Deltares

# Design Considerations for Urban Green Infrastructure taking into account Water Quality

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# Summary


Urban green infrastructure, such as green roofs, trees, or infiltration measures, can mitigate urban heat island effects and reduce flooding. It can have positive, but also negative effects on water quality, depending on factors like design, proper installation, maintenance, and location of the measure. The impact of urban green infrastructure on water quality is a complex interplay of various factors, including **sources** and **pathways** of pollutants, and **receptors** affected by surface water pollution.

Pollutants in urban areas that deteriorate the water quality of adjacent surface water bodies stem from diverse **sources** such as landscape maintenance practices (pesticides, fertilizers), street runoff (traffic-related pollutants, e.g. metals, PAH's), and direct discharges from point sources (e.g. sewer outlets with faecal contaminants). Major **pathways** for the transport of pollutants are surface runoff, soil infiltration and direct discharges (from e.g. sewer outlets or illegal disposals). Concerning human health, **receptors** of pollutants in surface waters are mainly people who use the waters for recreation (e.g. swimming, canoeing) or for other purposes such as irrigation.

The implementation of urban green infrastructure can alter pollution sources, pathways and receptors by changing the function of an area and its maintenance. A newly developed green space can e.g. draw more dog walkers that increase the pathogen concentration through more faecal pollution (**source**). The green measures can alter the pollution **pathways** by reducing surface water runoff through increased infiltration of rainfall, as well as enhancing bioremediation processes and improving the water quality of the runoff. Attractive green spaces adjacent to surface water may also promote water recreation, such as swimming; which leads to an increasing number of **receptors**. However, wrongly designed, implemented or maintained urban green infrastructure can also negatively impact the surface water quality and eventually human health. Challenges such as insufficient maintenance capacity, lack of experience in construction, and the need for norms in design and installation must be addressed for successful integration.

This report provides an overview of sources, pathways, and receptors that can be influenced by urban green infrastructure (Chapter 2) and recommendations for the design, implementation, and maintenance of green infrastructure to maximize their positive impact on surface water quality and reduce negative impacts. Section 3.1 provides an overview of process guidelines covering design, construction, and maintenance phases. Section 3.2 includes technical guidelines, which are crucial for ensuring the effectiveness of urban green infrastructure in reducing surface runoff and improving runoff quality. The realization of the interplay of sources, pathways, and receptors affected by urban green infrastructure and the proper implementation of guidelines can help designers and maintainers of urban green infrastructure to prevent unintended consequences of measures on water quality.

# Contents

# 1 Introduction

## 1.1 Aim and scope

The health impacts related to climate change, such as heat stress (indoors and outdoors) and changes in water quality and plant diversity, are increasing. Blue (e.g., lakes, canals) and green infrastructure (e.g., trees, green spaces) can significantly contribute to reducing heat stress and urban warming. The research project BENIGN (“BluE and greeN Infrastructure desiGned to beat the urbaN heat”) aims to investigate how blue and green infrastructure in urban areas can be utilized to create healthy living conditions (BENIGN, 2024).

Within this research project, physical and social experiments are conducted in the built environment by collaborating with three municipalities in the Netherlands (Leiden, Dordrecht, and Hilversum) to design, implement and evaluate blue and green solutions in living labs. A key outcome of BENIGN is to indicate attention points for municipalities to guide them in creating healthier living conditions when designing and implementing urban green interventions.

BENIGN adopts a holistic approach by combining the disciplines of health with thermophysiology, water and plant ecology, spatial design, spatial planning and governance, behavioral and cognitive science, and geoinformatics. One of the aims of this research project is to provide insights into the impacts of urban green infrastructure on urban surface water quality and their functional quality in connection with effects on human health.

This report provides insights into the potential sources, pathways, and receptors of surface water pollution in the urban environment and how these can be influenced by urban green infrastructure (Chapter 2). Additionally, it offers an overview of design considerations, encompassing the design process and technical requirements for urban green infrastructure to mitigate negative effects and enhance positive impacts on sources, pathways, and receptors, and improving urban water quality (Chapter 3).

