats and ecosystems.

The consequences of climate change are also particularly serious for our country. According to a study by ISAC-CNR, Italy is overheating faster than the global average. As proof of this, in 2014, the temperature reached by our planet registered an increase of 0.46°C compared to the 30 years 1971-2000, while Italy far exceeded this value, with an increase of 1.45°C. In parallel, the intensification of rainfall and soil sealing aggravate our territory's already critical hydrogeological situation. In fact, in a recent report on hydrogeological instability published by the Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA) in June 2018, 91% of Italian municipalities (compared to 88% in 2015) are located in hydrogeological risk zones. This is reflected in the higher frequency with which such events are occurring in recent decades.

In the light of these changes and their dramatic consequences, public authorities and communities are called upon to respond to this emergency with timely land-use planning actions that consider increasingly environmentally sustainable mitigation measures. Planning interventions to mitigate these changes is also a social issue. What is needed is a strategy that combines technical solutions with awareness-raising actions. The former include sustainable urban drainage systems, the integration of building regulations aimed at environmental protection, the implementation of targeted structural interventions, the identification of agricultural species and varieties best suited to the new climatic conditions, the increased use of renewable energy, the redevelopment and recovery of abandoned territories, the enhancement of weather monitoring and forecasting tools, etc. These are complemented by, not least, educational and awareness-raising initiatives aimed at creating an environmental and risk culture through information and education campaigns.

The classic runoff management approach aims at the construction of large hydraulic works with the function of rapid removal of runoff water from urban areas and subsequent lamination of this flow. However, besides being costly and, in some cases, environmentally impactful, this management needs to be adapted to the urban area served. An alternative encouraged by experts in urban runoff management is to relocate the flooding works by placing them in a diffuse form and as close as possible to the sealed areas that generate the runoff. This perspective is also encouraged by EU and national policy, whose directives and guidelines are in turn implemented by the regions. Rules defining the concepts of hydraulic and hydrological invariance further direct experts in the public and private sectors to implement forms of hydraulic compensation whenever there is a change in land use. These new works are based on the use of so-called Sustainable Urban Drainage Systems (SuDS). Experiences in some European states where SuDS works have been implemented widely within built-up areas have demonstrated a significant reduction in runoff conveyed to the main hydrographic network, decreasing both the risk of localised and diffuse flooding. Furthermore, the integration of SuDS within urban areas changes the view of urban runoff from a problem to an opportunity. In fact, in addition to decreasing hydrogeological risk, SuDS can provide several other benefits, including reusable water storage in times of water scarcity, increasing the aesthetic value of the landscape and urban areas in which they are inserted, improving the quality of runoff water and reducing the heat island effect typical of larger cities.

This manual aims to provide public and private planners, managing bodies and practitioners, and ordinary citizens with practical guidelines for the correct selection or realisation and maintenance of SuDS. The handbook's content is based on the direct experience of the LIFE BEWARE pilot project, which enabled the implementation of different types of sustainable urban drainage systems in two municipalities in the upper Vicenza area (Santorso and Marano Vicentino). This project aimed to go beyond the classic design and implementation of SuDS interventions, promoting citizen participation and raising awareness on the issue of hydrogeological risk. In this context, the aim was to give communities a sense of responsibility for urban runoff management by encouraging them to carry out small interventions themselves that could have a positive effect on the community (reducing the risk of flooding, reducing the heat island effect, etc.), and on individual homeowners (accumulation of water for irrigation, increased property value, etc.). The manual aims to promote the dissemination of SuDS in particular by facilitating the work of designers who will be able to find in it a support tool both in terms of the choice of possible solutions and their hydraulic dimensioning.

The manual begins with a brief description of the LIFE BEWARE project. It then presents the general concepts related to runoff estimation and hydraulic invariance to be achieved through SuDS according to Veneto Region regulations. Finally, eight different types of SuDS are presented through a general description of them, a list of the most appropriate methodologies for their correct dimensioning, a description of the materials and construction methods, and the costs to be incurred in the short and long-term for construction and maintenance operations.

1.1 THE LIFE BEWARE PROJECT

The LIFE BEWARE project (Better Water Management for Advancing Resilient Communities in Europe) is a project that promotes the adoption of sustainable interventions (Natural Water Retention Measures) for flood risk reduction. The project aims to improve the safety and hydraulic resilience of the Altovicentino territory through a participatory approach that actively involves all the main stakeholders, encouraging individual citizens to carry out small actions spread throughout the territory for the whole community's benefit. We believe that the objective of improving the safety and hydraulic resilience of the territory cannot be pursued solely through the realisation of large-scale structural works but requires articulated and incisive action also at the social level on a small scale (housing complex or individual dwelling). Inspired by the principle that a virtuous action practised by each citizen can produce a collective benefit even greater than that obtainable from a major work, the LIFE BEWARE Project activated a participatory process for the involvement of all the main stakeholders: citizens, freelancers, farmers, administrators and technical offices, students. Seven pilot interventions for flood risk reduction and sustainable rainwater management in urban and agricultural areas were implemented as part of the project. The effectiveness of these interventions is urrently being researched through a monitoring campaign with special instrumentation.

The LIFE BEWARE project is innovative because it aims to tackle the problem of flooding in urban and rural areas through a new participatory perspective. In fact, the project promotes the adoption of sustainable solutions for hydraulic risk mitigation (Nature-Based Solutions, NBS) in a context where the risk from flooding and inundation is important but where the proposed types of intervention are almost unknown and unused, even though the effects of climate change and land consumption are further exacerbating the problem. In this area, the mitigation of hydraulic risk is delegated to the public authority, which often aims to solve the problem by carrying out large hydraulic works. But in a context where, at a national level, 9.15 % of useful soil is consumed, with peaks of over 30 % in metropolitan areas (Munafò, 2021[1]), it is essential to raise awareness and responsibility among all citizens. To this end, the LIFE BEWARE project implements a series of concrete actions for which the results are already well documented.

[1] Munafò, M. (ed.), 2021. Consumo di suolo, dinamiche territoriali e servizi ecosistemici. (Land consumption, spatial dynamics and ecosystem services.) Edition 2021.
SNPA Report 22/21

LIFE BEWARE PROJECT PARTNERS

Comune di
Santorso

Comune di
Marano Vicentino

VENETO AGRICOLTURA

Università degli Studi di Padova
TESAF

alda
European Association for Local Democracy

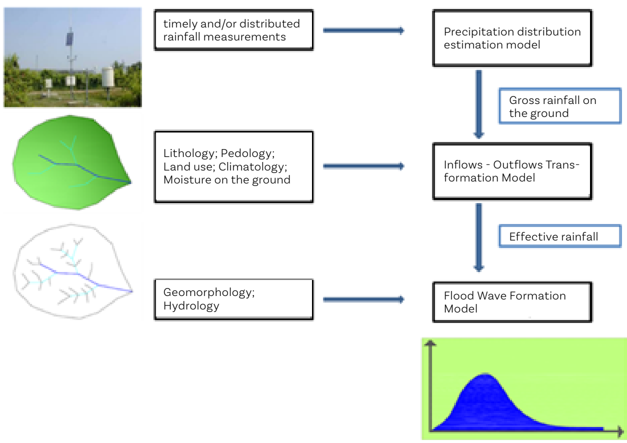
Alta Pianura Veneta
Consorzio di Bonifica

2 HYDROLOGY ELEMENTS FOR ASSESSING HYDRAULIC COMPATIBILITY

2.1 FLOOD FLOW RATE

The flood discharge is the consequence of various hydrological processes that contribute to the rise in flow levels in the hydrographic network due to surface runoff generated by meteoric events (inflows).

However, surface runoff is only a part of the total precipitation. The vegetation intercepts a certain amount of the inflow; some infiltrate the soil, and some accumulate in small reservoirs or watersheds. The remaining precipitation (effective precipitation) generates runoff and will flow over the surface to contribute to the formation of the flood discharge. The vegetated soil system represents a key element in flood mitigation, as it can intercept meteoric precipitation through evaporation, leaf transpiration, percolation, surface retention and hypodermic runoff. Part of this volume may reach the main hydrographic network, but this occurs with delayed times compared to the times of surface runoff.



In the study of flood phenomena, the types of processes listed above have different consequences on the hydrological response of the basin under consideration. The basin response time, concentration time, or time of concentration is defined as the time interval between the moment of the onset of the meteorological phenomenon and the arrival of the flood crest at the point defined as the basin closure section. In fact, the basin's surface area, shape and location influence the concentration time and thus the formation of the flood wave.

The calculation that leads to the definition of the flow rate at the closure section is derived from a series of cascading processes with meteoric rain as their starting point (Figure 1). To most realistically determine the design flood event, it is of fundamental importance to assess the precipitation associated with a given probability of occurrence along with the duration of the event relative to the response time of the basin under consideration.

Figure 1: Factors influencing and contributing to flooding flow formation (source: Veneto Region, 2009[2]).

[2] Veneto Region. Hydraulic Compatibility Assessment - Guidelines. Published in 2009 by the Commissario Delegato for the emergency concerning the exceptional weather events of 26 September 2007 that affected part of the Veneto Region.

2.2 RETURN PERIOD

Any phenomenon's return period (T_R)) is defined as the average duration of the period between two events of equal intensity In the case of meteoric events, it is expressed in years and is defined by the following formula:

$$T_R = \frac{1}{1-P} \quad \text{Eq. 1}$$

where P is the probability of failure associated with a characteristic variable (rainfall height, flow rate, draught) of the phenomenon under analysis. Accordingly, the risk of occurrence (R_N) associated with a given event occurring in n years is expressed by:

$$R_N = 1 - \left(\frac{1}{1-T_R}\right)^n \quad \text{Eq. 2}$$

Assuming $T_R = n$, the risk of occurrence does not vary significantly and is 63%.

The return period identified for a given project is of absolute importance as it defines the effectiveness of a given intervention concerning the magnitude of the meteoric phenomenon. The reference value provided for PAT/PATI by DGR 1322 of 10.05.2006 Annexe A for the dimensioning of works to counteract flooding is 50 years. This value may increase in rare cases if the assets to be safeguarded are of particular value.

2.3 CONCENTRATION TIME

The duration of the event is a parameter that influences the peak flow value and the total volume. Since these values do not occur for the same event duration, it is necessary to analyse different precipitation durations to predict the maximum values.

The maximum flow rate generated (Q_{max}) by a basin for a given return period is a function of the precipitation (h_p) that insists on the basin area, which in turn is related to the time of concentration. Consequently, the relationship $Q_{max} = f(h_p(t))$, must be determined, corresponding to each precipitation of duration t the flow rate from which the maximum flow rate can be derived.

The same procedure is followed to determine the maximum volume. In this case, the curve's envelope is calculated instead of deriving the function's maximum value. As several studies have shown, the duration of precipitation that maximises runoff volume is significantly longer than that which maximises peak flow.

It is, therefore, evident that the concentration time, and consequently the duration of the design precipitation, is a determining parameter for the sizing of the works. Different run times must be referred to in the design for the sizing of collectors and reservoir volumes. Consequently, the elaborations to derive such data presuppose the use of appropriate mathematical models and a hydrological study that includes the processes within the basin under study. However, in less complex cases, where soil changes are minor, less complex approaches can be used (see Chapter 3)..

