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# Nature Base Solutions in New Orleans: Opportunities and limitations

Testing, Observing, Discussing

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# Summary


The project 'Reshaping the Urban Delta', funded by the National Disaster Resilience Competition (NDRC), aims to deliver groundwater and subsurface insights and data which will help the planning of initiatives that increase flood resilience and can be used in the design of the same initiatives. The project consists of eight subprojects.

This report focuses on **subproject 8**. As part of this subproject, locations and data (characteristics) of existing green infrastructure were collected and mapped, and several sites (permeable pavement, rain gardens, etc.) were visited and tested in October 2022.

The objective of this subproject was not only hydrological testing of green infrastructure facilities, but also to analyse existing green infrastructure focusing on design, maintenance and cost effectiveness. These findings provide valuable insight in the infiltration capacity of various facilities for both dry and wet conditions, and indications for design and maintenance improvements.

Testing was supported by GROUNDWORK New Orleans.

The most important conclusions of this study are:

- Nearly all tested rain gardens and bioswales functioned well. Most facilities met the norm for emptying within 48 hours to prevent a mosquito infestation Figure S1).
- Permeable pavement tests were less glorious. Only recently constructed sites functioned well and met the City infiltration guideline of 10 inches/hour. This guideline was obtained through informal communication with the City of New Orleans.
- The design of rain gardens and bioswales can be greatly optimized by enlarging the storage volume capacity, raising the overflow level, and ensuring that first the rain gardens fill up before street runoff enters the stormwater drainage pipes.
- Maintenance of permeable pavement rarely takes place, due to a lack of (expensive) cleaning machinery and insufficient knowledge on ideal cleaning intervals. Rain gardens and bioswales are generally well-maintained, but the focus should be more on sediment removal.
- Regarding the larger scale, existing rain gardens, bioswales and other green infrastructure facilities are too small and too expensive to meet the water assignment of New Orleans. This water assignment can only be solved by relatively large interventions, such as the construction of large, well-maintained open water bodies (canals), and large storage areas on neutral grounds of streets.
- The construction and maintenance costs of existing green infrastructure are very high. Money can spend only once. Therefore, at a city-wide scale a strategy is needed for cost-effective design and implementation of green infrastructure taken cost effective maintenance in consideration at the design phase. Keep it simple as possible.

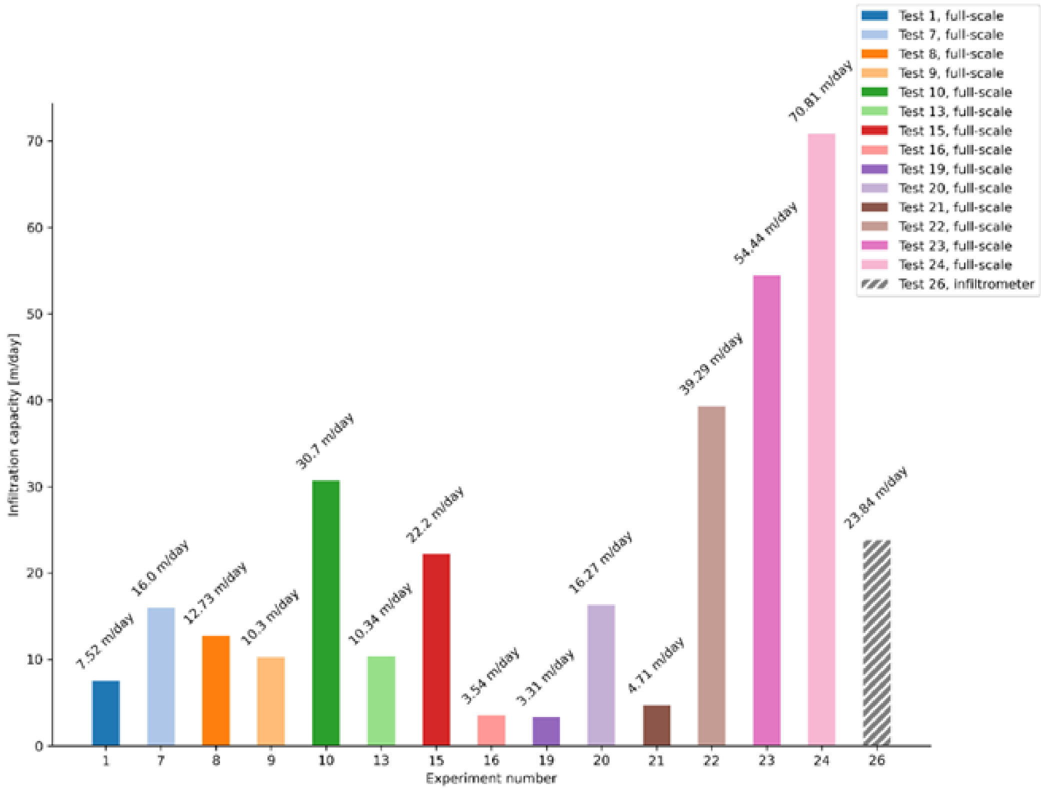


*Figure S1: Performance of rain gardens.*

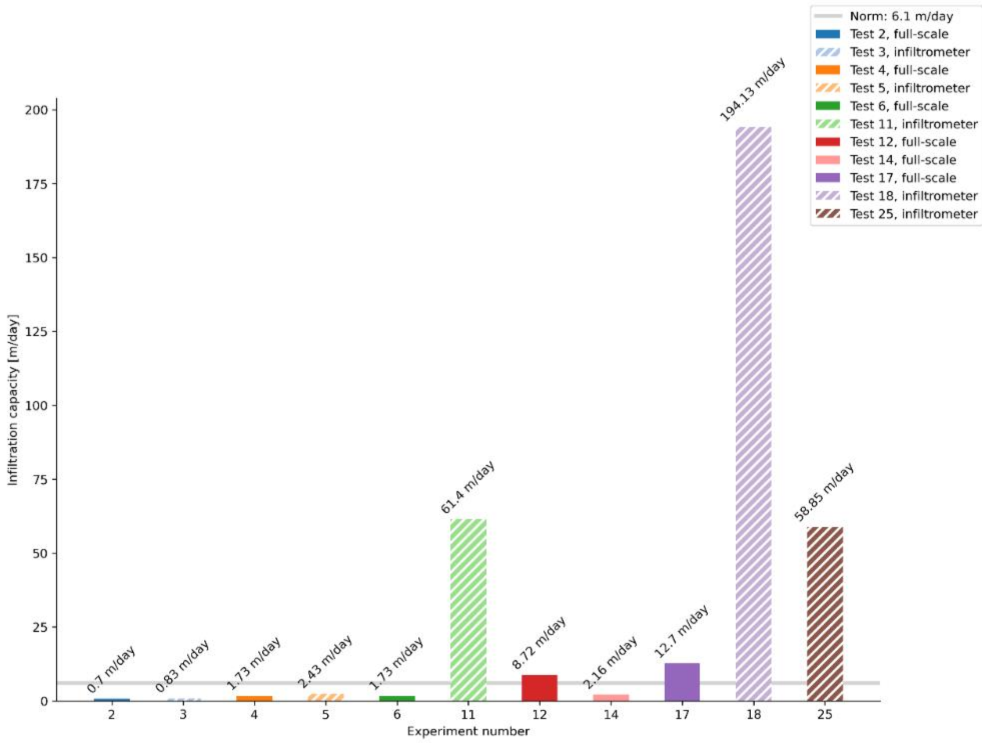


*Figure S2: Performance of permeable pavement in comparison to the infiltration criterium of 10 inches/hour (6.1 m/day).*

Concrete action points resulting from the findings in this study are outline in a step-by-step approach to better organize drainage of urban storm water in the future. This approach encompasses a diverse set of actions, on different scales and by different actors.

*Full scale testing of permeable pavement (City Park, picture Ramiro Diaz).*

# Contents

# 1 Objectives and execution

## 1.1 Introduction

New Orleans is located in the low-lying Mississippi delta and is vulnerable to subsidence, sea-level rise, and regular pluvial flooding. The oldest parts of the city were built in 1722 on relatively stable and elevated ground formed by natural levees of the Mississippi River. In later times, large parts of the city were built on soft soils in swamps further away from the river. In these areas, historical drainage and loading of peat and clay soils has caused land subsidence due to oxidation (degradation) and compaction of soft organic soils. Droughts may also cause subsidence due to peat oxidation, when groundwater levels drop, and peat is exposed to air. A large part of the city is now below mean sea level (MSL). With ongoing subsidence and sea-level rise on the one hand, and a predicted increased in intensity and frequency of droughts, rainfall events and hurricane systems on the other, the risk of flooding and subsequent societal disruption is increasing. To make the city more resilient to future flooding a new approach to groundwater and subsurface management for New Orleans is needed. Landscaping needs to be durable enough to withstand both flooding and drought. Landscape designers should continue to keep this in mind.