# 2 Impact of urban green infrastructure on water quality

Urban green infrastructure measures, such as green roofs, infiltration measures (e.g., bioswales, raingardens), green spaces, trees, urban forests and green walls, can help cities adapt to climate change by reducing the urban heat island effect, and reducing flooding and drought events (Green et al., 2021; Marando et al., 2021). Further, they can have positive as well as negative effects on the surrounding (surface) water quality depending on the implementation and location of the measure (NKWK, 2022). Green infrastructure measures can influence surface water quality on different levels: through their impact on **sources** of pollutants (where the pollutants come from), on **pathways** of pollutants (how pollutants are transported), and/or on the **receptors** of pollution (who are affected by the pollution).

This chapter describes the sources, pathways and receptors of urban surface water pollution (Figure 1-1) and how the specific components can be influenced through the implementation of urban green infrastructure.

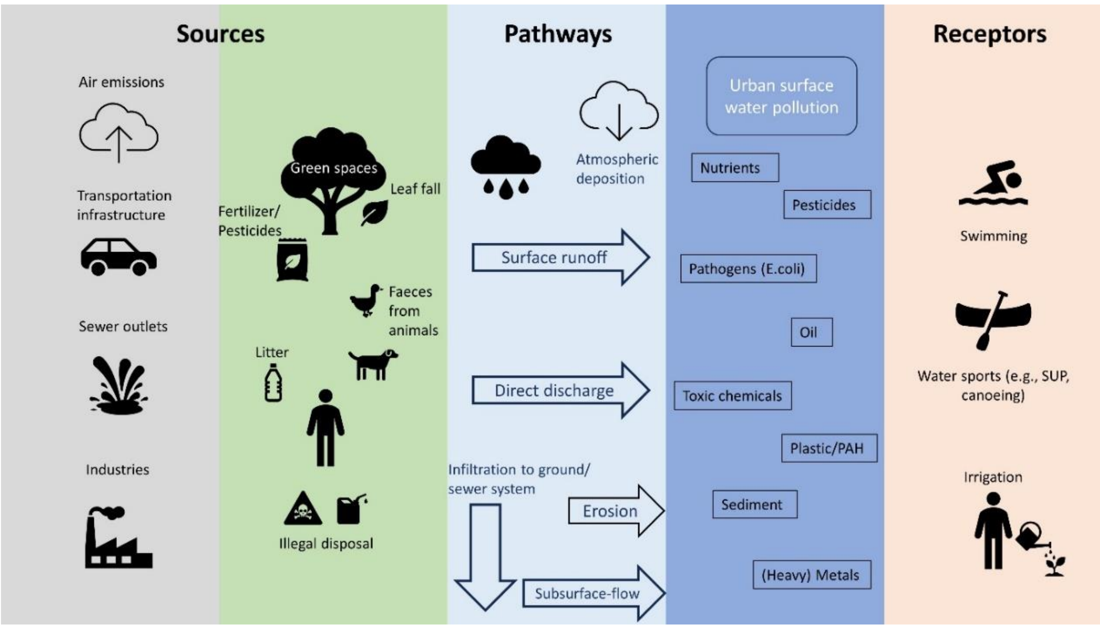


*Figure 1-1 Conceptual model of sources, pathways and receptors of urban surface water pollution. The single components (source, pathway, receptor) are described in more detail in Section 2.1 -2.3.*

## 2.1 Sources of pollutants in the urban environment

In urban environments, surface water pollution originates from a combination of diffuse and point sources. Point sources involve localized outlets with distinct origins, such as industrial discharge, sewer outlets, and other specific (intended) discharge points. These sources release pollutants directly into surface waters. On the other hand, diffuse sources are more dispersed, encompassing a broader array of origins across the urban landscape, such as agricultural/landscape management practices, transportation infrastructure, air emissions from e.g. industries, sewer outlets or navigation.