2.4 DESIGN PRECIPITATION

To determine the design flow rates and volumes, it is necessary to calculate the expected precipitation volumes for a given design return period. The design flow rate is then determined through a series of calculations to convert rainwater into runoff and flow to the closure section. The starting precipitation must be referred to as a specific return period associated with duration. Through statistical probabilistic regularisation of annual rainfall maxima recorded by weather stations, it is possible to derive the relationship between rainfall height as a function of return period and duration. These analyses lead to the definition of so-called rainfall possibility curves. The parameters of these curves were identified within the ARPAV study 'Regionalised rainfall analysis for the identification of reference rainfall possibility curves' through regionalised analysis of data from 27 rainfall stations. This report shows the curves expressed with the Italian two-parameter formulation $h = a\,t^n$, where a and n are the parameters of the curve. Furthermore, the coefficients a, b and c of the more general formulation given by the formula $h = \frac{a}{(t+b)^c}\,t$. ARPAV then calculated the coefficients for both expressions for the characteristic time intervals (5', 10', 15' 30', 45', 1 h, 3 h, 6 h, 12 h, 24 h) by dividing the municipalities into homogeneous zones.

Once the probable height for a given duration has been calculated, we calculate the rainfall that contributes to the formation of the flood wave, i.e. net of losses due to interception, infiltration and surface retention. This value of net rainfall height is called effective rainfall. The calculation of effective rainfall can be derived using the runoff coefficient (c) or with Curve Number (CN).

The runoff coefficient is given by the ratio of effective rainfall to total rainfall. The runoff coefficient c thus represents the percentage of falling rainfall that contributes to surface runoff, considering soil and stand type. The F.A.O. carried out a soil classification to derive the runoff coefficient. Therefore, the value of c changes as a function of soil and subsoil. The final value of c, referring to the basin under consideration, is given by the weighted average of c with respect to the relative area over which it lies.

$$c = \Sigma \frac{c_i A_i}{A}^{n} \qquad \text{Eq. 3}$$

For the calculation of effective rainfall using the Curve Number (CN), method, an empirical relationship is used together with the continuity equation. Unlike the runoff coefficient, in this method, the initial losses due to interception and the saturated water content of the soil typical of the soil and its cover are taken into account. Consequently, the value of P_e varies as a function of time, as interception and infiltration losses decrease with increasing time. The following formula gives the value of the effective rainfall P_e by the CN method:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \qquad \text{Eq. 4}$$

where P is the value of the design rainfall height calculated using the LSPP for the area of interest, I_a are the initial losses, and S è il contenuto idrico massimo del terreno saturo. is the maximum water content of the saturated soil. The variables in Eq. 3 are values expressed in mm. The initial loss value is usually given in the range of 5 - 10 % of the maximum water content but can also be expressed directly by a value (e.g. 5 mm is the suggested value in the case of a dense deciduous forest).

S is parameterised through the value of CN according to the following relationship:

$$S = 25{,}4\left(\frac{1000}{CN} - 10\right) \qquad \text{Eq. 5}$$

CN values range from 0 to 100, where the maximum value represents a totally impermeable surface. *CN* is determined by crossing land permeability classes (soil) with land use categories (topsoil). Four soil permeability classes (A, B, C and D) represent the soil's capacity to promote infiltration processes. Class A is where soils can infiltrate water very quickly, while Class D has the worst hydrological characteristics. The following table shows the CN values as a combination of soil and topsoil.

CN parameter values (dimensionless)	**← Hydrological type Soil →**			
↓ Type of use of the territory	**A**	**B**	**C**	**D**
Crops, in the presence of soil conservation practices	62	71	78	81
Crops, in the absence of soil conservation practices	72	81	88	91
Grazing land: bad crops	68	79	86	89
good crops	39	61	74	80
Woods, in the presence of sparse coverage and without undergrowth	45	66	77	83
Woods and forests, in the presence of dense cover and with undergrowth	25	55	70	77
Open spaces with turf over 75% of the area	39	61	74	80
Open spaces with turf between 50 and 75% of the area	49	69	79	84
Open spaces with turf of less than 50% of the area	68	79	86	89
Industrial areas (72% waterproof area)	81	88	91	93
Commercial and industrial areas (85% waterproof area)	89	92	94	95
Residential areas, lots up to 500 m^2 (65% waterproof area)	77	85	90	92
Residential areas, lots of 500 + 1000 m^2 (waterproof area 38%)	61	75	83	87
Residential areas, lots of 1000 + 1500 m^2 (waterproof area 30%)	57	72	81	86
Residential areas, lots of 1500 + 2000 m^2 (waterproof area 25%)	54	70	80	85
Residential areas, lots of 2000 + 5000 m^2 (waterproof area 20%)	51	68	79	84
Residential areas, lots of 5000 + 10000m^2 (12% waterproof area)	46	65	77	82
Parking lots, roofs, highways ...	98	98	98	98
Paved or asphalted roads, equipped with drainage	98	98	98	98
Streets with gravel bed	76	85	89	91
Streets beaten on earth	72	82	87	89

Table 1: the value of parameter CN II as a function of land use and lithology of the area.

The *CN* value shown in the table represents that the humidity conditions before the event under study are average *CN (II)*. Il *CN (I)* on the other hand, is where conditions before the event are relatively dry so that the soil will have a good capacity for absorption and infiltration. In contrast, *CN (III)* represents wet pre-event conditions. The antecedent moisture condition indicator is called *AMC* (Antecedent Moisture Conditions). The *AMC* value is then defined according to the amount of rain that fell on the previous five days (see table below).

Vegetative period	Vegetative rest	AMC
Precipitation height fallen in the five days preceding the event less than 35mm	Precipitation height fallen in the five days preceding the event less than 13mm	I
Height of precipitation falling in the five days preceding the event between 35 and 53mm	Height of precipitation falling in the five days preceding the event between 13 and 28mm	II
Precipitation height fallen in the five days preceding the event greater than 53mm	Precipitation height fallen in the five days preceding the event greater than 28mm	III

Table 2: indicates the soil's AMC (Antecedent Moisture Content) value according to pre-event conditions.

However, the most precautionary value is used for design purposes, namely *AMC (III)*. The following formula is used to change the values of *CN (II)* usually provided by tables (see Table 1) to *CN (III)*:

$$CN\,(III) = \frac{23\,CN\,(II)}{10 + 0.13\,CN\,(II)} \qquad \text{Eq. 6}$$

2.5 THE PROJECT SCOPE: RATIONAL METHOD

Once the runoff times and the value of the effective rainfall have been calculated, it is possible to calculate the flow rate as a function of time for the basin closure section under consideration. Among the different methodologies, that of the rational method is reported. This system is reliable on small basins (< 2-3 km^2) but can also be applied for design purposes to larger basins (up to 50 km^2). The rational method assumes three hypotheses: the rainfall is of constant intensity over the entire basin area, the critical rainfall duration is equal to the basin's runoff time, and the flood hydrogram $(Q = f(t))$ is isosceles triangular in shape with a total duration equal to twice the runoff time. In particular, the rainfall time equal to the concentration time is used because this is the condition in which the flood flow is maximum. The longer the duration of precipitation, the more the intensity decreases. Conversely, if the precipitation time is shorter than the concentration time, only part of the basin area under consideration will contribute to the production of the peak flow.

The final formula for calculating the peak flow rate *(QT)* is:

$$Q_T = \frac{P_e A}{3.6\, t_p} \qquad \text{Eq. 7}$$

where basin area is expressed in km^2, rainfall time in hours, effective rainfall in mm. The result of the flow rate at the peak is then expressed in m^3/s. To the value of the peak flow rate given by Eq.7, the base flow rate must be added if necessary.

3 URBAN RUNOFF AND THE PRINCIPLE OF HYDRAULIC-HYDROLOGICAL INVARIANCE: **Veneto Region Law No. 1322/2006**

Given the progressive increase in impermeable areas caused by the expansion of urban and industrial areas, urban planning instruments and building regulations are obliged to incorporate the hydraulic invariance provisions to prevent and mitigate the phenomena of flooding and hydrogeological instability caused by the most extreme weather events. At the national level, the regulation governing the management of hydrological runoff and water resources is the Consolidation Act on the Environment (Legislative Decree No. 152/2006). In particular, Part III of the text bears the title: 'Regulations on soil protection and combating desertification, water protection from pollution and management of water resources'. Given that the national legislation leaves it to the regions (art. 61) to legislate on this subject, the Veneto region, with resolution no. 2948/2009 issued Annexe A to D.G.R. no. 1322/2006. The annexe sets out the operating methods and technical guidelines for the new hydraulic compatibility assessments for drafting urban planning instruments with regard to hydraulic-hydrological invariance.

In particular, the concept of hydraulic invariance aims to avoid aggravating the conditions of the hydraulic regime in areas where an increase in the sealed surface area is planned, in some cases providing for the construction of suitable infrastructures to compensate for the alteration to the water regime caused by the change in land use. Compensatory measures aim to maintain or at most improve the hydrological-hydraulic response of runoff volumes generated by interventions that increase the impermeable surface of the lot.

Annexe A of the regional resolution provides a dimensional classification of urban interventions based on which to choose the type of hydraulic investigation to be implemented and the consequent types of infrastructure/devices to be adopted. The classification is based on the area for which the land-use change is planned. Each class is assigned a dimensioning criterion to be adopted to limit the runoff generated by the land-use change.

Class	Reference	Intervention classification	Dimensional thresholds	The criterion to be adopted
1	Ordinances	Negligible waterproofing potential	S* < 200 mq	0
2		Modest waterproofing	200 mq < S* < 1.000 mq	1
3	D.G.R. 1322/06	Modest waterproofing potential	1.000 mq < S < 10.000 mq	1
4		Significant potential sealing	10.000 mq < S < 100.000 mq /	2
			S> 100.000 mq e Φ < 0,3	2
5		Marked potential waterproofing	S> 100.000 mq e Φ < 0,3	3

Table 3: Type of criterion to be adopted for calculating hydraulic invariance according to Annexe A of the regional resolution depending on the project's size and the surface sealing rate.

The classes in which the interventions fall describe the steps that must be taken to implement the project:

Class 1: It is sufficient to adopt good construction criteria to reduce impermeable surfaces, such as increasing the infiltration rate in parking areas, providing for the installation of green roofs, etc.

*Class 2: T*he network should be oversized for peak flow transport needs alone by creating compensatory volumes for flood lamination functions. In such cases, exhaust ports should not exceed a diameter of 200 mm.

Class 3: In addition to the dimensioning of the compensatory volumes to be entrusted with the function of laminating the runoff, it is necessary that the drainage spans do not exceed the dimensions of a 200 mm diameter and that the water draughts allowed in the hydrographic network do not exceed one metre.

Class 4: The permissible water draughts in the reservoir and the drainage spans must be sized to ensure that the maximum outflow from the transformed area is maintained at the values before sealing.

Class 5: Submitting a detailed hydrological-hydraulic study to the managing body of the hydrographic network is required. The latter may require modifications or limit the volume or flow values generated.

3.1 THE NEW BUILDING REGULATIONS OF THE MUNICIPALITIES OF SANTORSO AND MARANO VICENTINO

To reduce impacts on soil consumption and consequent alterations to the natural circulation of water, the municipalities of Santorso and Marano Vicentino have adopted new building regulations as part of the BEWARE project. The following is an excerpt from the regulations.

Interventions of new construction, extension, restructuring under Article 10 of Presidential Decree 380/2001 and demolition and reconstruction must provide for:

- a minimum extension of the green filtering surface area equal to 25% of the impermeable surface area of the new building intervention, or an extension of the green filtering surface area at least equal to the existing one for restructuring interventions under Article 10 of Presidential Decree 380/2001 and demolition and reconstruction. A filtering surface is considered to be a green area that is neither above-ground nor below-ground (i.e. a green area superimposed on a slab cannot be considered a filtering surface). The surface mentioned above area must be used so that it does not cause subsoil pollution under regulations in force (Article 39 of the Regional Water Protection Plan, Annexe A3 to Regional Council Resolution No. 107 of 5/11/2009 subsequent amendments and additions).
- compliance with the principle of hydraulic invariance, i.e. the stormwater runoff discharged from urbanised areas into natural or artificial receptors must be kept unchanged; This is achieved through the adoption of systems for the sustainable management of rainwater (acronym SUDS, from the well-known English definition Sustainable Urban Drainage Systems) preferring, where possible, those with a low impact on the landscape, such as depressions and morphological remodelling of the land, rain gardens, dinfiltration trenches, giving priority to those types of intervention that provide for the insertion of vegetation and allow for multifunctional use of the work (creation of green and leisure areas).