To develop an approach such as this, high-quality and high-resolution subsurface and groundwater data are needed. This information is currently largely lacking and, even if present, is not readily available for the city. Detailed information on geology, hydrology and soil characteristics in the city can be used to effectively design tailor-made measures to limit urban flooding and subsidence. One example of such a measure is installing green infrastructure to increase infiltration of rainwater in the subsurface. Another example is increasing groundwater levels to reduce subsidence by oxidation of organic soils, which occurs mainly above the groundwater level where organic soil is exposed to air.

The project ‘Reshaping the Urban Delta’, funded by the National Disaster Resilience Competition (NDRC), aims to deliver groundwater and subsurface insights and data which will help the planning of initiatives that increase flood resilience and can be used in the design of the same initiatives. The project consists of eight subprojects (see Figure 1.1). A first step towards making New Orleans more resilient to urban flooding is to design a monitoring network to measure water levels, precipitation, water quality and subsidence (**subprojects 1 & 4)**. This provides information on spatial and temporal trends in groundwater flows and subsidence, which is needed to design effective measures to limit urban flooding and subsidence. The monitoring data will be stored within a database making all the collected information available for the City and the public (**subproject 2**). Existing knowledge and knowledge gaps on soil conditions and groundwater dynamics in New Orleans will be identified in **subproject 3**. A shallow subsidence vulnerability map will be produced based on geologic and groundwater information collected from shallow boreholes distributed over the entire city (**subproject 5**). In addition to the shallow subsidence, the extraction of groundwater at greater depth (more than 50 meters) is likely to contribute to subsidence as well. A major difference with regards to the shallow component is the scale on which this happens (generally a smaller area is subsiding at greater rates) and the impact it has on all kinds of infrastructure. Therefore, a 3D deep groundwater-subsidence model will be constructed using existing and new cross sections and borehole in- formation (**subproject 6**).

This model will be used to analyze groundwater flow, salinization risks, subsidence, climate change impacts, and effects of deep groundwater pumping. **Subproject 7** investigates the potential benefits of real-time control of urban water system using weather forecasting. In **subproject 8** the costs and water storage efficiency of existing rain gardens and permeable pavements will be analyzed. A user-friendly performance quantification tool will be produced.

This report focuses on **subproject 8**. Therefore, the locations and data (characteristics) of existing green infrastructure were collected and mapped, and several sites (permeable pavement, rain gardens, etc.) were visited and tested.

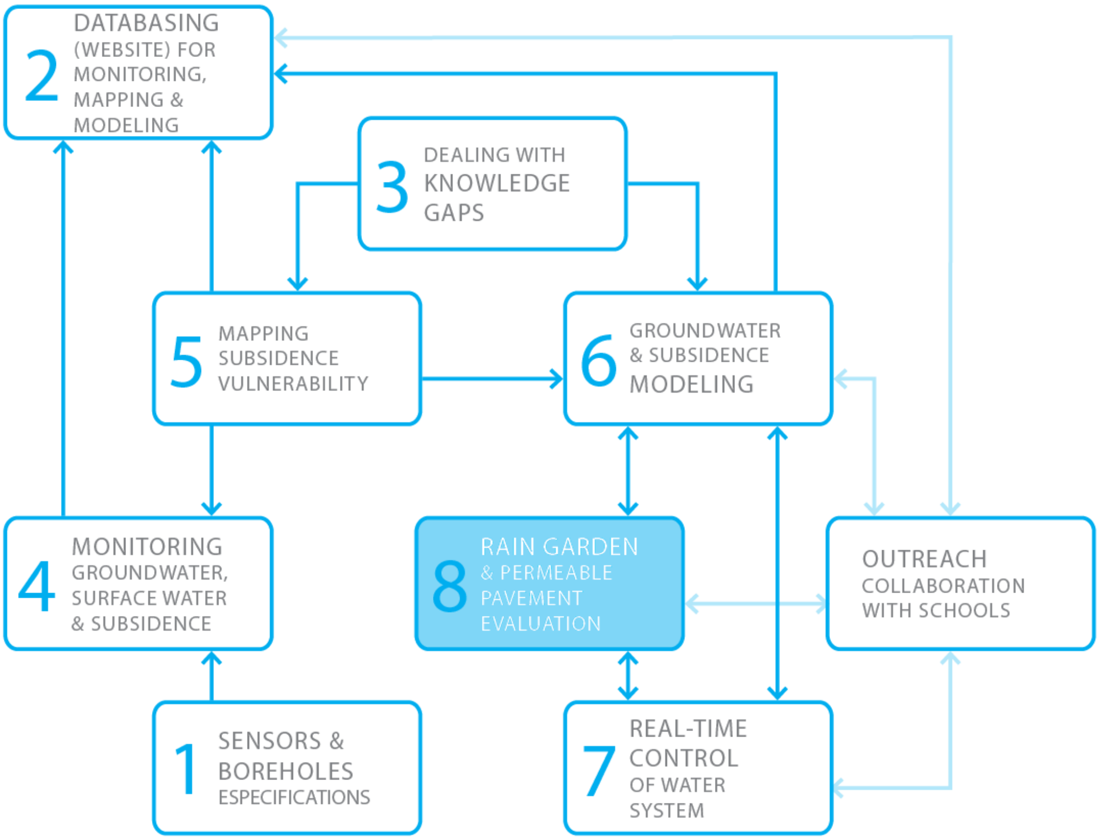


*Figure 1.1: Sub-projects within the NDRC grant.*

## 1.2 Objectives

The objective of this phase is to conduct operational research on applicability of new sustainable drainage systems (SuDS) and consider best management practices (BMP's) for rainwater harvesting and storm water treatment in New Orleans (figure 1.2).

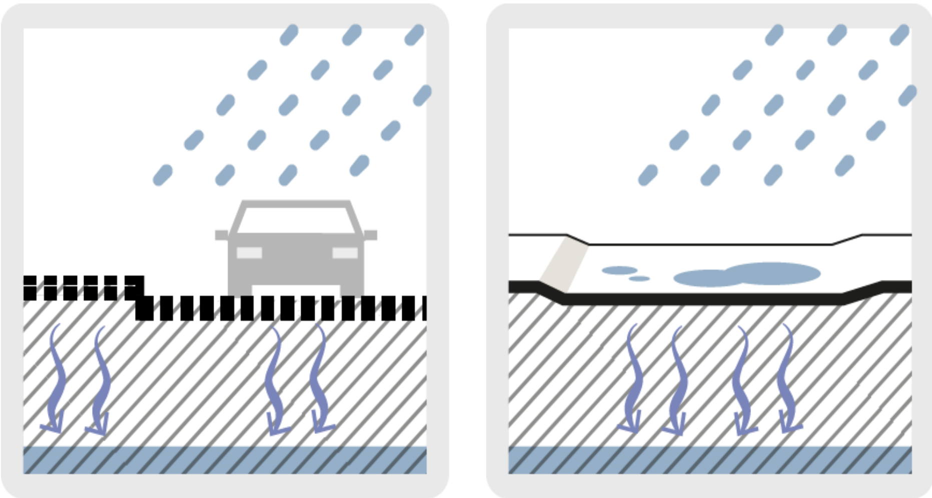

*Figure1.2 Diagrammatic representation of the tested green infrastructure facilities.*

### 1.2.1 Testing Research questions

Stormwater managers and other stakeholders want to have an understanding of the design, construction and maintenance of green infrastructure. Guidelines dictate that green infrastructure should be drained within 48 has communicated on signs at the green infrastructure (SWBN, 2014 and Boogaard et all, 2022). Permeable pavement has a different guideline: permeable pavement should show a minimum of 10 inches/hour according to stakeholders[1].

- Which variation of the (un)saturated infiltration capacity can be expected in New Orleans?
- Does green infrastructure drain within 2 days under all circumstances according to the New Orleans (and Dutch guidelines)?

Information of green infrastructure is gathered from several organizations and locations are mapped (with photos and videos) on climatescan.org (Restemeyer & Boogaard, 2021)

## 1.3 Activities according to contract

1. Mapping, classification of all existing (private and public), or soon to be developed, SuDS (Rain gardens, permeable pavement) in New Orleans. Describe (soil type, design, ecology, water and soil quality, estimated water quantity effectiveness, building costs, maintenance cost etc.), classify and evaluate design by expert judgment (based on field visit).
2. Organize a half day workshop with stakeholders. The main discussion topics are design, effectiveness, costs and public perception. How can rain garden design be optimized? This workshop will be organized in 2023.