Important sources of surface water pollutants in urban areas are summarized in Table 2-1 below.

*Table 2-1 Overview and description of sources of urban surface water pollution.*

| Source | Description |
|---|---|
| **Landscape maintenance** | Landscape maintenance practices, where improper application of fertilizers and pesticides introduces chemical pollutants and nutrients into the ground and to urban surface waters through runoff. Also, improper management of riverbanks can cause erosion (Wilson et al., 2004; CIRIA, 2015; NKWK, 2022). |
| **Litter and faecal matter** | Litter and faecal matter from human and animal activities are noteworthy contributors, with litter causing contamination and faeces potentially carrying harmful bacteria and pathogens that can adversely affect human health and aquatic ecosystems (Wilson et al., 2004; Ottburg et al., 2017; NKWK, 2022). |
| **Transportation infrastructure** | Traffic introduces chemical pollutants (e.g., PAHs and heavy metals) which are transported by the surface runoff (Wilson et al., 2004; STOWA, 2022). |
| **Air emissions** | Air emissions and atmospheric deposition, predominantly originating from industrial processes, introduces chemical pollutants, nutrients, and heavy metals into the surface waters (Wilson et al., 2004, CIRIA, 2015). |
| **Industries** | Industries, wastewater treatment plants can introduce diverse chemical pollutants and pathogens into the surface waters through direct discharge or leakages/spillages. Industries and agricultural practices also significantly contribute to air emissions and pollution from atmospheric deposition (Wilson et al., 2004; CIRIA, 2015). |
| **Sewer outlets** | Sewer outlets introduce sewage water through sewer misconnections or sewer overflows (containing e.g. pathogens, medical substances, nutrients) into the environment and adjacent surface waters (Wilson et al., 2004, CIRIA, 2015). |
| **Illegal disposal** | Illegal disposal of chemicals/oil/sewage on small (domestic) or big (industrial) scale, where various chemicals, oil and sewage water (e.g. from ships) can be introduced into the surface water (Wilson et al., 2004, CIRIA, 2015). |

The amount and type of pollutants in the runoff water are dependent on the source, location, and external conditions such as extreme weather events. A longer dry weather period can lead to the accumulation of pollutants and increase their concentration in the source and ultimately in the runoff after the next precipitation event (CIRIA, 2015). The risk of these pollutants for surface waters and human health depends on the type and total load that reaches the surface waters. The pollution of the surface waters can be acute, e.g. high concentrations after an extreme event, or chronic, e.g. long-term accumulation of pollutants due to permanently low pollutant concentrations in the runoff. The type of pollutant determines its conservation in the soil or potential for bioaccumulation (CIRIA, 2015). An overview of contaminants in the urban runoff dependent on the land use and their potential toxicity can be found in the CIRIA report (CIRIA, 2015, Chapter 23, Annex A).

The sources of pollution can be affected by urban green infrastructure measures in various ways, depending on different factors such as the design, maintenance, and use. For instance, green infrastructure can create more green spaces for residents to enjoy and walk their pets, and also other animals (birds, bats etc.) can be attracted by the green spaces. This can increase the load of pollutants (e.g. pathogens, nutrients) from more animal droppings and waste from visitors (Kennisportaal Klimaatadaptatie, 2022; NKWK, 2021; Lõhmus & Balbus, 2015). The proper design and maintenance of green spaces are essential to avoid the build-up of pollutants in the topsoil and runoff (NKWK, 2022). Additionally, fertilizer and pesticides might be applied for the maintenance of green spaces, which can further release nutrients and other toxic pollutants into the environment (NKWK, 2022). The most significant sources of nutrient pollution caused by urban green infrastructure are leaf fall and faecal pollution through more dogs that are visiting the green spaces (Janke et al., 2017; Bratt et al., 2017; RIONED and STOWA, 2020).

## 2.2 Pathways of pollutants in the urban environment

Urban surface water is susceptible to pollution through various pathways that arise from anthropogenic activities and natural processes within urban environments. The main pathways of pollution are direct discharges from point sources and diffuse pollution carried by the surface runoff from mainly non-point sources.