The sizing of these structures can be carried out in different ways according to the extension of the intervention, in compliance with the regional indications on the matter and described in the document "Valutazione di compatibilità idraulica - Linee guida" (Hydraulic compatibility assessment - Guidelines) published in 2009 by the Commissario Delegato for the emergency concerning the exceptional meteorological events of 26 September 2007 that hit part of the territory of the Veneto Region.

The following table summarises the criteria for classifying interventions and the criteria to be adopted in measuring measures to maintain hydraulic invariance.

Dimensional thresholds	Criteria to be adopted
$S \leq 1000\ m^2$	Simplified dimensioning mode (described in this regulation)
$S > 1000\ m^2$	Preparation of hydraulic compatibility verification as per regional regulations

Table 4. Criteria to be adopted for the dimensioning of measures to maintain hydraulic invariance. S: reference area for which the change in land use is planned

Simplified dimensioning mode

In the simplified dimensioning mode, rainwater collected from impermeable surfaces cannot be conveyed directly to the drainage network. Still, it must be fed into lamination systems or sustainable rainwater management systems that allow it to be stored, reused and/or infiltrated underground. The dimensioning of systems for maintaining hydraulic invariance in the simplified mode must follow the criteria of Table 5. System type A), which includes measures that ensure the infiltration of rainwater, is preferable to system type B), which only allows for its accumulation and should be used as a priority except in cases where

- the quality of the water to be managed is not compatible with the qualitative protection of the water table; (see art. 39 of the Regional Water Protection Plan, Annexe A3 to Regional Council Resolution no. 107 of 5/11/2009 and subsequent amendments and additions).
- the seepage process may cause slope or subsoil stability problems;
- the infiltration process may interfere with foundations or even the basement floors of existing buildings;
- the site is not suitable for infiltrating rainwater into the soil and surface layers of the subsoil: areas with a sub-surface water table and poorly permeable soils.

Type	Examples	Dimensioning criterion
A) Systems that guarantee the infiltration process	Rain gardens, bioretention areas, permeable bottom rolling basins, drainage trenches, and leaking wells.	Infiltration surface equal to at least 10 % of the impermeable drainage area
B) Storage-only systems	Concrete lamination tanks, underground or above-ground tanks, and lamination basins with impermeable bottoms.	Invadable volume of at least 30 litres per square metre of the impermeable drainage area

Table 5. Criteria for simplified dimensioning of systems to safeguard hydraulic invariance

In the simplified dimensioning mode, the green roof or green roof allows a reduction coefficient K to be applied when calculating the draining impermeable surface area (only for the impermeable surface area covered by the green roof system). K is equal to 0.7 in the case of extensive green roofs and equal to 0.5 in the case of intensive green roofs (thickness of growing substrate greater than 20 cm). The draining impermeable surface area is then calculated as the sum of the impermeable surface area not covered by green roofs, plus the area with green roofs multiplied by the coefficient K.

The area covered by permeable pavement, on the other hand, is not included in the calculation of the impermeable area. In fact, alternative solutions, such as gravel surfaces or permeable paving, that do not compromise the permeability of the soil and, in any case, that guarantee a permeability of at least 2,500 mm/hour (from the technical data sheet provided by the manufacturer of the paving used) are considered filtering.

For interventions involving the reduction of the existing impermeable surface area by at least 50 square metres and its replacement with green filtering surface area or alternative filtering solutions guaranteeing a permeability of at least 2,500 mm/hour, an incentive equal to a 5% increase in volume or a 10% reduction in the construction cost is envisaged.

3.2 DESIGN FLOW RATE AND VOLUME CALCULATION

With the Veneto Region regulations listed above, hydraulic and hydrological invariance must be ensured. The concept of hydraulic invariance has the objective of not increasing peak flow, while hydrological invariance has the objective of not increasing flood volumes. Hydrological invariance is more difficult to achieve and usually requires the design of new infrastructure. In particular, volumes from rainfall can be managed through:

- Water holding volumes: projects aiming at storing and slowly releasing the accumulated volume.
- Retention water volumes: projects that aim to reduce surface runoff by favouring the process of infiltration and evapotranspiration.

The types of projects that can be implemented to achieve hydraulic and hydrological invariance can be summarised and represented by the following figure.

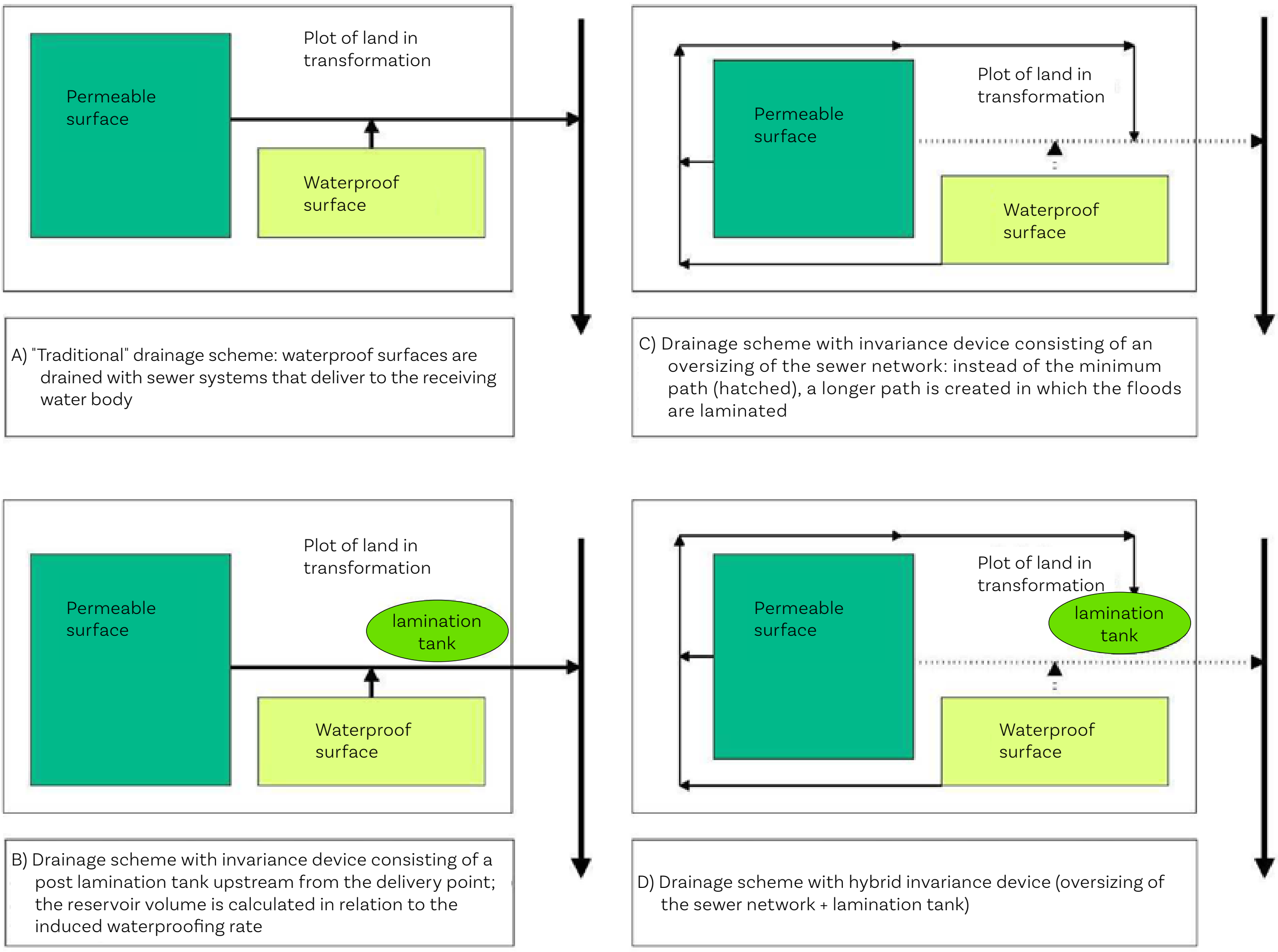


Figure 2: Representation of the types of interventions that can be implemented to maintain hydraulic invariance (source: Veneto Region, 2009[2]).

In particular, the volume of water coming from an area where the degree of waterproofing has increased must be managed by a specific reservoir area that is able to laminate rainwater. Schematically, there will be an area from which the volume of water generated by the precipitation originates and a lamination zone with a defined flood volume (W). $Q_e(t)$ represents the flow produced by the reservoir and which would temporarily enter the designed flood storage area, and $Q_u(t)$ is the outflow from the designed flood storage area.

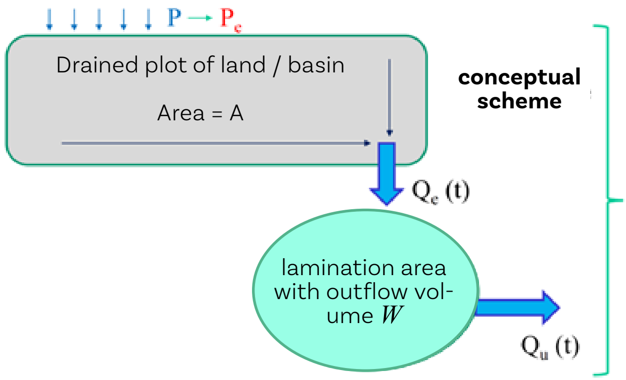


Figure 3: Functional diagram of a runoff lamination zone.

The ratio $\eta = \frac{Q_{u,max)}}{Q_{e,max)}}$ represents the rolling ratio: the lower its value, the greater the efficiency of the rolling system.

This chapter explains two procedures for calculating the inflow rate into a lamination system and its outflow rate from meteoric precipitation. The results of these calculations will be the subsequent input data used in the dimensioning of the works.

3.2.1 Rain only method[3]

The rainfall-only method simplifies the inflow-runoff phenomenon by assuming the reservoir equation instead of the one-dimensional current continuity equation. The calculation of the reservoir volume is based solely on the rainfall possibility curve and the maximum outflow, assumed to be constant over time. The method provides a precautionary result as it overestimates the volume entering the reservoir (it neglects leakage and lamination processes occurring in the drained area).

The entry volume (W_e) is determined by the product of surface area of the subtended basin (A) for the effective rainfall of given return period and duration. The hydrological response of the basin system can be calculated by adopting a runoff coefficient (c). The volume entering the reservoir will, therefore, be equal to:

$$W_e = P_e A = A\, c\, h(t) = A\, c\, a\, t_{cr}^{\ n} \qquad \text{Eq. 8}$$

where a and n are the coefficients of the rainfall possibility signal lines and t_{cr} rrepresents the critical duration of the design rain event. Implicit in this application is the fact that rain lasts longer than the basin's concentration time.

The volume flowing out of the reservoir (Wu) is then defined as constant and calculated as the product of the outflow (Qu, usually equal to the permissible udometric coefficien u) times the critical duration.

$$W_u = Q_u\ t_{cr} \qquad \text{Eq. 9}$$

The ratio will give the height of the water blade exiting the basin to the area of the drainage basin:

$$W_u/A = Q_u\ t_{cr}/A \qquad \text{Eq. 10}$$

And the invaded volume inside the tank will then be the balance between incoming and outgoing volume:

$$W = W_e - W_u \qquad \text{Eq. 11}$$

For hydraulic compatibility, the rainfall-only method identifies the maximum volume (W_{max}), as shown in the graph in Figure 4..