[1] Note that in 'Ordinance City of New Orleans, calendar no.32.180, No. 27702 Mayor Council Series February 8, 2018 as amendments to the adopted International Building Code 2015 is stated '*All permeable paving installations shall be subject to infiltration testing after installation. Testing shall be conducted according to the ASTM International C1701 or C1781 standards, as appropriate. All types of permeable pavement shall maintain a minimum infiltration rate of 200 inches per hour.'* Since not all test are performed according to ASTM and this guideline is very high comparing to international standards and stakeholders refer to 10 inch/mm this guideline is regarded in this study.

3. Select and monitor 10 existing rain gardens. At each site also the local soil and shallow geology conditions will be considered. Water and soil quality conditions will be analyzed by a limited number of samples (groundwater, surface/rainwater, soil).
4. Organize 5 permeable pavement tests by using “ring infiltrometers” to determine how much and how fast (rain) water will infiltrate during different type of rain storms.
5. Literature study, data compilation and development of design rules for the New Orleans situation, including a simple instrument (tool) to calculate storage effectiveness and costs.
6. Reporting, publications and outreach workshop.

## 1.4 Deliverables according to contract

Green Infrastructure Performance Research, as follows:

a. Documentation and performance report of existing green infrastructure projects in New Orleans
b. Report with participants and notes from one-day green infrastructure workshop
c. Report with locations and performance analysis results of ten green infrastructure projects and five permeable pavement tests
d. Memo with practical hydrological design recommendations. Part of this report.

This report will fill the deliverables a, c and d. In the first quart of 2023 a Blue Green Infrastructure workshop will be organized and executed in cooperation with the stakeholders in New Orleans.
The proposed objective of this workshop is: *"to share experiences with design and implementation of Green-Blue Infrastructure, to improve new designs or improve existing infrastructure"* with the support of local designers, local constructers, local ecologists, local hydrologists and geologists, cost-benefit experts, maintenance specialists, social expertise, clients (City, NORA, SWBNO), international expertise (e.g. Deltares).

## 1.5 Participating stakeholders and partners during this reported test project

| Organization | Stakeholders and partners |
|---|---|
| **City of New Orleans** | Mary Kincaid, Austin Feldbaum |
| **Sewerage & Water Board of New Orleans** | Grace Vogel, Tyler Antrup |
| **New Orleans Redevelopment Authority** | Abrina Williams, Charlotte Giroux, Seth Knudsen |
| **New Orleans City Park** | Jake Webster |
| **Greater New Orleans Foundation** | Don Favre |
| **Dana Brown & Associates, Inc.** | Dana Brown, Danielle Duhé |
| **Waggonner & Ball** | Ramiro Diaz |
| **Groundwork New Orleans** | Todd Reynolds, Denzal Peters, Joshua Lewis, Bruce King |

## 1.6 Review

This report is reviewed by City of New Orleans, Abrina Williams (NORA), Dana Brown (Dana Brown & Associates, Inc.), Todd Reynolds (Groundwork New Orleans), Orion Stand-Gravois (SWBNO) and Joshua Lewis (Bywater Institute, Tulane University).

# 2 State of the art: Worldwide types of Green and/or hybrid infrastructure

## 2.1 Introduction

Urbanization and climate change effect the water balance in our cities, resulting in challenges such as flooding, droughts and heat stress. The development and urbanization of watersheds increases impervious land cover and leads to an increase in stormwater runoff volume. Stormwater management has shifted to include techniques that reduce runoff volumes and improve runoff water quality in addition to reducing the peak flow rate. A large variation in the hydraulic performance of Green Infrastructure in New Orleans can be expected by the several discussed factors as different filter media, soil moisture content, side-slope length, type of vegetation, soil composition and (human) errors in the design, implementation and maintenance phase. Figure 2.2 shows a collection of possible interventions.

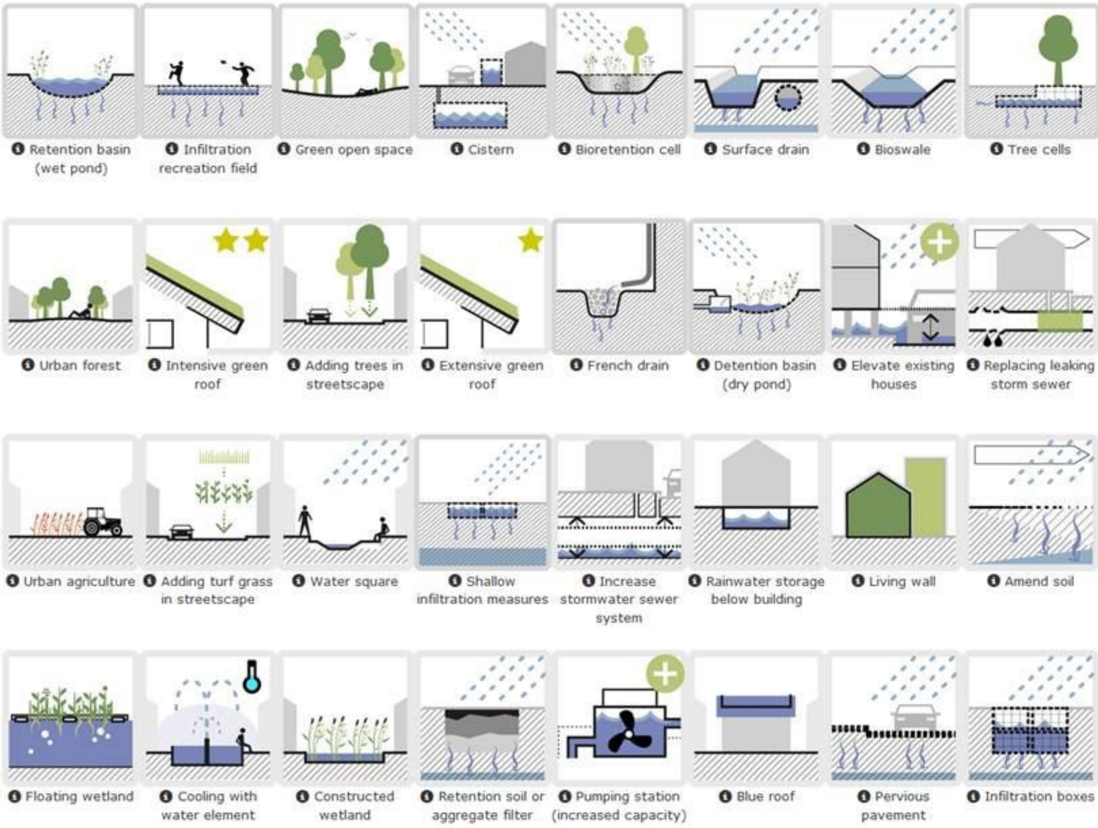


*Figure 2.1: Types of green infrastructure (not complete, source: Atelier GroenBlauw, CRC tool Deltares)*

## 2.2 Goal: to reduce storm water

Urbanisation and climate change effect the water balance in our cities, resulting in challenges such as flooding, droughts and heat stress. The development and urbanization of watersheds increases impervious land cover and leads to an increase in stormwater runoff volume (Ballard, B.W.; Wilson, S.; Udale-Clarke, H.; Illman, S.; Scott, T.; Ashley, R.; Kellagher, 2017; Fletcher et al., 2013). Stormwater management has shifted to include techniques that reduce runoff volumes and improve runoff water quality in addition to reducing the peak flow rate. Sustainable Urban Drainage System (SuDS), green infrastructure (GI), nature-based solutions (NBS) and bio-retention practices are typically designed to reduce runoff through infiltration and have been used for decades globally to provide infrastructure conveyance and water quality treatment. Swales and raingardens are typical landscape surface-drainage system vegetated (generally grass-lined) channels that receive stormwater runoff through gentle side-slopes and convey this stormwater downstream by way of longitudinal slopes .

The hydraulic performance of GI can be expected by the several factors as different filter media, soil moisture content, side-slope length, type of vegetation, soil composition and (human) errors in the design, implementation and maintenance phase. Several studies show that the performance of in general can be influenced by (human) failures in the design, implementation and maintenance of swales (F. Boogaard, 2015; Vollaers et al., 2021). There are several international studies that determined the variation in mean volume reduction in GI from 11 to 75% (Deletic, 2001; Rushton, 2001), high variations in infiltration capacity and peak flow rate reductions from 10 to 74% with detention provided by infiltration or check dams improving this mitigation (F. C. Boogaard, 2022; Davis et al., 2012). However, little is known about the long-term infiltration capacity of GI under sea level such as New Orleans with high groundwater tables and low permeable soils such as clay.