Direct discharge of pollutants in the urban environment originates through e.g. industries, stormwater outfalls, wastewater treatment plants, sewer outlets, but also discharges from shipping, such as ballast water or illegal waste disposals. Mostly, these point sources actively release pollutants, in other cases (sewer overflows, misconnections) technical failures or excessive precipitation can cause a release of pollutants from a point source, which is then carried by the runoff. Pollutants originating from diffuse sources can be introduced directly into adjacent surface waters through atmospheric deposition (air emissions), erosion and via runoff from sealed and unsealed areas caused by precipitation. The runoff from the sealed and unsealed areas, such as streets (containing pollutants such as metals, PAH’s) and green spaces (containing pollutants such as nutrients, pathogens, litter, and pesticides) can significantly contribute to the deterioration of water quality in adjacent water bodies. A significant amount of the runoff also infiltrates into the ground and then ends up as drainage water in the urban surface waters through the subsurface flow. Another diffuse pathway that is not influenced by rainfall is the leakage from the bilge of ships into surface waters, such as oil, fuel, or chemicals from the façade (EC, 2012; STOWA, 2019).

The implementation of urban green infrastructure can alter the pathways of pollution, mainly by 1) reducing the surface runoff through infiltration/retention of rainfall and 2) reducing the concentration of pollutants through infiltration and bioremediation (NWRM, 2013; CIRIA, 2015; Muerdter et al., 2018; Eisenberg & Polcher, 2019).

Especially when replacing hard surfaces with green measures such as infiltration strips bioswales or rain gardens, the infiltration capacity of the landscape can be significantly increased which leads to less sewer overflows and less direct runoff to the surface waters (Kennisportaal Klimaatadaptatie, 2020; NKWK, 2022). Specific plants (e.g. helophytes in riverbanks) and trees are also capable of reducing the pollution concentration in runoff or surface waters (Dotro et al., 2017; Boogaard, 2020). In the case of good design, implementation and maintenance, urban green infrastructure mainly has positive impacts on the water quality. The pollution reduction rates in the runoff from green measures can be up to 90% for nutrients, heavy metals and pathogens (NKWK, 2022).

## 2.3 Receptors who are harmed by surface water pollution

Pollution of urban surface water can harm people, animals, other living organisms, or non-living objects like buildings. In this project, the focus lies on the impacts on human health. The main impacts of urban surface water quality on human health follow from water recreation, especially bathing/swimming/canoeing, and irrigation of urban green spaces, especially in the case of food crop irrigation. Within this research project, a local survey was conducted in Leiden that was distributed amongst all citizens, which revealed that about 43% of the respondents use the surface waters several times per year of which most of them swim or put their feet in the water, 15% indicated that they do this in canals.

Urban green infrastructure measures can influence the exposure of people to pollutants in surface waters by creating spaces that are more attractive to stay around and recreate. The green environment, especially the presence of grassland and natural riverbanks, increases the chance that people go swimming and use the water for other recreational activities (de Jong et al., 2022). Green infrastructure can also increase the water demand and could lead to more extractions of water from adjacent water bodies for irrigation (NKWK, 2021).

# 3 Guidelines for the design, construction, use and maintenance of urban green infrastructure measures.

Several pitfalls during the design, construction and maintenance phase can arise that hinder a successful integration of urban green infrastructure into the landscape. Factors contributing to suboptimal setups include insufficient maintenance capacity, lack of general experience in design, implementation or maintenance and lack of norms for the design and construction of urban green measures (Water Europe, 2022; Vollaers et al, 2021). The implementation of urban green infrastructure makes sometimes use of different or new technologies in comparison to conventional solutions, which can imply risks due to unfamiliar practices and techniques, leading to incorrect implementation of the design (Brown and Farrelly, 2009). This can further lead to failures of the technical functioning such as infiltration, conveyance, and storage through e.g. clogging or interference with obstacles (Vollaers et al., 2021).