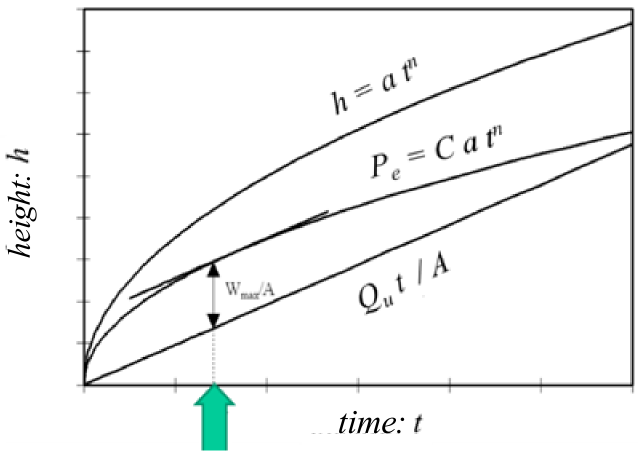


Figure 4: Development of rainfall (h)) and effective rainfall (P_e) within the basin and flow rate at the closure section as a function of time. The arrow indicates the critical dura that maximises the difference between incoming and outgoing volume.

[3] On the Beware website, material section (https://www.lifebeware.eu/materiale/) an online tool for semi-automatic application of the method is available

In mathematical terms, the maximum condition is given by the following formula:

$$W_{max} = A\ c\ a\ t_{cr}^{n} - Q_u\ t_{cr} \qquad \text{Eq. 12}$$

where

$$t_{cr} = \left(\frac{Q_u}{A \cdot c \cdot a \cdot n}\right)^{\frac{1}{n-1}} \qquad \text{Eq. 13}$$

W_{max} is ultimately the volume that the planned work must encompass to ensure hydraulic compatibility.

3.2.2 Kinematic envelope method

The kinematic reservoir method involves applying the rational method for calculating the flow rate using a longer rainfall time (t_c), instead of the concentration time (t_w) maggiore. With this assumption, the flow conditions at the peak will be less critical, but the runoff volumes entering the reservoir will be maximised. The graphic scheme for calculating the storage volume (W) can be represented by Figure 5.

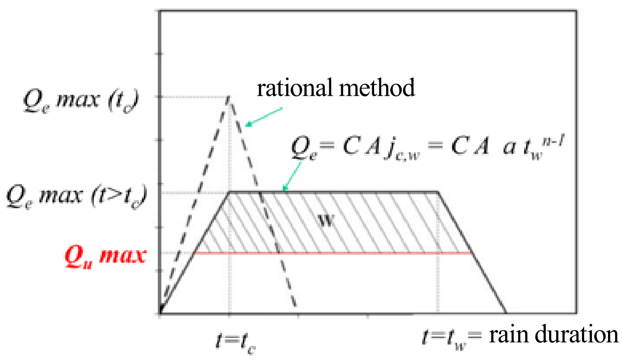


Figure 5: Calculation diagram of the flow rate and inlet volume in a lamination zone

The mathematical solution of the kinematic reservoir to find the maximum reservoir volume condition W will then be given by a system of two equations:

$$\begin{cases} W = A \cdot C \cdot a \cdot t_w^{n} + \dfrac{t_c \cdot Q_u^2 \cdot t_w^{1-n}}{A \cdot C \cdot a} - Q_u \cdot t_w - Q_u \cdot t_c \\ t_w = t_c\ y \end{cases} \qquad \text{Eq. 15}$$

Where y is a function of the rolling ratio

$$\eta = \frac{Q_{u,max)}}{Q_{e,max)}} .$$

For the application of the kinematic method, it is, therefore, necessary to know the value of the characteristic running time of the area under investigation (t_c). Once the input parameters have been entered, the software automatically identifies the value of y that maximises W, thus identifying $Wmax$, i.e. the volume of the planned structure.

3.3 CONCLUDING REMARKS

The volumes calculated using the rainfall-only method and the kinematic reservoir method represent the minimum reservoir volumes to be created to ensure hydraulic invariance in terms of inflow to the main collector. Concerning areas falling under design criterion 1, these do not require the design of a water disposal regulation system. However, the outflow pipe must be protected at the closure section by a clapet-type non-return valve to prevent flow back into the lamination zone. For interventions falling under design criteria 2 and 3, the calculated volumes must convey the outgoing volume to a flow regulation work, e.g. a taxed outlet or a lifting station.

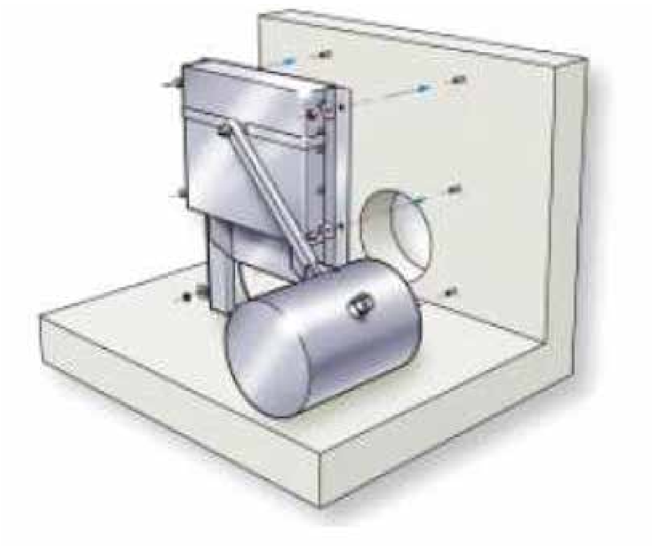


Figure 6: Example of a flow regulation work using a common fee metre (source: Veneto Region, 2009[2])..

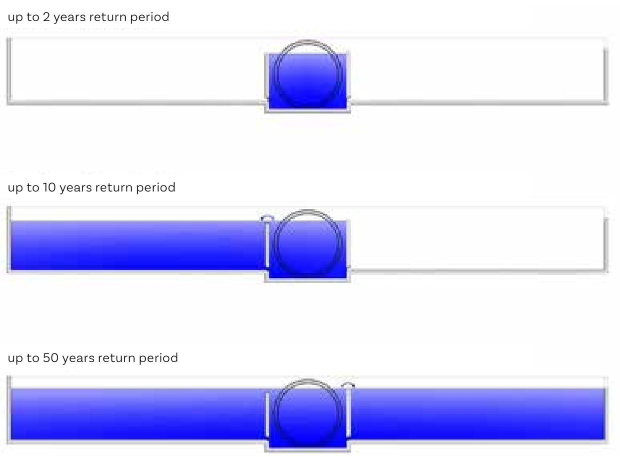


Figure 7: Schematic diagram of the operation of a lamination basin for different return periods of the rain event (source: Veneto Region, 2009[2]).

Given the particular conditions of the Veneto Region territory, if the project falls in an already urbanised area, the maximum outflow rate of the project may generally not exceed 10 litres per second per hectare (permissible udometric coefficient, which may vary depending on the context). In general, the value of the outflow from the study area must be discussed and agreed upon in advance with the relevant offices of the hydrographic network management bodies. These may impose more cautious design conditions if the area falls under particular conditions of hydraulic risk or possible overloading of the receptive hydrographic network. If lamination basins are also adopted, creating three separate compartments, each corresponding to 1/3 of the volume required to cope with runoff volumes with a return period of 50 years is recommended.

Furthermore, Ordinance 1322/06 on hydraulic invariance, in addition to defining the limits of the flow rate exiting a lamination zone, suggests:

- The invariance of the delivery point: it is, in fact, appropriate to discharge the water generated in the same collector as the pre-settlement state so as not to aggravate other water bodies.
- Maintaining elevation: in the past, implementing some projects has led to a change in the area's topography with a consequent change in water runoff. It is, therefore, advisable to limit height variations as much as possible.
- Keeping the drainage capacity of neighbouring areas unchanged: one aspect to be carefully considered is the management of runoff arriving in the intervention area. In some cases, the interventions require the drainage network to be tombed. In such a case, the disposal capacity may be reduced and may result in the areas belonging to the disposal system not being discharged. Therefore, it is advisable to construct a new drainage network if it is impossible to size the tombed network adequately. However, it is recommended that ditches or small conduits be built at the intervention areas' boundary to separate the runoff from the planned new subdivision hydraulically.

Finally, special boundary conditions might make it impossible to maintain the above criteria for hydraulic invariance. In this case, the professional responsible for the allotment must contact the responsible bodies, who will make arrangements for the implementation of the project.

Turning to water management from a qualitative point of view, water cannot, in some cases, be routed directly to the main hydrographic network. Generally, non-runoff rainwater can be drained directly into the existing water supply without treatment. However, the minor drainage network has completely disappeared in dense urban fabrics. Therefore, the planner must identify the effluent's separation according to bio-chemical qualities. The document (Discipline of white water discharges - Venice Lagoon AATO Regulations 29/04/2008 - Art.7 paragraph 5) to which reference is specifically made defines that the discharge of white water to the sewerage system, or mixed, must be envisaged in the event of an exceptional event and in any case this operation must be for the shortest possible time. Therefore, direct qualitative surface runoff to any surface water body is essential. In other cases, the office responsible for the sewage system will give precise design instructions so as not to overload the system (Art. 11 para. 3 of the regulation). In the dimensioning phase, the mandatory limit imposed is equal to the value of the udometric coefficient of 10 l s-1ha-1, which in some urban contexts with strong, impermeable coverage is hardly achievable. However, exceptions may be made by the managing body of the hydrographic network, which will assess each case on a case-by-case basis, providing guidance and permissible limits.

A final indication concerns first rainwater: the regulation defines that for charged runoff water, collection and lamination systems must be designed before being directed to the disposal network. This volume must be at least equal to or greater than the volume of the first rain (Art. 11 para. 2).

4 METHODS FOR SELECTING SUSTAINABLE URBAN DRAINAGE

There are different types of sustainable urban drainage devices for maintaining hydraulic and hydrological invariance. However, each site has unique characteristics that will influence the choice of the most appropriate drainage system.

To identify the most suitable solution for the area of interest, the following must be taken into account:

- Soil characteristics and land use
- Qualitative and quantitative characteristics required
- Aesthetic and ecological characteristics required

Most of the sustainable urban drainage systems are listed in the following table, referring to the surrounding characteristics required for their implementation and effectiveness

Concerning soil characteristics, these may restrict or preclude the use of certain drainage infrastructure. The characteristics that influence the design of drainage systems can be found in Table 6.

Tipologia del sottosuolo	Caratteristiche sistema di drenaggio necessario
Tipologia del sottosuolo	La funzione dei differenti dispositivi è molto dipendente dal sottosuolo del terreno. Molti terreni permeabili possono accrescere alcuni dei processi, ma possono impedirne altri (es. stagni e zone umide) impedendo la ritenzione e la formazione di piscine d'acqua a meno che non si provveda a rendere il terreno impermeabile con l'utilizzo di guaine impermeabili
Distanza minima richiesta della falda acquifera	Dispositivi per l'infiltrazione dovranno posizionarsi ad una idonea altezza dalla falda affinchè il sistema possa operare con efficienza durante precipitazioni eccezionali evitando il rischio di allagamento del sistema di drenaggio dovuto alla saturazione della falda.
Disponibilità di spazi	Alcune tecniche richiedono la necessità di occupare più spazio di altre, sebbene questo non sia necessariamente un impedimento. In zone ad alta densità, ma anche in tutte le zone di sviluppo urgano dove siano presenti ampie zone aperte e campi gioco, si possono usare queste zone per la gestione di eventi estremi.

Table 6: Area characteristics that influence the design of sustainable drainage systems (source: Veneto Region, 2009[2]).