*Figure 2.2: example of green infrastructure in New Orleans: test location 2 with signs on the right of the inlet. https://www.climatescan.nl/projects/7399/detail.*

## 2.3 Goal: to improve water quality

Water quality treatment in a swale occurs through the process of sedimentation, filtration, infiltration and biological and chemical interactions with the soil. Green infrastructure has been shown to be very efficient in removing sediment particles from urban runoff (F. Boogaard, 2015; Kachchu Mohamed et al., 2014; Vernon et al., 2021). Regarding soil composition in general, bioswales are composed of loamy sands, loams, or sandy loams resulting in variation in the infiltration rates of bio-swales and bio filters (F. C. Boogaard, 2022; Vernon et al., 2021). Floating water gardens (figure 2.3) improves canals water quality mostly by triangle mussels, and also improves ecology in general.

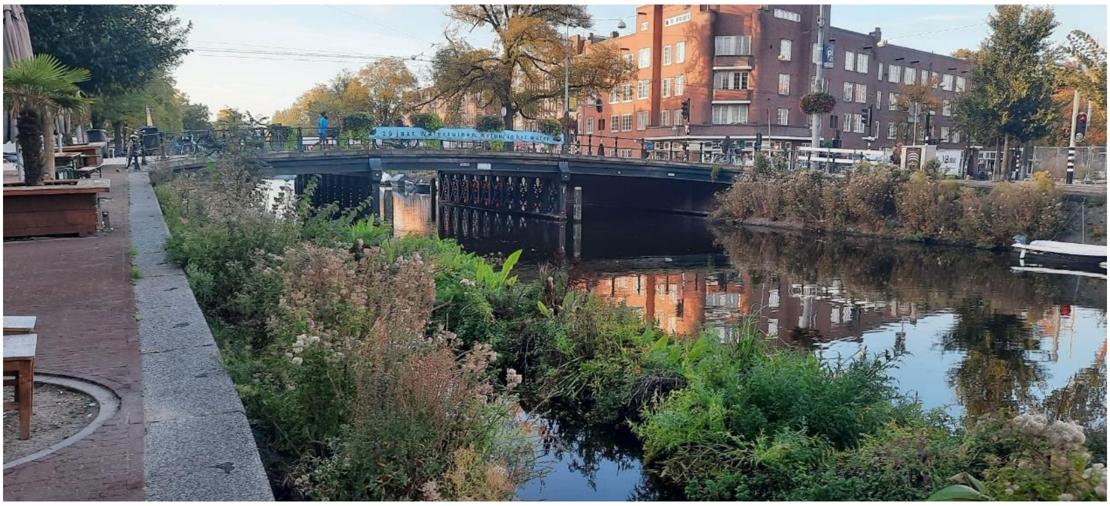

*Figure 2.3: Example of floating water garden in Amsterdam (27th years anniversary)*

Like many urban areas, also storm drainage water of New Orleans possesses an important polluting effect on the surface water quality. Most of NO storm drainage water is discharged into Lake Pontchartrain causing pollution with nutrients (garden and parks fertilizers, leaking waste water, street pollution like car wash soap), bacteria and very likely pesticides (figure 2.4). Solving this problem needs a step-by-step approach.


*Figure 2.4: Creating awareness that pollution storm drainage water will pollute Lake Pontchartrain.*

Starting with reducing fertilizers use, perhaps in combination with other garden designs, is the most important treatment step. Also, other polluted water discharges from private properties need to be reduced (e.g. car wash water). A next step is improving the soil health, becoming less dependent on fertilizers and at the same time improving the infiltration capacity for intense rain storms. The catch basins deliver opportunities for treatment (collecting leaves, grass clippings, plastics etc.). The next treatment step could be the outfall locations (pipes, ditches). In “open” surface water system additional treating wetlands could be designed. So, to reduce the discharge of nutrients (and other pollutants like plastics. oil and pesticides) a “tackling at the source and treating in a network” approach is needed.

Of course, public participation is essential (see *Public awareness explanation of Hempstead, Virginia in figure 2.5).*

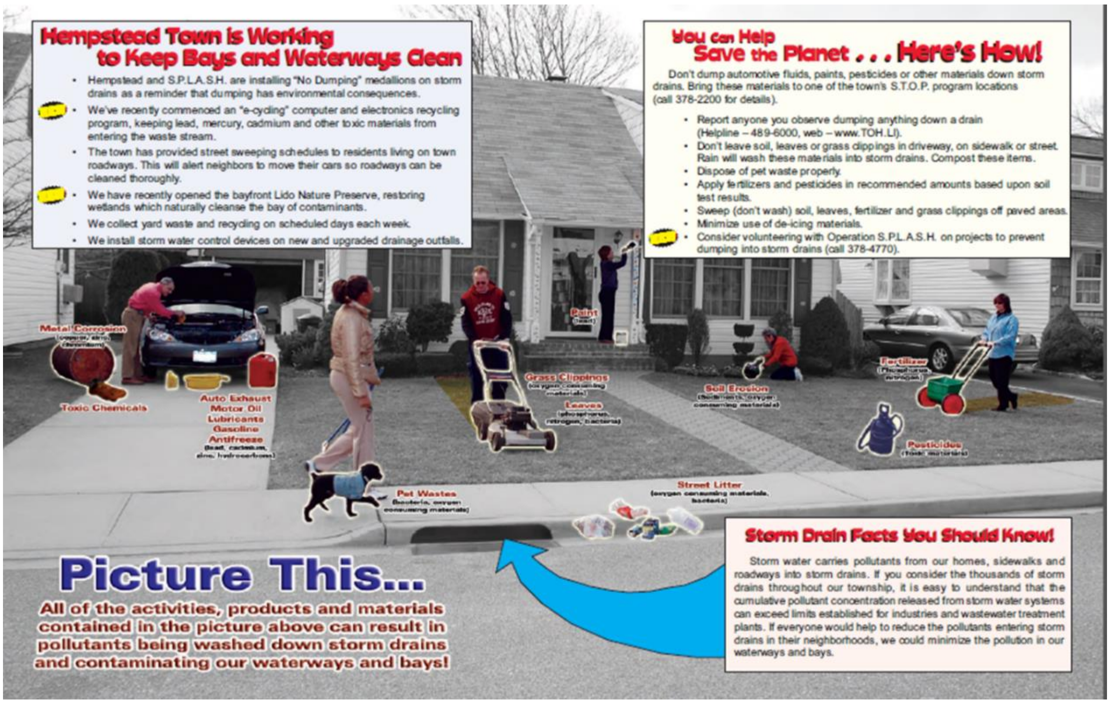


*Figure 2.5: Public awareness activity in Hempstead, Virginia.*

Water treatment takes time (especially biological treatment). The best treatment locations are the capillaries of the water network, starting at the catch basins. The NGO SPLASH at Long Island has already many years of experience with “catch basin collectors” (figure 2.6). With these collectors’ solid pollutants like plastics, but also organics (tree leaves, grass clippings etc.) can be collected before polluting the Lake. Organics are considered a main pollutant because they consume oxygen. Also, micro-plastics and metal need to be considered.


*Figure 2.6 The catch basin collector from SPLASH, Long Island (https://www.operationsplash.com/). This collector could be improved treating nutrients.*

## 2.4 Hybrid solutions

In literature hybrid solutions are more and more referred to. Hybrid, green-grey approaches utilize combined grey and green infrastructures. An example is when wetlands restoration is coupled with engineering measures such as small levees for coastal flood protection. Other examples are bioswales, rain gardens, green roofs, street trees installed in sidewalk tree pits, and other engineered ecosystem approaches (source: https://link.springer.com/chapter/10.1007/978-3-319-56091-5_6)

## 2.5 Sub conclusion

- ❑ There exist many types of Green (Blue) infrastructures. Most are focused on retaining and/or storing storm drainage water. Less are focused on treating water quality.
- ❑ Green Blue Infrastructure should not be considered as an individual intervention but be part of a network.
- ❑ Planning and organizing green infrastructure needs a step-by-step approach, starting at the capillaries of the storm water drainage system (gardens, roofs).

# 3 Historical, geological and spatial perspective

## 3.1 Introduction.

The vulnerability for pluvial flooding in New Orleans increased in time due to the following historical developments (van Asselen, Arellano, Stuurman, 2020; Campanella, 2002):

1. In the beginning New Orleans was mainly constructed on (relatively) higher grounds, like the Mississippi riverbanks. Rainwater was drained by gravity flow towards lower grounds (mainly swamps).
2. Later urban development descended into to lower grounds. These areas became more vulnerable for flooding.
3. Related to this vulnerability for flooding drainage canals were constructed: starting subsidence because of dropping groundwater levels.
4. In the arised “bowls” pumps became needed, creating extra subsidence.
5. Also, the increased impermeability (streets, houses) created extra vulnerability for pluvial flooding.
6. Last but not least, climate change produced more intense rain storms (including “rain bombs”). Pluvial flooding hazards increased the last decades and years.