There is limited knowledge about the introduction of a new system into the urban environment and how they interact with each other (Veeneman, 2004; Nieuwenhuis et al., 2021). About 40% of failures occur where two urban systems meet (e.g. public and private space) and are not properly connected to the processes within the newly installed urban green infrastructure (Vollaers et al., 2021). This stretches the importance of seeing urban green infrastructure not as single entities, but rather as interconnected parts of the landscape with connections to sources and pathways of pollution cycles that should be properly managed (CIRIA, 2015).
In addition to that, the involvement of multi-disciplinary actors can imply risks of process-delay or misunderstandings (Fratini et al., 2012; Hoang and Fenner, 2016; Cotterill and Bracken, 2020). Vollaers et al. (2021) concluded that a great amount of root causes of failures are primarily of a socio-institutional nature more than a technical issue.

To prevent negative effects and to maximize the positive effects of green urban infrastructure on water quality, proper design, construction, and maintenance are key factors for success (NKWK, 2022). This can be achieved by following existing guidelines for the **process** of design, construction, and use & maintenance, and by implementing **technical** guidelines according to the specific measure. In the following, general design considerations and recommendations from guidelines are summarized to give guidance for the implementation of urban green infrastructure with water quality in mind.

## 3.1 Process guidelines

The process guidelines for urban green infrastructure can be separated into three phases: 1) the design phase, 2) the construction phase and 3) the use and maintenance phase. Every phase has its own requirements of actions and is important for the successful implementation of urban green infrastructure. In general, green designs should focus on the protection of surface water and groundwater by knowing the 1) water pollution sources, pathways, and receptors, 2) removal efficiency of green measures and 3) risks and methods to manage those (CIRIA, 2015).

Table 3-1 outlines essential process guidelines for the design, construction, and use and maintenance phases of urban green infrastructure implementation.

In the design phase, actions include determining the impact of those measures on pollution sources and pathways, considering design and technical guidelines, understanding hydraulic and hygienic functioning, and acknowledging the ecological interactions of the urban green infrastructure with the environment (CIRIA, 2015, Vollaers et al., 2021). The inclusion of other stakeholders in the process also across the different phases is crucial, such as addressing unforeseen circumstances and clear maintenance requirements (Vollaers et al., 2021).

The construction phase involves adhering to the design and reviewing the impact of any practical challenges encountered in the field, with an emphasis on avoiding alterations that may lead to failures. Especially the hydraulic and hygienic functioning of an urban green infrastructure measure are dependent on proper construction and the right materials. Otherwise, technical failures such as e.g. clogging or insufficient slope can hinder the proper functioning of a measure (Vollaers et al., 2021).

The use and maintenance phase focuses on pollution prevention through regular maintenance practices, education, and the limitation or elimination of fertilizer and pesticide use. Monitoring and preventing unintended alterations to source-pathway-receptor dynamics and ensuring proper maintenance requirements, especially in unforeseen or extreme events, are important aspects of a well-functioning green infrastructure.

*Table 3-1 Selection of process guidelines and support material for the design, construction and use & maintenance of urban green infrastructure.*

| Phase | Design considerations | More info/support |
|---|---|---|
| **Design Phase** | Determine impact of measure on **sources**<br>• Determine <u>expected pollutants</u> based on land use<br>• Determine desired <u>maintenance</u> and its requirements, identify impact of maintenance practice on source (fertilizer, pesticides, pollution removal (e.g. leaf fall, litter)) | McFarland et al. (2019) section 3.3 and table 4 with expected pollutants based on land use; see also CIRIA, 2015, Chapter 25, Annex 1<br><br>NKWK (2022), Vollaers et al. (2021) identify inaccessibility as bottleneck for maintenance, also unclear responsibilities |
| | Determine impact of measure on **pathways**<br>• Consider <u>hydraulic/ecological interactions</u> of measure with the environment (infiltration capacity, removal efficiency of pollution treatment designs/vegetation)<br>• Consider design/technical <u>guidelines</u> for specific measures (with regard to hydraulic and hygienic functioning) | Designing for specific site conditions and the urban environment (CIRIA, 2015, Chapter 8, Chapter 9)<br><br>See technical guidelines for specific measures and technical design considerations in this document (see Chapter 2.2 and Annex Table 1)<br><br>For Water Quality Design Criteria: CIRIA, 2015, chapter 4; Table 3 and Table 4 in this report |