The indications (Annexe A of DGR 1322) define that in soils with high infiltration capacity (filtration coefficient greater than 10-3 m/s and silty fraction less than 5%), where the water table is sufficiently deep, infiltration systems can be realised by resorting to hydraulic invariance for only 50% of the flow increase. The parameters assumed as the basis for dimensioning must be calculated from experimental tests carried out in the field. If the designer wants to increase this capacity up to 75 per cent, the functionality of the system to dispose of excess flow from designed impermeable surfaces must be documented, at least for a return period of 100 years in a hilly environment and 200 years in a lowland environment.

Land use is an important factor in the hydraulic invariance of the hydrological system. In fact, depending on this, it may be necessary to treat the collected water before directing it to the hydrographic network. For areas characterised by medium and high intensity, it may be necessary to treat first rainwater, depending on the final discharge. As far as roads are concerned, the amount of traffic must also be considered. If this is high, an evaluation is required to define the required treatments.

Finally, the drainage system must consider the need to increase the aesthetic and ecological values of the area in which it is placed. However, future maintenance and management must be carefully considered. This must also be established early in the design process.

The Table 7 defines some quality parameters of the most common drainage systems.

		PROCESS				MANAGEMENT			INTENDED USE							FREE SPACE		TYPE OF SOIL		HYDRAULIC RISK		POLLUTION						
Code	DEVICE	Infiltration	Detention / Attenuation	Carriage	Reuse	Local control	Control around	Territorial control	Low density residential	High density residential	Road	Commercial	Industrial	Requalification	Contaminated	Low	High	Impervious	Pervious	Reduction of outflow peaks	Reduction of volume	Reduction of suspended bodies	Reduction of nutrients	Reduction of heavy metals	AESTHETIC VALUE	ECOLOGICAL VALUE	COSTS	MAINTENANCE
D1	Tetti Verdi	●	●		●	●			●	●		●	●	●	●	●	●	●	●	AVERAGE	AVERAGE	HIGH	LOW	AVERAGE	GOOD	GOOD	HIGH	HIGH
D2	Collection tanks		●		●	●			●	●		●		●	●			●	●	HIGH	HIGH	HIGH	LOW	AVERAGE	LOW	HIGH	HIGH	HIGH
D3	Domestic tanks		●		●	●			●	●		●		●	●			●	●	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
D4	Permeable surfaces	●			●	●			●	●		●	●	●	●	●	●	●	●	GOOD	GOOD	HIGH	HIGH	HIGH	LOW	AVERAGE	AVERAGE	AVERAGE
D5	Bioretention systems	●	●			●	●		●	●	●	●	●		●		●	●	●	AVERAGE	AVERAGE	HIGH	LOW	HIGH	AVERAGE	AVERAGE	AVERAGE	HIGH
D6	Infiltration bands	●				●	●		●	●	●	●	●		●		●		●	LOW	LOW	AVERAGE	LOW	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
D7	Infiltration galleries	●	●			●	●		●	●	●	●	●		●	●	●		●	AVERAGE	HIGH	HIGH	AVERAGE	HIGH	LOW	LOW	LOW	AVERAGE
D8	Underground tanks	●	●		●	●	●		●	●	●	●			●	●	●		●	GOOD	GOOD	AVERAGE	LOW	AVERAGE	LOW	AVERAGE	AVERAGE	LOW
D9	Modular geocellular systems	●	●			●	●		●	●		●			●		●	●	●	GOOD	GOOD	LOW	n/a	LOW	LOW	LOW	LOW	LOW
D10	Infiltration basins	●	●				●		●	●	●	●			●		●		●	AVERAGE	GOOD	HIGH	AVERAGE	HIGH	GOOD	LOW	LOW	AVERAGE
D11	Trays	●	●	●		●	●		●	●	●	●	●		●		●	●	●	AVERAGE	AVERAGE	HIGH	LOW	AVERAGE	AVERAGE	AVERAGE	AVERAGE	LOW
D12	Detention basins	●	●				●	●	●	●	●	●	●		●		●	●	●	GOOD	LOW	AVERAGE	LOW	AVERAGE	AVERAGE	LOW	LOW	LOW
D13	Wetlands		●		●		●	●	●		●	●	●		●		●	●	●	GOOD	GOOD	HIGH	AVERAGE	HIGH	GOOD	HIGH	HIGH	HIGH
D14	Ponds		●		●		●	●	●		●	●	●		●		●	●	●	GOOD	LOW	HIGH	AVERAGE	HIGH	GOOD	AVERAGE	AVERAGE	AVERAGE

Table 7: qualitative assessment of processes that are favoured by major urban drainage systems (source: Veneto Region, 2009[2]).

5 SUDS DESCRIPTION AND DESIGN

In this chapter, the different types of SuDS (Sustainable Urban Drainage Systems) are described with their dimensioning, description of the materials used, costs and maintenance required for proper operation. The merits and limitations of each system are also reported, along with the relevant constructional measures. The ultimate goal of designing SuDS systems is to reduce the impact of urban development on the hydrological cycle through technical solutions that maintain or restore the site's original hydrological and hydraulic functions. Therefore, an optimal design of sustainable in-situ management must minimise surface runoff volumes and preserve existing naturally occurring flow paths as far as possible, as required by hydraulic and hydrological invariance regulations.

5.1 ABOVE-GROUND TANKS

Reservoirs allow rainwater falling on roofs and impermeable surfaces (typically collected from the roofs of buildings) to be stored and then reused for non-drinking purposes such as irrigation and water supply for fire-fighting purposes or in more virtuous water management systems, filling toilet cisterns and use in washing machines.

This chapter considers above-ground tanks for storing water for irrigation purposes (garden, vegetable garden). Tanks are usually located outside buildings in the vicinity of outflow pipes from which a certain volume is taken. The runoff mitigation effect is a direct function of the size of the reservoir, and since they are installed outdoors, their capacities are constrained by the available space. They usually do not have a water pumping system and, therefore, have to be positioned lower than the surface that generates the runoff.

Figure 8: examples of rainwater storage tanks placed above ground at the Corte Acquasaliente intervention (for a descriptive video, visit the link https://youtu.be/Owlrip5QYLU).

5.1.1 Dimensioning

The dimensioning of such structures is straightforward by applying the continuity equation. Given the inflow hydrograph (estimated inflow-runoff of the area considered) and the expected outflow hydrograph, the change in the invaded volume is equal to:

$$\Delta W = (Q_E - Q_U)\,\Delta t \qquad \text{Eq. 16}$$

Where Q_E is the flow entering and Q_U the flow leaving in the time interval Δt . A fundamental parameter for the dimensioning of such structures is the design duration of precipitation, on which the potential storage volume depends. Generally speaking, choosing a value of about one hour is a good idea. Alternatively, the rainfall-only or kinematic method, described in Chapter 3, can be used.

Generally speaking, the tank should still have a storage capacity in the range of 30 - 90 l/m^2 of managed impermeable surface area. When the invulnerable volume has been reached, the overflow will come into operation, resulting in the loss of the rolling effect. The connection of the overflow to the drainage structure must, in any case, follow the values prescribed by the regulations regarding outflow. If one tank is insufficient to create a consistent rolling effect, it is possible to install several tanks in series.

5.1.2 Materials and Installation

The shapes of surface tanks are basically of three types: cylinders, parallelepipeds and panettones. The material used is usually non-transparent plastic (UV-resistant) or galvanised steel. Tanks must be treated against algae and mucilage not to compromise the quality of the water collected over time. The accumulable volume of a single tank ranges from 100 to 15,000 l.

As far as installation is concerned, smaller tanks can be placed directly on site. If the volume that can be invaded increases, a foundation structure sized concerning the full-load weight must be designed. Depending on the source (roofs or paving or car parks), water must be treated before it is used. The connection between the tank and the drainage system must be made to not create turbulence in the tank to maintain a continuous and stable flow. A bypass must be activated when the tank is completely full and an overflow for additional safety. The tank must have a non-return valve in the bypass to prevent water from entering the sewerage system. Finally, the tank must be equipped with an opening for inspection and cleaning and have a tap to allow the collected water to be used and the system to be emptied.

The presence of a water treatment system to reduce the coarse component present is essential. If it is to be installed indoors, it is best to set up a water disposal system in case of any spillage/leakage.

Type	Storage volume (l)
Horizontal cylindrical	1000-15000
Vertical cylindrical	200-10000
Panettone	500-14300
Parallelepiped	300-2000

Table 8: Schematic description of the main types of above-ground tanks for storing runoff water.

5.1.3 Costs and maintenance

The report on the costs of interventions carried out within the BEWARE project, and available at this link, analysed 4 sources to indicate the possible range of costs that need to be incurred to realise the different types of intervention. The results obtained for the tanks are reported in Table 9.

The analysis of the information from the different sources led to considering different costs for high-capacity and low-capacity tanks for visible installation in gardens. For the estimation of the small tanks, the values reported by the different sources were taken into account; in particular, the market analysis resulted in the following minimum and maximum values of approximately 0.6€/l and 2.6€/l being estimated. Concerning estimating costs incurred for the construction of large reservoirs, the range of values is consistent across all sources, as reported in Table 9. To summarise, we consider using a price range of between €0.11 and €0.70 per litre capacity for high-capacity tanks and values between €100 and €500 (average value of €300) for low-capacity tanks for visible installation in private gardens.

	Minimum cost	Maximum cost	Average cost
Tank X < 500L	0,6 €/l	2,6 €/l	1,6 €/l
Tank 1,000 < X < 13,000	0,12 €/mq	0,70 €/mq	0,43 €/mq

Table 9: summary of purchase costs (excluding installation and ancillary works) of an above-ground cistern for collecting runoff water..

To these tank purchase costs must be added to installation and any costs arising from ancillary works. These costs normally increase with the size of the tank.

Maintenance is relatively simple, consisting of ordinary and extraordinary tank cleaning. The first will be to check and clean the operation of the inlet filter and that of the pump if installed. The extraordinary one consists of emptying the tank, removing debris, and overhauling the pump impeller, if installed.

5.2 UNDERGROUND TANKS

Underground tanks have the same operating system as above-ground tanks. As the name implies, these reservoirs are positioned below ground level at a depth that usually varies between 2 and 6 metres. The overburden thickness is generally in the range of 2 m. Therefore, as in the previous system, the accumulated volume required to reduce surface runoff is in the range of 30-90 l/m^2 relative to the drainage area.

5.2.1 Dimensioning

The dimensioning of underground tanks is exactly the same as that of above-ground tanks. These tanks' pumping system varies, given their location below ground level. It is conservatively represented by two pumps working in parallel, equipped with inverters. The optimal soils for installation are clay soils due to the ease of excavation. They are contraindicated in unstable terrain: landslides, swampy or that do not allow deep drainage. In addition, the tank should not be placed in areas with a steep slope or where there is intense surface runoff. As mentioned in the previous chapter, if the intercepted water comes from raised roofs, it does not need to be treated. If, on the other hand, runoff water is expected to enter, a treatment system must be provided at least for the volume of first rainwater. Finally, to always have a safety margin, a drainage well must be provided that is activated in the event of an overload of the system.

5.2.2 Materials and Installation

The types of underground tanks fall into two broad categories according to the construction material used: plastic and concrete. The former are divided into three types and are similar to those installed above ground. Concrete ones are divided into prefabricated (modules built and then transported) or in-situ.

The following table shows the most frequently used types of tanks with an associated invasible volume range.

Material	Type and form	Storage volume (l)
Polyethene (plastic material)	Panettone	750 - 2,000
	Horizontal or vertical cylindrical	2,000 - 3,000
	Composed of modular elements	10,000 - 35,000
Calcestruzzo	Prefabricated	1,000 - 30,000
	Laying with reinforcement	8,000 - 50,000

Table 10: types of underground cisterns for rainwater storage.