Therefore, solutions to solve or reduce these flooding problems became more urgent. Green infrastructure is thought to be one of the solutions.

## 3.2 Urban water before 1900

Historical accounts state that the river was used initially both for water and waste disposal via hauling. In nineteenth century cisterns for household water became common. They were often cypress tanks, one or two stories high, fed from slate roofs. Water was taken from a spigot in the side of the tank and hauled inside. These tanks were banned in early twentieth century because of reputed mosquito problems, and the availability of “piped” drinking water. Cesspits were also common in nineteenth century. Well water was never potable but used for cleaning etc.

So, during the past (>100 years ago) in the 18$^{th}$ and 19$^{th}$ centuries in nearly all neighbourhoods and private properties urban rainfall returned indirectly into the subsurface, recharging groundwater. Rainfall from roofs was collected into cisterns and discharged into the subsurface by cesspits (figure 3.1). Nowadays, this type of rain water harvesting is rare. Perhaps also river water was used at home, creating extra recharge. After the introduction of the (SWBNO) drinking water and waste water networks this recharge system reduced drastically.

Rain water was often drained by shallow ditches along the streets. These ditches were also used for draining waste water. Also because of related mosquito problems, in the 20$^{th}$ Century, these ditches were replaced by pipes.

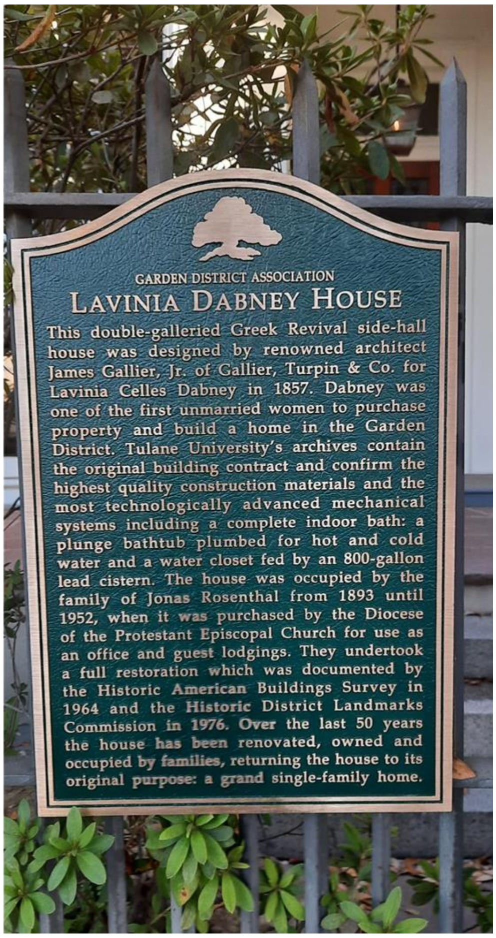


*Figure 3.1: Plate at St. Charles Avenue mentioning 800-gallon cistern (3028 litre, approx. 3 cubic meter)*

## 3.3 Soil, geology and groundwater situation

### 3.3.1 Soil permeability

The infiltration characteristics of Green Infrastructure largely depends on the permeabilities of the soil and deeper subsurface and the groundwater level before and during rain storms. The largest area of New Orleans possesses a clay soil. Clay has a low permeability. However, the topsoil area (approx. the zone above the mean lowest groundwater level) is more permeable. Probably, because shrink-swell clay cracking processes during dry periods with cracks filled with more permeable fine sands, and because of roots effect. This theory agrees with several groundwater fluctuation observations. Groundwater levels rise very fast during rain storms but drops also in a short period (figure 3.3). So, although having a clay soil the soil is permeable enough to support (relatively) fast water infiltration in bio swales etc.

In figure 3.2 our test locations are compared with the soil (lithology) characteristics.

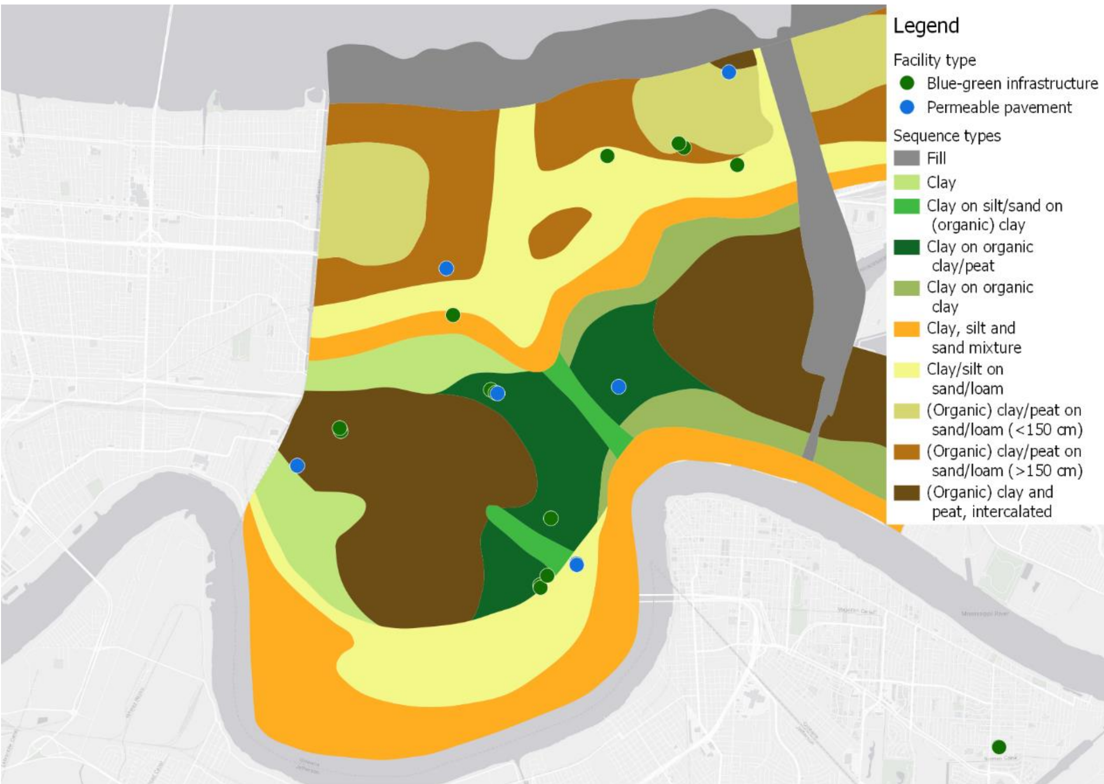


*Figure 3.2: Lithological sequence type map, constructed based on borehole information (van Asselen e.al. 2020).*

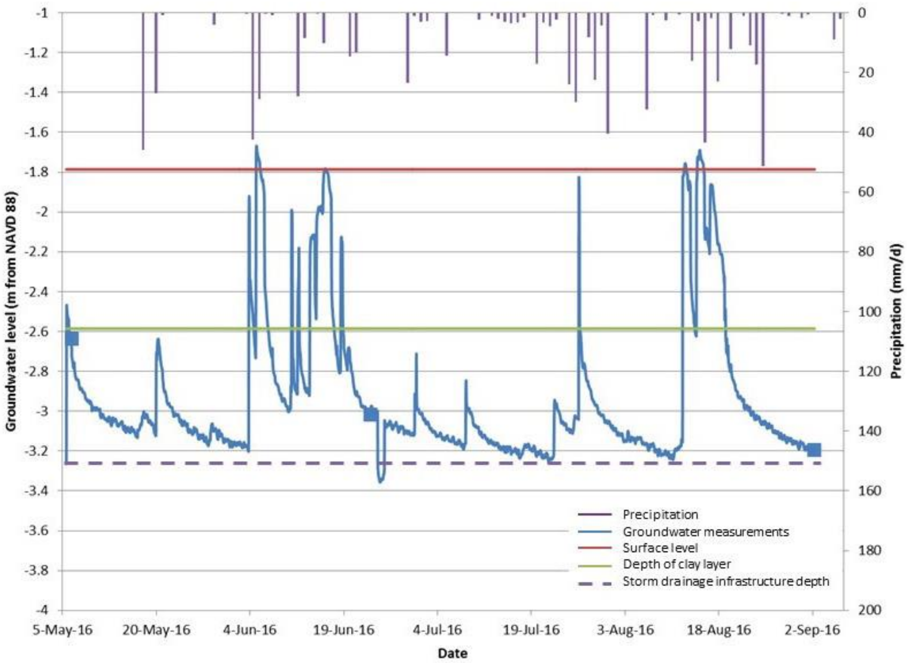


*Figure 3.3: (Above) A diagram of the groundwater behaviour before and after rainfall. After rainfall, we see the groundwater sinking back to the depth of the rainwater drainage system (location Mirabeau, Gentilly New Orleans, data summer 2016, Nougues and Stuurman, 2022)*

### 3.3.2 Green infrastructure as instrument to help subsidence?

Unfortunately, smaller green infra sites will not help to reduce subsidence, as long as the storm drainage pipes and waste water transport pipes below the adjacent street are draining groundwater very efficient. Nearly all groundwater in New Orleans is drained by the leaking (broken) waste water pipes (approx. 42%) and by the storm drainage pipes (approx. 58%, figure 3.4 by Nougues and Stuurman, 2022)). In New Orleans East exists additional drainage by open canals. So, the best tool to reduce subsidence is renovation of these pipes.[2]


*Figure 3.4: The proportions and quantities of the various fluxes in the period 2018-2020 (precipitation 1,782 mm/year and evaporation about 1,289 mm/year).*

In figure 3.5 our test locations are combined with the subsidence vulnerability map of New Orleans (van Asselen, Arellano, Stuurman, 2020). All these locations are in areas with medium-high subsidence vulnerability. Presumably, because most subsided areas are also most vulnerable for urban flooding.