| Phase | Design considerations | More info/support |
| --- | --- | --- |
| | | |
| | Determine impact of measure on **receptors**<br><br>• Consider intended and potential unintended use (and related receptors who are impacted, e.g. bathers), and determine the impact of use on source-pathway-receptor. | Identify potential swimming locations and recipients (De Jong et al., 2022) |
| | General considerations<br><br>• Consider other actors in the process phases and guarantee good communication.<br>• Consider unforeseen circumstances to prevent that the design needs to be changed during the construction phase and to guarantee proper maintenance under all circumstances.<br>• Check if maintenance is possible (resources and accessibility).<br>• Allocate clear maintenance responsibilities and resources for the maintenance | Overcoming barriers (of stakeholders) to implementing green infrastructure: (EPA, https://www.epa.gov/green-infrastructure/overcoming-barriers-green-infrastructure)<br><br>Collaboration, Funding, and Community Engagement (EPA, 2017)<br><br>Designing for specific site conditions and the urban environment (CIRIA, 2015, Chapter 8, Chapter 9)<br><br>Vollaers et al., 2021, identified clear maintenance responsibilities and maintenance during unforeseen events as pitfalls |
| **Construction phase** | • Construct according to design, if not possible due to practical problems in the field, review impact of alterations (return to design phase).<br>• Use appropriate materials for construction. | Vollaers et al., 2021 identify these alterations as key causes of failure<br><br>Guidelines for materials to use and guidelines for the construction phase: CIRIA, 2015, Chapter 30, Chapter 31 |
| **Use and maintenance phase** | • Monitor use and maintenance on the long term (minimum ~3 years) concerning design and unintended alteration to source-pathway receptors. | Pollution control actions: CIRIA, 2015,Chapter 27 |

| Phase | Design considerations | More info/support |
|---|---|---|
| | • Water quality monitoring of nearby surface waters and runoff can be used as an additional indicator to check impact of measures.<br>• Prevent pollution from source (e.g. road sweeping, dog faeces, litter, leaf fall, fertilizer, pesticides) through:<br>— proper maintenance,<br>— no/limited use of fertilizer and pesticides,<br>— education of citizens,<br>— litter boxes,<br>— evaluation and improvement of treatment design to reduce contaminants<br>• Prevent unintended use of green infrastructure by humans through e.g. educational boards | NKWK (2022) gives an overview of maintenance requirements to avoid pollution<br><br>Maintenance guidance: CIRIA, 2015, Chapter 32<br><br>Vollaers et al., 2021, identified clear maintenance responsibilities and maintenance with unforeseen events as pitfalls |

## 3.2 Technical guidelines

In the design and construction phase, the correct technical implementation and connection to the environment are important to prevent negative impacts on water quality. The maintenance phase is important to ensure the technical functioning over a long period of time. In every phase, technical failures can occur and entail negative consequences for water quality. Most prevalent technical failures of urban green drainage systems are caused by interferences with obstacles, clogging, incomplete or wrong design, wrong construction material, insufficient slope, or low maintainability. These technical failures reduce or inhibit the infiltration, conveyance and storage functioning of urban green infrastructure (Vollaers et al., 2021).

Generally spoken, the measures should meet 2 technical requirements for a positive impact on water quality: 1) Preventing runoff from the site to the receiving surface waters and 2) treating the runoff at the site to enhance the quality (CIRIA, 2015). To reach these objectives, proper general hydraulic and hygienic functioning of the urban green infrastructures are crucial.