The process of burying the tank is a fundamental aspect for properly functioning the water recovery system. It is, therefore, necessary to take into account the characteristics of the terrain on which the pool is installed, as well as the intended use of the surface covering it (walkable or driveable). A distance of 30 cm more than the dimensions of the tank must be calculated for the excavation. Depending on the type of soil, different excavation angles must be observed. Generally speaking, for soft soils, the angle should be less than 45°, while for medium-hard soils, less than 60° and rock excavations values of 80° can be achieved.

After excavation, the tank must be placed perfectly level and above 15 to 20 cm of non-recycled sand. Finally, the stability of the ground on which it rests must be checked, considering the tank's fully-loaded weight. The ground must be sufficiently solid. Otherwise, a foundation will have to be built (especially if the water table is shallow). In the case of clay soils, creating an adequate drainage system at the bottom of the pit is a good idea to facilitate rapid runoff. If an installation is planned on a slope, it is a good idea to consider designing concrete retaining walls to increase stability. Once the tank is in place, the filling must be carried out in successive layers so that all spaces are evenly filled. When filling the pit, it is a good idea also to fill the tank to prevent the earth from generating excessive compression and damaging the tank. It is advisable to leave it full for a couple of days until the soil has completely settled around it. Once backfilling is complete, the surface may be walkable or driveable, but take care not to encumber the inspection cover. The excavations must be at least one metre apart for systems consisting of a series of tanks. If this is not possible, a load-bearing wall of at least 20 cm must be built.

5.2.3 Costs and maintenance

Polyethene tanks have a cost per litre of the potted volume of 0.4 - 0.5 € for tanks between 1,200 and 5,000 l. In the same size range, precast concrete tanks cost 0.31 - 0.71 €/l. These values are very similar to those for above-ground tanks, but in this case, burying costs must be added, which are approximately 20 €/l. Finally, for water storage systems made of in-situ concrete, costs range between 0.34 - 0.92 €/l for tanks between 8,000 - 30,000 l.

In addition to these costs, ordinary and extraordinary maintenance must be provided. The first consists of checking the proper functioning of the pumps and the overflow system and assessing the amount of sediment in the tank. Extraordinary maintenance will overhaul the pumps, empty the tanks and collect the solid material accumulated in the tank.

For example, a detached house that wants to equip itself with a rainwater recovery system needs to invest an amount of approximately €4,000 to €5,000. However, even though this expense may seem onerous, the long-term economic and ecological benefits are undisputed.

5.3 DRYWELLS

The intervention consists of creating a hole that is subsequently filled with inert material characterised by a large volume of voids. They are very useful in the urban context due to their small size and where the soil is not very permeable. They require a very small amount of space for their construction, equal to about 1% of the drained area. The mechanism of operation is to collect and facilitate the infiltration process of rainwater. However, runoff water must be lightly polluted. Otherwise, it must be treated beforehand.

Figure 9: installation of the leaking well carried out within the framework of the LIFE BEWARE project at Corte Acquasaliente (for more pictures of the intervention, watch the video at the link https://youtu.be/OwIrip5QYLU).

5.3.1 Dimensioning

The dimensioning parameters for drywells are depth and diameter. The calculation is made by setting the number of works that serve a given drained area. The infiltration's outflow rate (Q_u) can be calculated from the following equation.

$$Q_u = \frac{K}{2} \left(\frac{L+z}{L+z/2} \right) A_f \qquad \text{Eq. 17}$$

Where K is the permeability under unsaturated conditions and thus in eq. 16 is halved, z the height of the drainage layer of the well, L the difference in height between the bottom of the well and the water table and A_f the effective horizontal surface area (that of a ring of width z/2). As a precaution, the drainage capacity of the bottom of the well is not considered as it tends to clog easily.

In addition to the function of augmenting the infiltration process, drywells can also store water by playing a role, albeit a small one, in laminating runoff, depending on their storage capacity.

5.3.2 Materials and Installation

The drywells currently on the market consist of stackable modular systems formed by fenestrated rings in vibrated concrete. The most common diameters on the market vary between 100 and 200 cm for a height of 15 to 50 cm. The total reservoir capacity varies between 300 and 9,000 litres.

In Table 11, the volumes that can be drained by drywells and the associated drainage areas that they can serve are shown. The height of the well remains constant at about 2 to 3 metres.

Diameter (cm)	Invariable volume (l)	Drainage area served (m^2) and soil permeability		
		Low	Media	High
100	1576 - 2358	175 - 260	280 - 420	700 - 1045
125	2452 - 3678	315 - 475	510 - 760	1270 - 1900
150	3532 - 5298	390 - 590	630 - 940	1570 - 2350
200	6280 - 9420	690 - 1050	1100 - 1675	2740 - 4180

Table 11: calculation of the draining area served by a dispersing well according to its diameter and type of terrain

The positioning of the well is crucial to its proper functioning. Depending on the soil type, the excavation walls can be of different inclinations (see the previous chapter on installing underground tanks). A layer of sand and crushed stone is placed at the bottom of the excavation for a recommended thickness of 40 to 50 cm. The rings constituting the shaft must be laid on each other dry without sealing. The well must be connected to the drainage system at an elevation of -0.5 m above ground level to prevent freezing and make the well driveable. Around the cement rings, crushed stone is placed for a horizontal thickness of 0.8 - 1.0 m, increasing grain size towards the centre. It is advisable to lay a layer of 'nonwoven fabric' between the gravel and the soil to avoid possible occlusions.

In addition, the water table must be at a minimum distance of 2 m from the bottom of the well, and there must be no aquifers for drinking water supply nearby (it is good practice to place them at least 50 m from drinking water sources). If placed in series, these must be spaced at least four times the diameter of the well to maintain adequate system efficiency.

5.3.3 Costs and maintenance

The report on the costs of interventions carried out within the BEWARE project, and available at this link, analysed 4 sources to indicate the possible range of costs that need to be incurred to realise the different types of intervention. The results obtained for leaky wells show that the supply and installation of a leaky well costs between €1,000 and €2,000, depending on the size of the well and the depth reached. To these costs, it is necessary to add the cost of the geotechnical analysis, the design, any ancillary works such as gutters, pipes and sumps, and the cost of any disposal of waste material.

If an average cost for accessory items necessary for the operation of the facility is also factored into the cost, the cost range for a single leakage well is on average €2,000 to €4,000, with an average cost of €3,000..

	Minimum cost	Maximum cost	Average cost
Total expenditure	0.77 €/l	1.32 €/l	1,6 €/l
Expenditure without ancillary costs	0.18 €/l	0.78 €/l	0.48 €/l

Table 12: summary of costs for constructing a dispersing well.

Regarding maintenance, drywells requires inspection every 6 to 12 months and, if necessary, emptying the solid component accumulated at the bottom.

5.4 PERVIOUS PAVEMENT

Drainage pavements are surfaces containing voids that allow a high filtering capacity. They are combined with a highly draining underlying surface such as coarse sands or crushed stone to decrease surface runoff and retain dissolved pollutants. This system has a dual function: the lamination of runoff due to the pore volume in the pavement layer and the increased infiltration capacity. Paving stones also reduce the velocities of surface runoff by reducing the possibility of localised erosive phenomena.

The most common use is in car parks and walkways, especially in areas where no other rainwater management system can be installed due to space constraints. The placement of pervious pavement in cycle paths, dirt roads, and paths in parks and gardens is also widespread. Pervious pavement can reduce rainwater channel size because runoff is intercepted quickly.

Figure 10: Drainage pavement was constructed as part of the LIFE BEWARE project interventions (further details at the link: https://youtu.be/lARDtC1_kQE).

5.4.1 Dimensioning

The infiltration capacities of drainage pavements are significantly higher than the highest observed rainfall intensities, so the choice of type is not a limiting factor. Generally, a reliable infiltration value for new floors can be around 2,500 mm/h. Several studies, however, recommend that an infiltration rate through the drainage surface reduced by 10% be considered in the design to account for the effect of clogging over a system life of 20 years without maintenance. Such pavements can, therefore, handle rainfall of any intensity. What makes the difference is the soil's infiltration rate and the underlying layer of sand and/or crushed stone. To calculate the rolling process, the percentage of voids in this layer must be calculated: sand has a porosity of 0.2 - 0.3, while fine gravel has a porosity of 0.3 - 0.4. Regarding the infiltration process, reference must be made to infiltration coefficients that can be derived from literature values or field tests.

Drainage pavements can also be dimensioned to handle rainwater falling directly onto their surface and surface runoff from adjacent surfaces. In this case, the drainage layer of the pavement should be sized according to the volume of water to be handled using the methods described in Chapter 3.

5.4.2 Materials and Installation

Concerning materials, drainage pavements can be divided into two types according to the covering materials:

- Permeable pavements are surfaces made up of elements that are per se impermeable but contain hollow spaces through which drainage is permitted. This usually occurs between joints or gaps between blocks.

- Porous floorings: these are surfaces composed of factually porous elements that allow water to pass through. Examples are grass or gravel reinforced surfaces, porous concrete and asphalt.

The main materials used for porous flooring are, therefore:

- Modular permeable block paving: the most common material for this system is concrete, but vitrified clay bricks, natural stone, etc., can also be used. Important is the presence of enlarged joints filled with gravel to facilitate the passage of water. These pavements are excellent for driveways, walkways and roads with little traffic. The underlying layers should be composed in a sequence of two types of gravel and a layer of sand.

- Porous asphalt and porous concrete: Porous asphalt can be used as a stand-alone surface or to provide a resilient base for permeable concrete block surfaces where there is heavy traffic. In addition, the porosity of the asphalt reduces traffic noise.

  On the other hand, porous concrete is recommended in areas with heavy truck traffic.

- Reinforced lawns: the system consists of lawns that are reinforced through the use of plastic or concrete grids filled with material on which herbaceous species can grow. This cover is suitable for locations with limited traffic, preferably for seasonal use. This gives the herbaceous layer time to grow. Reinforced lawns are excellent for parking areas of infrequently used structures (e.g. sports facilities), private driveways and schools. Finally, it is important that the implementation does not lead to increased soil compaction and that the grass is suitable for the local climate.

- Porous block paving: the paving is made of blocks (concrete, natural or recycled elements) characterised by many pores that allow water to drain away. However, the various waterproof floor coverings are the least effective as the pores can become occluded over time, reducing infiltration capacity. Such pavements should, therefore, be used in areas where the presence of sediment is limited.

5.4.3 Costs and maintenance

The report on the costs of interventions carried out within the BEWARE project, and available at this link, analysed 4 sources to indicate the possible range of costs that need to be incurred to realise the different types of intervention. The results obtained show that the costs of creating pervious pavement range on average between 20-40 €/sqm for the cheapest solutions (plastic or concrete grassed gratings), up to 100-150 €/sqm for the best performing solutions (including installation).

The maintenance of drainage pavements is practically absent. An exception are reinforced lawn areas for which grass mowing may be necessary during the growing season.

5.5 GREEN ROOFS

These are multilayer vegetated structures built on the flat or sloping roofs of buildings or other infrastructures (canopies, garages, carports) to regulate rainwater that falls on top of the roofs and improve the quality of the water output. They also increase the structure's insulation, resulting in energy savings and the house's aesthetic value. These structures are composed of layers with different functions: waterproofing, storage, drainage and substrate for developing herbaceous vegetation. According to UNI 11235, a green roof or green roof is defined as any structure that is not in contact with the natural ground. The benefits of a green roof are many, such as treatment and fixation of particulate matter in the atmosphere, reduction of peak water runoff, mitigation of climatic extremes in buildings and reduction of noise pollution.

Green roofs retain and store rainwater, returning it to the atmosphere through evaporation and leaf transpiration. This way, the structure benefits the heat island phenomenon typical of the highly urbanised environment. Excess water is drained into the water network through gutters. Green roofs can be installed on any roof, such as urban buildings, industrial buildings or canopies.

Figure 11: Example of buildings with green roofs.