[2] Groundwater is also recharged by leaking drinking water (> 50% of produced drinking water). This loss is more than precipitation minus evaporation. Little is known about the effects of this leakage. Most will be drained by the damaged pipes. It would be good to know which zone is influenced by this chemical-treated (e.g. chlorine) leaked drinking water. Chlorine is added to kill bacteria. What will be the effect on soil health killing microbial soil bacteria?

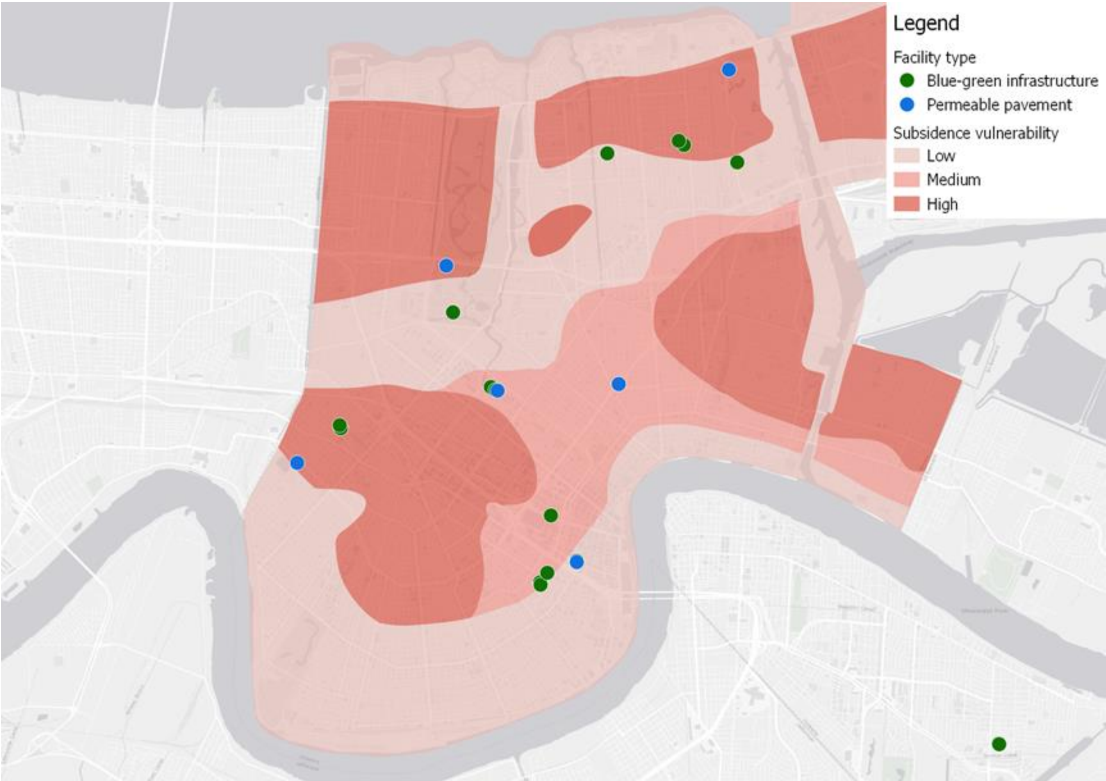


*Figure 3.5: The subsidence vulnerability map (van Asselen et al, 2020) combined with our tested sites.*

## 3.4 Vegetation and Green Infrastructure[3]

Little is known about the optimal vegetation planting of Green Infrastructure in New Orleans.

- ❑ In relation to infiltration velocities?
- ❑ In relation to reduction of urban heat?
- ❑ In relation to support ecological qualities?
- ❑ Reduction of air pollution. Trees remove pollutants (Kabisch at all, 2017).
- ❑ In relation to health (e.g. mosquitos).
- ❑ In relation to costs (incl. maintenance).

The plant species used in GI must be able to withstand: (1) prolonged periods of drought; (2) periodic, several-day inundations; (3) relatively nutrient-rich conditions.

### 3.4.1 Canopy layer

Green Infrastructure's main function is to infiltrate rainwater. The drainage of rainwater to waterways (drains) is subordinate to this. Vegetation that is used in Green Infrastructure must therefore not adversely affect the storage capacity (Boogaard et al, 2003). However, indicative calculations showed that this (above-surface) storage decrease (marsh vegetation instead of grass) is very small (0.75 %). A more varied vegetation in GI leads to a larger (and deeper) part of the top layer of the soil being rooted through. Planting trees (urban forest) and shrubs can have additional advantages because of their “canopy layer”. Tree with wide canopy spreads, long stems and limbs, that do not lose their leaves/needles are going to be best for stormwater interception. Tree canopies can store a surprising volume of water (USDA, Forest Service 2020). Think of this is as mostly a question about surface area. A large tree with many leaves and stems with a wide spread, whose bark and outer layers are also contoured to increase surface area (like live oaks) are going to give you higher volume

[3] This paragraph is partially based on information from Joshua Lewis

of interception in a given event. The canopy detains some water and slows water input into the rain garden/GI project.

### 3.4.2 Ground layer

Here again we are thinking in terms of surface area. There needs to be a balance between allowing uncompacted leaf litter/mulch to accumulate on the site while also not allowing too much sedimentation occurring on the site such that you lose too much storage. Leaf litter and organic debris can store and slow water just like a canopy can. But obviously there is a tradeoff here. There needs to be more experimentation in these rain gardens to look at how often you need to go in and muck out/clear the site of accumulated organic debris and other sediments. In this sense it’s a good rule of thumb to dig the initial project depressions deeper than the specifications you want, to buy some time on future maintenance. This must be negotiated with the potential impacts to surrounding home foundations and other infrastructure of digging a deep depression. The other benefit of allowing some leaf litter to accumulate is that you might mitigate the rate at which the soil itself on the rim and slope of the rain garden erodes into the bottom of the site. There are still a lot of basic questions here that need to be answered in terms of how to best manage the ground layer.

### 3.4.3 Root and soil layer

Tree roots can act a bit like soil engineers, using their structures and growth patterns to try and condition the soil for optimal water retention, drainage, oxygen, and soil quality. Many trees in New Orleans have shallow rooting depths, however this is very site specific. Generally, the larger and more expansive the tree root ball and root mat, the more soil permeability it is contributing to. Baldcypress and Live Oak are two examples of trees that have wide root structures that often protrude through the soil layer, even several meters away from a tree trunk. Cypress knees do this; however they create issues for maintenance if the goal is to maintain grass/turf in the bottom of the GI site.

Over time, plant roots will improve the soil structure (Wisconsin Department of Natural Resources DNR, 2018). Native plant roots get 1-2 feet deep and provide more and deeper paths for infiltration (communication Dana Brown).

The root zone of plants is the area of soil and oxygen surrounding the roots of a plant. The roots will not grow into groundwater because then it will suffer oxygen deficit. In general, the root zone depth is related to the mean highest groundwater level. These root zones support preferential flow and subsurface flow of water by the following types of root channels: (a) channels formed by dead or decaying roots, (b) channels formed by decayed roots that are newly occupied by living roots, and (c) channels formed around live roots (Ghestem at all, 2011). In clay areas this subsurface flow system (figure 3.6) can also be related to “cracked” (heavy) clay soils, originated during drought periods.