Table 3-2 gives an overview of general technical requirements and design considerations for urban green infrastructure with water quality in mind.

Depending on the type, location, and environment of urban green infrastructure, the technical requirements differ, which is why specific technical guidelines for each measure need to be considered. An overview of guidelines and types of green infrastructure discussed can be found in the Appendix (Table A-1).

*Table 3-2 Selection of general technical guidelines and support material for the implementation of urban green infrastructure with water quality in mind. Specific measures require specific guidelines (Appendix, Table A-1).*

| Technical requirements | Design considerations | More info/support |
|---|---|---|
| **Preventing runoff from site to receiving surface waters** | • Ensure proper hydraulic functioning (calculations, modelling, monitoring, maintenance)<br>• Important parameters for the calculation of hydraulic functioning:<br>— Precipitation events<br>— Infiltration capacity (decreasing over time)<br>— Retention time<br>— Ground water table<br>— Subsurface/ material for measure<br>— Vegetation type<br>— Sewer connection<br>— Slope<br>— flow | Technical requirements for specific measures (Appendix, Table 4), CIRIA, (2015) Chapter 24, Chapter 25 |
| | • Interception: No runoff from small precipitation events (< 5mm) should enter the receiving surface waters.<br>• Infiltration through vegetation/soil on the site. Although most of the pollutants are likely to be degraded in urban green infrastructure, some pollutants are prone to ac cumulate in the top soil e.g., heavy metals. Then they need to be removed regularly<br>• Right choice of plants: Tree/plant species, tree size, canopy density, plant density, canopy storage capacity, seasonal presence or absence of canopy, slope of the ground, and rainfall intensity (NKWK, 2022)<br>• Adaptive to extreme weather, 'climate trees': among others: sweetgum, oak, maple, alder, ash, linden, acacia, hornbeam, and linden. (CIRIA, 2015) , species should be chosen according to the local context<br>• Cover soil entirely with vegetation to prevent drying out of the soil (CIRIA, 2015) | CIRIA, 2015 Chapter 4.3<br>CIRIA, 2015, Chapter 24, Chapter 25 |
| **Treat runoff to prevent negative impacts** | • Consider accumulation of surrounding pollutants (measurements)<br>• Treatment systems/ vegetation can remove pollutants through chemical processes, sedimentation of infiltration | Minimum water quality requirements for discharge: CIRIA, 2015, Chapter 4.3 and Chapter 23 |

| Technical requirements | Design considerations | More info/support |
|---|---|---|
| | measures and serve as natural buffer systems for short- and long-term pollution events. Consider the removal efficiency of urban green infrastructure. | CIRIA, 2015, Chapter 24, Chapter 25 |

# 4 Conclusion

In conclusion, the successful implementation of urban green infrastructure measures for water quality improvement requires a holistic approach, considering the diverse factors influencing pollution sources, pathways, and receptors. Adherence to process and technical guidelines, along with effective multi-disciplinary collaboration, is essential for maximizing the positive impact of green climate adaptation measures on urban water quality. Through filtration and infiltration processes, green adaptation measures can improve the surface water quality by reducing the amount of surface runoff and pollutants and also the risk of floods with eventual sewer overflows. The reduction of the heat island effect further improves water quality by reducing thermal pollution of surface waters.

Nevertheless, green urban infrastructure can increase the risk of contamination of water bodies with pollutants if they are not properly designed, constructed and maintained. This can lead to reduced water runoff and accumulation of pollutants. To avoid negative impacts, it is important to implement green climate adaptation measures in a way that considers the potential effects on water quality. This may involve the following steps:

- Conducting site assessments to identify the potential effects of green infrastructure on water quality, including the identification of sources, pathways and receptors of pollution.
- Designing green infrastructure with water quality in mind, using specific technical and process guidelines for the measures, which include selecting appropriate materials, placement, hydraulic functioning and maintenance procedures.
- Construction according to design and best management practices, such as the use of organic/no fertilizer and regular maintenance/waste management, to ensure that green infrastructure is functioning as intended and not contributing to water quality problems.
- Regularly monitoring and evaluating the performance of green infrastructure (with regards to sources, pathways and receptors) to ensure that it is not having negative effects on water quality and to identify areas for improvement.
- Collaborating and communicating with other sectors, such as water management and waste management, but also the broader public, to prevent pollution from sources and unintended use of urban green infrastructure.