Green roofs are divided into two macro-categories:

- Extensive green roofs: these are installations often made on the roofs of industrial and commercial buildings, replacing the classic gravel or other material roofs. The purpose of this cover is to protect the waterproof layer, insulating the rooms below. The vegetation cover type requires little maintenance. The supply of water and nutrients occurs naturally without human intervention. Fast-growing but frost-resistant and dry-weather-resistant herbaceous species will be planted for this type of cover. The Sedum genus is widespread because it has shallow rooting and is resistant to extreme climatic conditions. Given the herbaceous vegetation cover, the total thickness of the layering usually never exceeds 15 cm and the substrate used is composed of mineral elements.
- Intensive green roofs are usually used to create real gardens on roofs and are usually usable and usable by users. In contrast to the previous type, various plant species and associations can be used, from turf to tree planting. However, this more aesthetically pleasing type requires constant maintenance over time. Therefore, the substrate's thickness varies depending on the rooting depth of the species, from 15 cm to 150 cm. To avoid water stress phenomena, an irrigation system is installed in these roofs to prevent the plants from dying.

Figure 12: left, extensive type green roofs with Sedum spp., right, intensive type green roofs with vegetable cultivation (source: Andri S., Sauli G., 2012[3]).

[3] Andri S., Sauli G. (2012). Green roofs: system performance and ecological value. ISPRA, Manuals and Guidelines, 78.

5.5.1 Dimensioning

A green roof structure commonly consists of a series of layers:

- Load-bearing structural element
- Water seal element
- Root protection element
- Mechanical protection element
- Water storage element
- Draining element
- Filter element
- Cultural layer
- Vegetation layer

Consequently, design criteria must take several factors into account:

- The objectives of the roofing and functions must be usability, aesthetic and energy performance improvement of the building and environmental compensation.
- The climate of the area where the green roof must be installed must be carefully analysed. Factors such as the amount of solar radiation, rainfall regime, temperature and air quality must be considered at the design stage.
- The agents that interact with the structure must be analysed. Examples are water, biological, chemical, and physical agents, i.e. permanent and variable loads related to the type of construction.
- The requirements of the green roof to be installed. In particular, consideration must be given to the agronomic, drainage and aeration capacity of the drainage layer, water storage capacity, aeration capacity of the crop layer, and resistance to biological attacks.

In particular, the UNI 11235:2007 standard regulates the minimum thickness of the cultural layer to be used at the design stage for green roofs. For the following vegetation types, a minimum depth of:

- Genus Sedum and small herbaceous perennials, 8 cm
- Large herbaceous perennials, 10 cm
- Turf and small ground cover shrubs, 15 cm
- Small shrubs, 20 cm
- Large shrubs and small trees, 30 cm
- Size III trees, 50 cm
- Size II trees, 80 cm
- Size I trees, 100 cm

From the point of view of mitigating rainfall phenomena, green roofs can reproduce various hydrological processes that can be associated with those of natural soils. Given the limited thickness of the roof, green roofing is very effective in mitigating short-term phenomena. Still, it has little effect on prolonged phenomena that saturate the roof's storage capacity before the rainfall peak occurs. However, it has been shown that in temperate climates, they can halve the annual volumes generated by runoff.

However, the drainage system must be very efficient, i.e. it must fulfil the functions of capturing and draining rainwater without flooding and seepage. The runoff coefficient (percentage of water leaving the system compared to water received) is used to quantify peak runoff reduction in high-intensity, short-duration phenomena. It calculates the maximum amount of water discharged from an enclosure to size the pipes for its outflow following the procedure identified in UNI EN 12056-3:2001. In cases where the water authorities define a maximum flow limit, the calculation can be carried out using the rational method. Andri S., Sauli G., 2012[4] report runoff coefficient values ranging from 0.15 and 0.50 for different types of green roofs.

[4] Andri S., Sauli G. (2012). Green roofs: system performance and ecological value. ISPRA, Manuals and Guidelines, 78.

5.5.2 Materials and Installation

The materials used for the two types of green roofs are practically the same. What varies is the thickness of the substrate. The series of layers that make up a green roof is shown in the following figure.

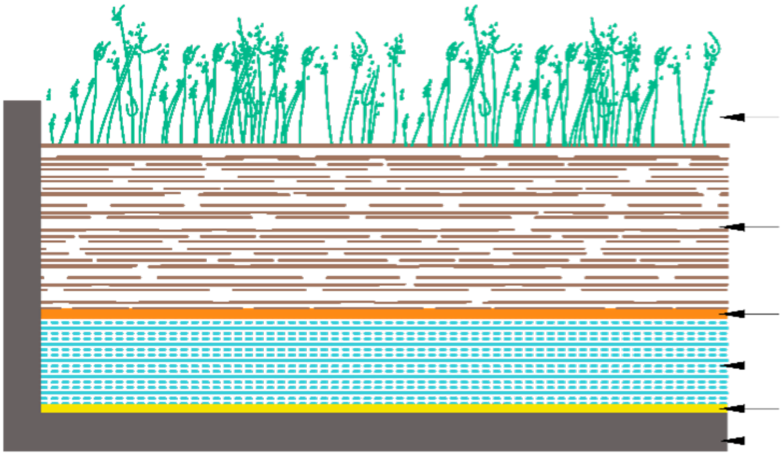


Figure 13: Typical layering used in constructing a green roof.

The load-bearing element, i.e. the support surface of the entire green roof, must be dimensioned to support the weight of the different layers. To this must be added the weight of water retained by the soil. Current legislation indicates the materials that can be used to make such elements. The static loads that can result from extensive roofing are in the range of 220 - 400 kg/m^2, while intensive roofing can reach 450 - 1,500 kg/m^2.

A sealing element is placed above the load-bearing element to waterproof the load-bearing surface and prevent seepage. The root protection element can be placed on top of the waterproofing layer or be integrated with the previous one. Commonly used products are bituminous membranes, synthetic membranes made of polyolefin alloys or plastics. As far as laying is concerned, the floor must not have any protrusions or hollows not to impair its functionality.

A root inhibitor layer (which may already be incorporated into the previous one) is placed on top. The function is to limit root propagation in the vertical direction. This layer's action is mechanical (anti-radiation) and bio-chemical (against the action of micro-organisms).

The mechanical protection element is then positioned. This must withstand the action of static and dynamic loads while protecting the sealing and root-resistant layer. The materials used are usually geosynthetic materials (geotextiles, geotextiles, geocomposites) or polystyrene panels. These materials cannot in any way constitute the root inhibitor layer.

Since there is no subsoil to which the water can flow, and the vegetation substrate is thin, it is necessary to provide a drainage and water storage layer activated in the event of heavy rainfall. Furthermore, the draining layer is necessary to avoid water stagnation and root asphyxia with possible plant death. Almost all cases, the water storage element is integrated into the drainage system to act as a water accumulator for the vegetation. The materials used are granular aggregates (volcanic lapilli, pumice, perlite, expanded clay, expanded slate, crushed bricks and perlite) or prefabricated elements (geo-mats and geo-nets). The volume that these materials can hold depends on their porosity.

Above this layer, the filter element is placed, whose purpose is to prevent the diffusion of solid particles into the drainage and storage layer. To function properly, this layer must have 10 times the permeability of the cultivation layer. In fact, one of the causes of failure of green roofs is caused by clogging of the drainage layer. For this reason, the characteristics of the drainage element must also be defined based on the granulometry of the soil used to form an 'inverted filter' within the soil to prevent the migration of fine particles or clogging of the filter. This layer can be made from natural aggregates or geosynthetics (nonwoven or woven geotextiles). This element can support the root system by ensuring greater stability of the vegetative substrate.

Finally, the cultural layer is placed, which is essential for the vegetative layer's planting, rooting and growth. The minimum thicknesses of this layer are given in UNI 11235:2007. The thicknesses, however, must be weighted and possibly increased depending on the load-bearing layer's exposure, anemometry and slope. The cultural layer is a mix of mineral and organic matter that must be appropriate for the type of species planted. Once the vegetative layer is complete, the plant species are planted and watered to encourage rooting and growth.

5.5.3 Costs and maintenance

The report on the costs of interventions carried out within the BEWARE project, and available at this link, analysed 4 sources to indicate the possible range of costs that need to be incurred to realise the different types of intervention. The results show that an average of 70 €/m2 (extensive economical systems) to 300 €/m 2 (intensive systems) is spent on the supply and installation of a green roof system. The cost ranges identified for the two main types of green roofs are shown in Table 13.

	Minimum cost	Maximum cost	Average cost
Extensive green roofs	70 €/m^2	140 €/m^2	105 €/m^2
Intensive green roofs	130 €/m^2	300 €/m^2	215 €/m^2

Tabella 13: riassunto dei costi per la realizzazione di aree a verde pensile.

The maintenance to be carried out on the green roof concerns the vegetation layer or other parts of the structure and, in particular, the rainwater drainage system and the sealing element: this consists of an inspection of the drainage terminals and, if necessary, cleaning of these elements; this is an operation to be carried out annually and before the winter season.

The maintenance of vegetation concerns the need to intervene with irrigation, fertilisation, weed removal, pruning for aesthetic and/or containment purposes, phytosanitary treatments, and mowing. Extraordinary maintenance may also be necessary in the event of irreparable damage to the entire system, such as the outbreak of disease or particularly adverse weather events. Maintenance is practically non-existent for extensive green roofs. At the same time, it plays an important role for intensive green roofs, depending on the species planted and whether an irrigation system is present.

5.6 DINFILTRATION TRENCHES

Drainage trenches are structures very similar to drainage ditches, but these are filled with inert material such as stones, sand or porous material. A drainage pipe can be installed at the bottom to remove accumulated water quickly. They can also provide a vegetation cover. These structures act as natural 'reservoirs' and, simultaneously, increase the infiltration capacity of the soil and groundwater recharge. In addition, if a certain slope is given to the bottom, they can direct the collected water to the drainage network or to a reservoir area. Trenches can increase water quality by decreasing the presence of pollutants, the suspended component and by degrading the bacterial component. These structures are usually built in large commercial areas or in medium- to high-density residential areas.

They can be placed in enclosed spaces with low surface requirements; as a rule, an impermeable surface generating runoff can be managed by a filter trench area of 10 per cent in size. The maintenance of these structures is minimal, and if grass cover is present, it must be mowed once or twice a year.

However, this device is unsuitable for karstic soils unless careful geological and geotechnical investigations are carried out in strongly clayey and compacted soils due to their impermeability. In addition, there is the risk of blockages in connection systems due to the presence of sediment. Finally, if the water originates from car parks or highly residential areas, there is the risk of oily substances seeping in (in which case a runoff treatment system equal to the volume of first rain must be provided).

Figure 14: in the foreground, the drainage trench realised in the Via dei Prati intervention (Santorso - more information and pictures at the link https://youtu.be/o-b_mHvysEM).

5.6.1 Dimensioning

The volume of water that a drainage trench can handle depends on the porosity of the materials used for construction and the structure's elevation. The water is dispersed through infiltration, accumulated between the coarse component (rubble) and in the concave section off the surface. The infiltrated water flow rate of the soil. To prevent the overflow of accumulated water, a central perforated pipe (minimum diameter DN 200) should be installed. The holes in the duct are at least 20 mm in diameter and at least 40 per running metre. The average width of the trenches is 60 cm with a depth of 120 cm. The methods described in Chapter 3 can be used to calculate the volume of design water to be divided between the infiltrated fraction and the fraction accumulated in the drainage layer and the surface depression. For safety purposes, the fraction of infiltrated water can be excluded from the calculation.

5.6.2 Materials and Installation

To construct filter trenches, the soil must be excavated according to the design dimension. Then, a geotextile layer is laid on the walls and bottom to prevent it from being clogged by fine particles. We continue with the backfilling of the bottom with washed gravel and then to the placement of the perforated central drainage pipe, which is also wrapped in a geotextile layer. It is backfilled with washed gravel up to half the depth of the excavation and finished by covering up to ground level with the previously excavated soil (this, however, is suitably mixed with sand and organic matter to increase its porosity and drainage capacity). Such devices are suitable for flat areas, while for sloping areas, their accumulation function is limited by the area's topography.