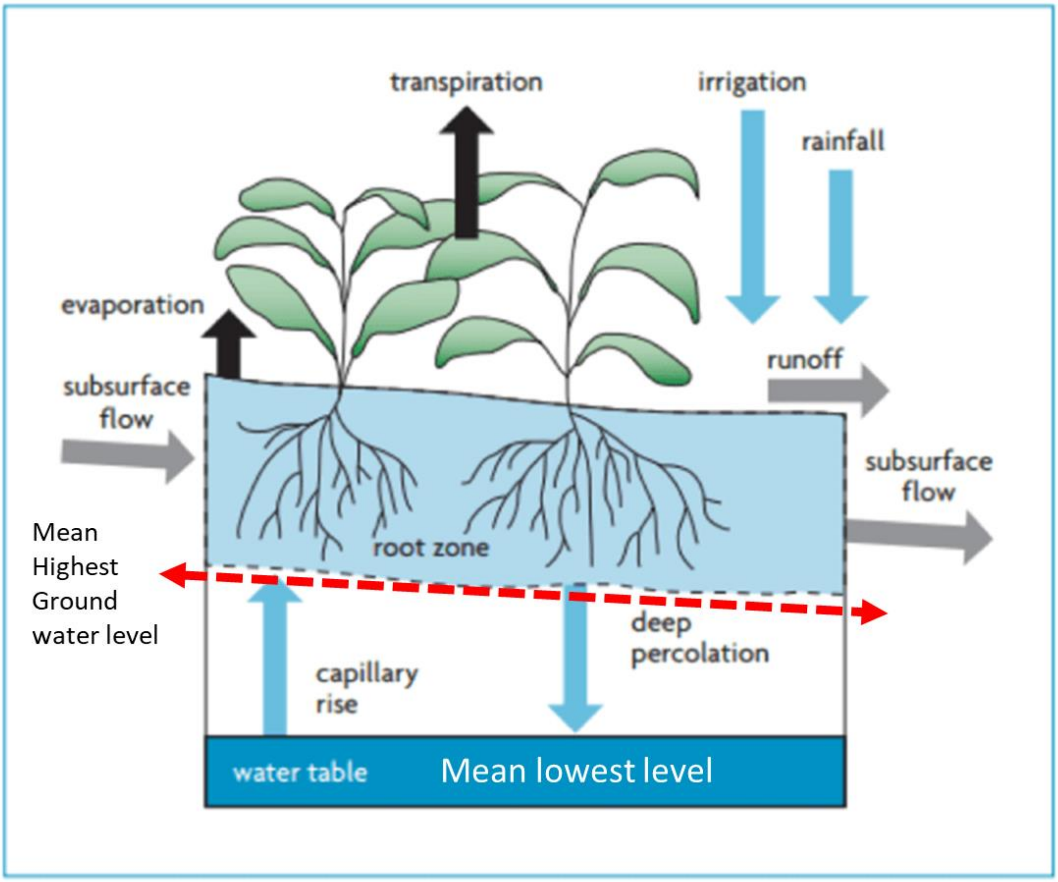


*Figure 3.6: Water cycle (source: ww.fao.org). Added mean highest and lowest groundwater level.*

A healthy root zone means a healthy plant. The root zone of healthy established shrubs will be approximately 1-2 feet (0.5 m.) deep and extend out past the drip line. The root zone of healthy established trees will be about 1 ½-3 feet (0.5 to 1 m.) deep and spread out past the drip line of the tree canopy. Some plants may have shallower or deeper root zones, but most healthy plants will have a root zone that extends out past the drip line. Roots can be stunted by compacted or clay soil and improper watering, causing them to have a small, weak root zone that does not absorb the water and nutrients a healthy plant requires. Roots can grow long, leggy, and weak in a root zone that is too sandy and drains too quickly. In well-draining soil, roots are able to develop a large, strong root zone. Read more at Gardening Know How: What Is A Root Zone: Information On The Root Zone Of Plants https://www.gardeningknowhow.com/garden-how-to/watering/root-zone-information.htm

Based on above information it seems obvious that Green Infrastructure should be planted by native deep rooting shrubs or trees. Organized in a way that this vegetation doesn't need fertilizers and pesticides.

## 3.5 Retaining storm water at higher areas

### 3.5.1 Example Audubon Park: redundant passing-on of drainage water towards urban storm drainage system.

Audubon Park is situated at the relative higher river bank of New Orleans. During a rainy Sunday afternoon quick-scan, was observed that most of the storm drainage water from areas with natural vegetation, as well as from the main lagoons discharged into the urban drainage system (e.g. below St. Charles Ave, figure 3.7 & 3.8). Also, an unpleasant surface water quality was observed with rotting debris and a relatively high salinity was measured. This brackish situation is related to recharge (during dry periods) of the lagoons by groundwater pumping. This groundwater well is near the golf course shop.

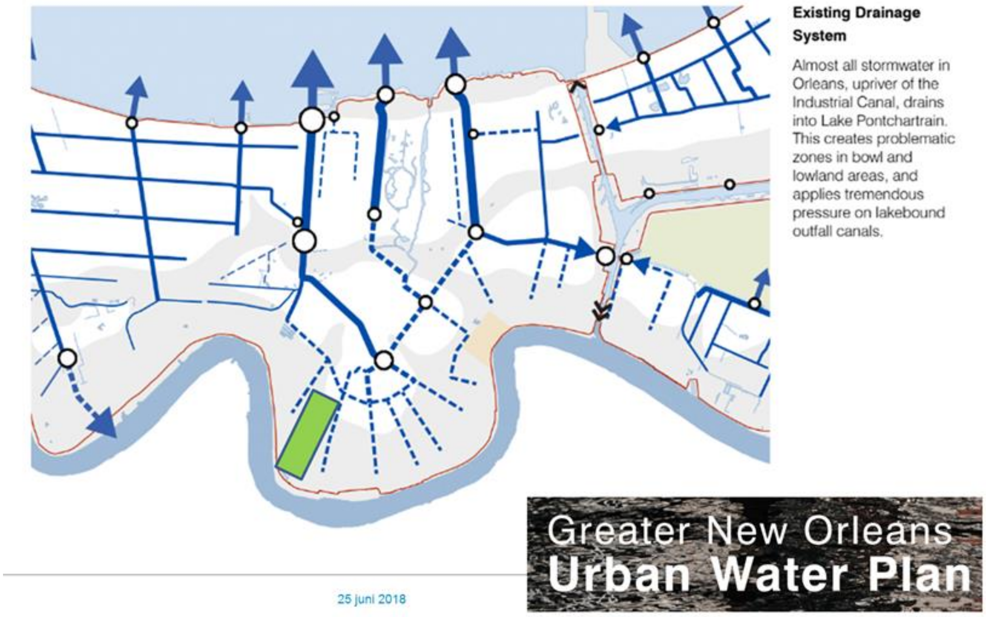


*Figure 3.7: The actual storm drainage system from high areas, mainly towards Lake Pontchartrain*

*Figure 3.8: Storm drainage in Audubon Park is discharged into urban storm drainage subsystem (and not into ponds).*

Drainage from Audubon Park into the urban drainage system impacts the risk for urban flooding, as well as the water quality of Lake Pontchartrain (figure 3.7). In the spirit of the Urban Water Plan (rain) water should be stored in the Park (mentioned in the plan, but only in relation to drainage and not in relation to water demand during drought periods) and not discharged, solving both issues.

Groundwater recharge by pumping is the reason of the high salinity of the ponds. And, probably causing part of the oxygen problems, e.g. by oxidation of reduced iron of recharged groundwater (figure 3.8). The (ground) water system should be optimized in a way that pumping becomes unnecessary. Currently water is drained outside the park during wet periods and not available during dry periods. All rain water should be stored locally and re-used during dry periods (including by evapotranspiration of park vegetation and considering (heritage) trees.

In figure 3.9 this groundwater-surface water-storm drainage interaction is visualized.