By taking these steps, planners and cities can maximize the positive effects of green climate adaptation measures on water quality while minimizing potential negative impacts.

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# A Appendix

*Table A-1 Overview of guidelines for urban green infrastructure, showing the types of green infrastructure discussed and available information about the design process and technical requirements.*

| Guideline | Year | Category | Type of green infrastructure | Information | Country | Source |
|---|---|---|---|---|---|---|
| **CIRIA SuDs** | 2015 | SuDs – Sustainable drainage systems | Green roofs, infiltration systems, swales, filter strips, bioretention systems, trees, wetlands | Design considerations, Site selection, hydraulic design (interception, peak flow control, volume control, exceedance flow control), treatment design, amenity/biodiversity design, physical specifications, materials, construction and maintenance requirements | UK | http://www.scotsnet.org.uk/documents/NRDG/CIRIA-report-C753-the-SuDS-manual-v6.pdf |
| **Design Manuals US EPA** | 2021 | Green infrastructure | Case studies of the implementation of various green urban infrastructures | Design, installation, maintenance, infiltration capacity, removal efficiencies, modelling, design tools | US | https://www.epa.gov/green-infrastructure/green-infrastructure-design-and-implementation#Design%20Manuals<br><br>https://www.epa.gov/green-infrastructure |
| **RIONED AND STOWA** | 2006 | Green infrastructure | Wadis/bioswales | Design (Process, Tools), Construction, Maintenance, removal efficiency | Netherlands | https://climatescan.nl/uploads/projects/969/files/162/FCB%20wadis%20aanbevelingen%20onderzoek%202006.pdf |

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|---|---|---|---|---|---|---|
| **Water Sensitive Urban Design** | 2010 | Green infrastructure | Bioswales and buffer strips | Design (Process, Tools), Construction, Maintenance, removal efficiency | Australia | WSUD_chapter_11.pdf (watersensitivesa.com) |
| **Green Streets Handbook (Low impact development) US EPA** | 2021 | Green infrastructure | Bioretention, bioswales, stormwater tree systems | Design considerations, Practices/case studies, Planning | US | https://www.epa.gov/sites/default/files/2021-04/documents/green_streets_design_manual_feb_2021_web_res_small_508.pdf |
| **Guide Green infrastructure in parks US EPA** | 2017 | Parks | Improving park services | A Guide to Collaboration, Funding, and Community Engagement | US | https://www.epa.gov/sites/default/files/2017-05/documents/gi_parksplaybook_2017-05-01_508.pdf |
| **Low Impact Development Technical Design Guideline – San Antonio River Basin** | 2015 | Green infrastructure | Green roofs, vegetated swales/filter strips, wetlands, planter boxes, bioswales, bioretention | Best management practices for water quality, Low Impact Development design principles, construction, operation and maintenance | US | https://www.sariverauthority.org/sites/default/files/2019-08/SARB%20LID%20Technical%20Design%20Manual%202nd%20Edition.pdf |
| **ISSO – Rainwater infiltration on private properties** | 2008 | Rainwater infiltration measures | Rainwater infiltration systems for private owners | Design considerations, construction, maintenance | Netherlands | https://issuu.com/stichtingisso/docs/isso-publicatie_70-1-2008 |
| **Boogaard & Wentink - Subsurface infiltration** | 2011 | Infiltration | Subsurface infiltration measures | Design, construction and maintenance | Netherlands | https://research.hanze.nl/en/publications/internationale-ervaringen-met- |

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| | ondergrondse-infiltratievoorziening |

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