The shapes of drainage trenches and the materials usually used for their construction are given in Table 14 but may vary depending on the quantities of water they have to handle.

Type	Excavation section	Minor base [m]	Depth [m]	Profondità [m]	Height of gravel from bottom [m]	Permeable soil layer height [m]
Filter trenches with soil vegetated by herbaceous species with high aesthetic value	Angle-head	0.8	2.0	1.3	0.65	0.65
Filter trenches with soil vegetated by rustic herbaceous species	Angle-head	0.8	2.0	1.3	0.65	0.65
Soil and plant-free filter trenches	Angle-head or rectangular	0.8	2.0	1.3	1.3	Absent soil

Table 14: types of filter trenches for runoff water management.

5.6.3 Costs and maintenance

A literature search revealed the implementation and maintenance costs in the following table.

Type	Implementation cost [€/m]	Maintenance cost [€/m]
Filter trenches with soil vegetated by herbaceous species with high aesthetic value	117-119	20-40
Filter trenches with soil vegetated by rustic herba-ceous species	81-93	10-20
Soil and plant-free filter trenches	44-53	2-3

Table 15: Unit cost for construction and maintenance of filter trenches.

5.7 RAIN GARDENS

Rain gardens are vegetated structures with ornamental plants with high permeability and depression for the accumulation of runoff from surrounding impermeable surfaces (roads, pavements, car parks). They collect runoff, facilitate its accumulation and infiltration into the ground, and promote water filtration to improve water quality by controlling water-borne fine sediment particles and pollutants. Infiltration can be increased by adding sandy material in the cultivation layer (up to 50%), possibly supplemented with vegetable compost (20-30%), which ensures vegetation maintenance over time without fertilisation and a good soil structure, ensuring high porosity and water retention capacity. Two main types can be distinguished: the under-drained, which are equipped with drainage pipes discharging directly to the sewage system and waterproofing membranes that isolate the system from the subsurface soil (an advisable choice in the presence of a surface water table or in the case of high pollutant loads), and the self-contained, which allow water to infiltrate into the subsurface and recharge the water table. Plant selection should be made by choosing species resistant to water stress and short periods of submergence. Furthermore, it would be preferable to use plants that flower at different times to create a long flowering season and to mix heights, shapes and various textures to give depth and shape to the green area.

Rain gardens should be built in areas with high permeability (at least 13 mm/h) to be effective. The ideal topography is flat, while for sloping areas, the construction costs are more important due to the need for larger excavations.

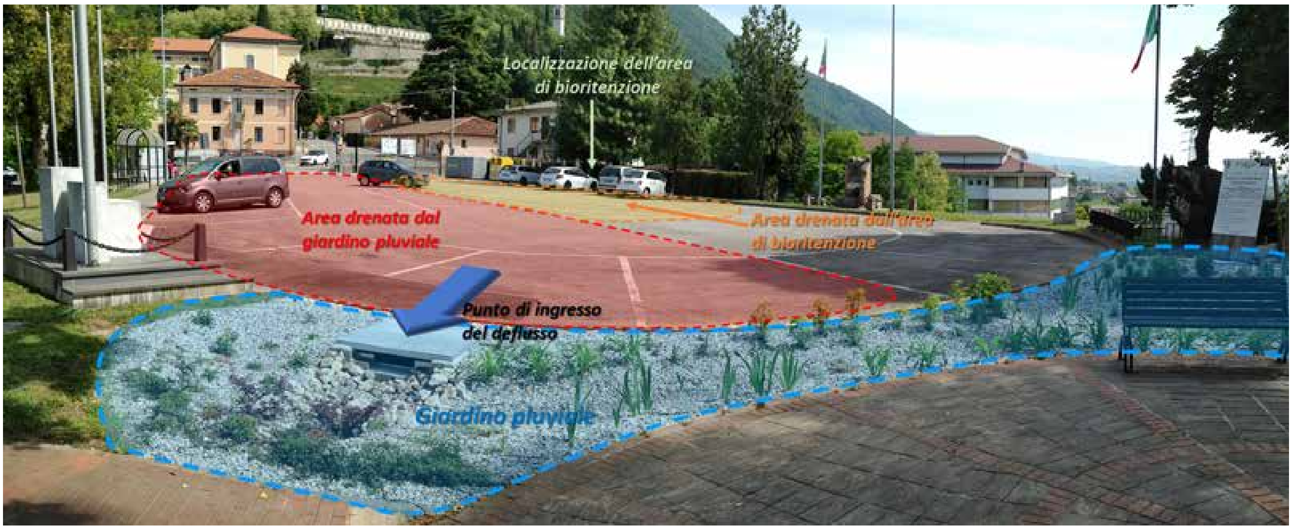


Figure 15. The garden was created as part of the LIFE BEWARE project in Piazza della Libertà (Santorso - more information and pictures at https://youtu.be/FFd24MyYfus).

5.7.1 Dimensioning

The dimensioning of these structures is generally carried out by solving the continuity equation, setting up the infiltrated volume, the outflow law that governs the works in charge of discharging the reservoir (in the case of excessive water volumes) and the reservoir law that depends on the project topography. Alternatively, it is possible to calculate the volume to be managed using the methods described in Chapter 3 (rainfall-only method, kinematic overflow method). Based on this value, it will be possible to size the surface area, thickness and stratigraphy of the rain garden, ensuring that the sum of the storage capacity of the different layers comprising it (subsurface draining layer, growing layer and surface flooding layer) is at least equal to the water volume to be managed.

5.7.2 Materials and Installation

As far as construction is concerned, if the soil drains sufficiently, the land is excavated, shaping the area to define the designed investable volume. If the subsurface soil has a low infiltration capacity, or if it is desired to increase the volume that the system can accumulate, a subsurface drainage layer made of stones or pebbles can be provided. As mentioned above, the cultivation layer is generally created by adding sandy material (up to 50%) and vegetable compost (20-30%) to the original soil. Lastly, the choice of vegetation must include species (usually herbaceous perennials and shrubs) suited to the climatic conditions in which they are inserted and tolerant to flooding and more or less prolonged periods of drought. To limit evaporation and combat weed growth, it is advisable to cover the area with a mulching layer.

A rough dimensioning of the rain garden can be obtained by multiplying the coefficients of Table 16 by the value of the impermeable surface area managed by the garden. The coefficients are a function of the soil type and the depth of the floodable upper part of the rain garden itself.

When designing a rain garden, it is always a good idea to provide an overflow device that conveys unmanaged water to the drainage network.

	Depth of rain garden		
SOIL TYPE	*8-13 cm*	*13 -18 cm*	*> 18 cm*
Sandy	0,19	0,15	0,08
Loam	0,34	0,25	0,16
Clayey	0,43	0,32	0,20

Table 16: calculation coefficient for dimensioning the surface area of a rain garden according to the area served, soil type and depth of the rain garden.

5.7.3 Costs and maintenance

The report on the costs of interventions carried out within the BEWARE project, and available at this link, analysed 4 sources to indicate the possible range of costs that need to be incurred to realise the different types of intervention. The results obtained for rain gardens show a cost range from 38 €/sqm to 242 €/sqm (Table 19).

	Minimum cost	**Maximum cost**	**Average cost**
Self-built rain garden (material only)	38 €/mq	120 €/mq	80 €/mq
Rain garden by a professional	110 €/mq	242 €/mq	175 €/mq

Table 17: summary of the unit cost of creating a rain garden (material cost and cost per complete intervention).

Maintenance work is entirely analogous to that required to maintain a flower bed and consists mainly of cutting and removing dry matter and replacing dead plants if necessary. In the first year, irrigation can be provided during summer to encourage the seedlings to take root. Finally, periodic inspection and cleaning of runoff water conveyance systems must be provided to avoid blockages and malfunctions.

5.8 DETENTION AND RETENTION BASINS

They are structures for managing runoff from the hydrographic network or a specific area. They are generally built near watercourses or other water bodies to store runoff water for a limited period of time. Detention ponds are also called 'dry ponds' because they are mostly dry. In its basic form, a detention basin has a great capacity to manage runoff while having limited effectiveness in protecting water quality. The preferred topography for these interventions is flat or gently sloping to keep construction costs down. As far as the quality of the soil is concerned, detention basins do not have any special requirements, as the surface can be made impermeable by a liner or a layer of bentonite clay. Conversely, if infiltration processes are to be promoted, it is possible to replace or mix the bottom soil of the basin with high porosity material. Since they are activated in critical situations of the water network, these facilities are without water for most of the year. However, part of the runoff can be channelled and stored in the dry season as a source for agricultural or urban garden irrigation systems.

Within the detention basin, turf can be placed, or shrub or tree-type plants tolerant of flooding can be planted. Besides increasing the aesthetic value of the area, vegetation also has the function of increasing water quality.

If water is expected to be kept in the reservoir for extended periods of time, it is referred to as a retention reservoir. These are real ponds and can also be designed to create wetlands and habitats for various animal species. In these cases, the presence of vegetation with a phyto-purification function is recommended. This can be arranged on the banks, even creating steps, or floated using special floating elements, while in the bottom, the presence of oxygenating plants keeps the system more balanced.

In these facilities, the inlet and outlet volume must be monitored through the construction of appropriate pipes and devices to regulate the water level within the basin.

Figure 16: The detention basin with bioretention pond (left - more information at the link https://youtu.be/hVwtT4dlSOI) eand the retention pond (right - more information at the link https://youtu.be/TjrFs7pSojo) realised within the framework of the LIFE BEWARE project.

5.8.1 Dimensioning

The sizing of the detention basins is conducted by applying the continuity equation, systemising the law of outflow (for loading and unloading pipes) and the law of reservoir, which is a function of the basin's topography.

5.8.2 Materials and Installation

The construction of these basins consists of moving the soil to create the project topography. The slope of the banks must be a function of the soil's quality; in any case, care must be taken of possible erosive phenomena that could occur in the inlet and outlet areas. Planting shrubs or tree species can limit these phenomena, as can the placement of stones or concrete pours. In this regard, verifying the correctness of the surface modelling work is crucial if the designed volume of invadable water is truly accumulable. If the basin is waterproofed, a layer of geomembrane, usually of the 2 mm thick HDPE type or a layer of compacted bentonite clay can be laid on the bottom. Pumps must be installed if the topography does not allow the flow to exit or enter due to gravitative potential. These should preferably be placed in pairs so that one always works in the event of a malfunction. In addition, the inlet and outlet points of the water outflow should be constructed at the extremes of the basin to ensure maximum infiltration volume capacity.

5.8.3 Costs and maintenance

The costs of such structures vary greatly depending on their size, shape, the volume of earth mobilised, the material used, and vegetation planting. The costs per unit area vary between 20 and 100 €/m^3

As far as maintenance costs are concerned, they depend mainly on the plant component planted in the detention basin, the frequency of activation of the basin, and the flow rates managed. In fact, for very intense phenomena, the runoff could carry large amounts of sediment that would have to be removed or could damage the banks or bottom of the basin through erosion phenomena. In Table 18, indicative cost values are given for ordinary and extraordinary maintenance of detention basins.

Type of maintenance	Frequency of intervention	Type of intervention	Estimated cost
Ordinary	Monthly	Mowing grass, maintaining green areas and pruning trees and shrubs	7 - 9 €/m^2 of vegetation cover area
Extraordinary	After the activation of the basin following an extraordinary event	Removal of sediment accumulated in the flood phenomenon, cleaning of the bottom and work to restore eroded areas if present	1 - 3 €/m^3

Table 18: summary of unit maintenance costs of detention basins.

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