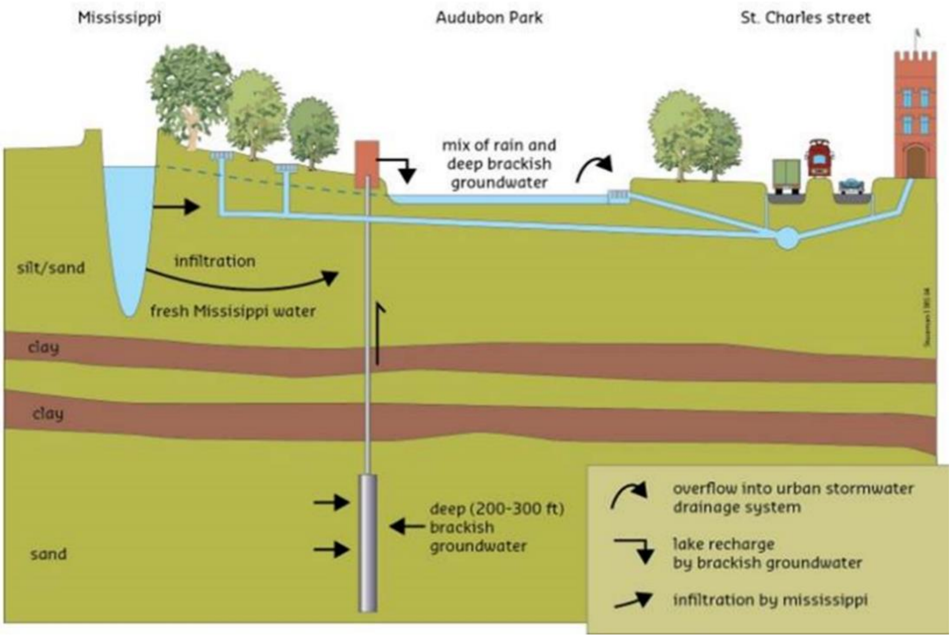


*Figure 3.9: Locations of groundwater well and overflow Audubon Park ponds into St. Charles urban storm drainage system.*

So, our vision for this park (but also for the other higher grounds) is <u>a water-neutral park system</u> with no drainage outside, no groundwater pumping, living from rain, decreased tap water use and re-used wastewater integrated into a Master Plan. The lagoon system would be more naturally resilient: circulating, widening and with higher lagoon water levels during wet periods, receiving water from the park area. The two-way flow system would drain during wet times and retain water in the lagoons and provide water for the park during dry times. The water management system would also take into account tree root vulnerability during-intense-rain-storm-flooding and improve water quality by making use of “working with nature” filtering methods. Groundwater pumps and “oxidizers” (figure 3.10) need to become redundant.

*Figure 3.10: Groundwater pump and machines adding air into the ponds.*

### 3.5.2 Priority retain zones

In accordance with our advice for Audubon Park retaining water at all higher grounds should have priority (figure 3.11).

1. At the higher ground's along river are many residential, business and school plots with relatively large gardens. These locations are ideal for the construction for green infrastructure. The objective should be to retain as much rain water as possible. In addition, water from roofs near the river should be discharged into the river. The aqueducts of the New Orleans Convention Centre are a great example.
2. Along Metairie and Gentilly Ridge the objective should be the same.
3. Also, the elevated area along Lake Pontchartrain possess great opportunities to retain water. At private plot scales (often with large gardens), but also the University (UNO) campus should reduce storm drainage towards the lower grounds.

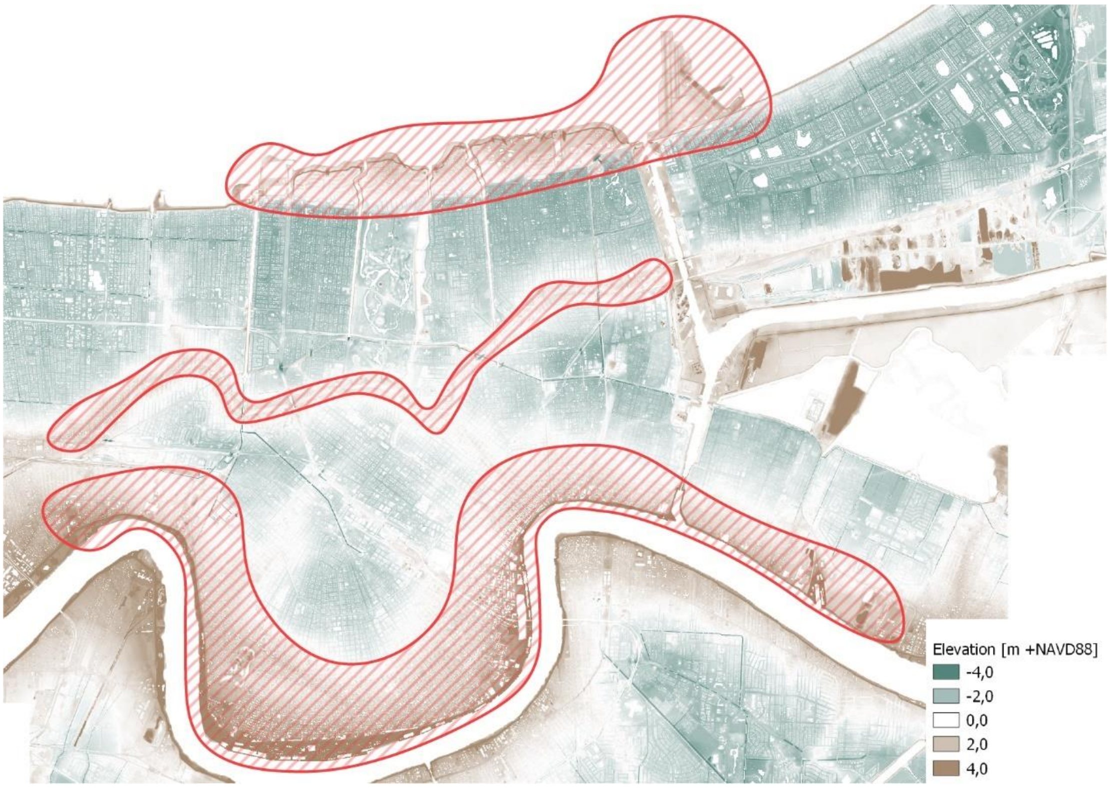


*Figure 3.11: Advised priority zoning for green infrastructure.*

## 3.6 Sub conclusion

- Although New Orleans possesses at most locations a clay soil, the top surface is permeable enough to support the construction of green infrastructure. The focus should be on the development of green infrastructure on higher ground. Of course, starting with public zones like parks. This will not only reduce storm drainage but increase groundwater recharge.
- In the past a lot of rain water was stored in cisterns, and therefore not drained. Rehabilitation of these cisterns or adding rain barrels will help to retain more water at “lot scale”.
- Only large area Green Infrastructure will help to reduce subsidence.
- Parks should not drain storm water into the public storm drainage system.
- At this moment all infiltrated rainwater and all of groundwater discharge (arriving from Lake Pontchartrain, Outfall canals and Mississippi) is drained by leaking pipes (storm drainage, waste water). The drinking water loss is higher than natural recharge by rain (minus evaporation). Therefore, networks need to be replaced and repaired. During (after) this renovation of the underground network activities the groundwater situation will change (probably rising groundwater levels) and additional interventions are needed, e.g. installation French drains on top of the new storm drainage pipes and waste water transport pipes.
- The choice of vegetation needs specific attention. Shrubs and trees support storage more than e.g. turf.

# 4 Gentilly: Polders without canals

## 4.1 Context

New Orleans has multiple city districts that have an elevation below sea level. Safe urbanization of these areas requires a thorough understanding and control of the (geo)hydrological processes. Urbanized areas below sea level face multiple risks: coastal, pluvial and groundwater flooding, subsidence and (brackish) seepage.

In the Netherlands, low lying areas which are hydrologically controlled are called ‘polders’. A polder can be defined as an area with minimal slope that is separated from the surrounding hydrological regime to control its surface water and groundwater level (Hoes & Van de Giesen, 2018).

An essential part of any polder is surface water: it is the main instrument by which the aforementioned risks can be mitigated. Although the low-lying parts of New Orleans can be classified as polders, they hardly contain regulated surface water bodies. This is especially true for Gentilly: all components of the urban water cycle are buried underground. Pumps switch on whenever the water level in downstream basins rise, but there is no control over the flow and groundwater levels in more upstream parts of the polder. In general, surface water in New Orleans is not regulated to control groundwater and stormwater storage capacity.

In figure 4.1 and 4.2 the New Orleans and Dutch type of polders are visualized.

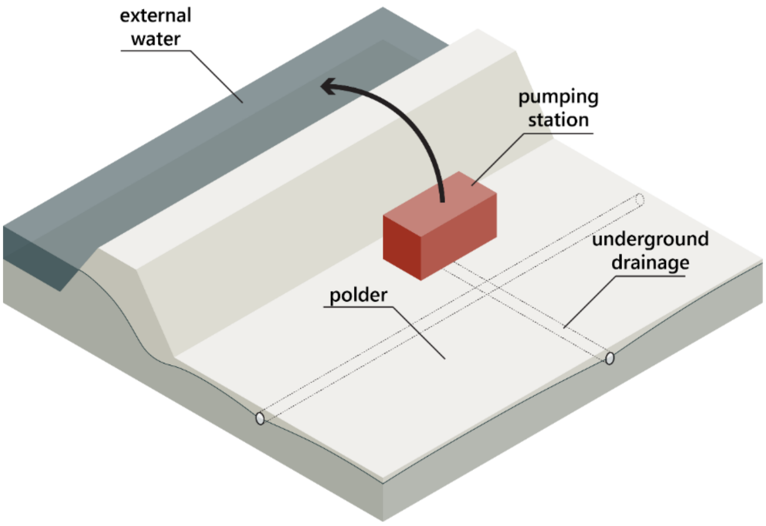


*Figure 4.1: An illustration of a New Orleans type of polder.*

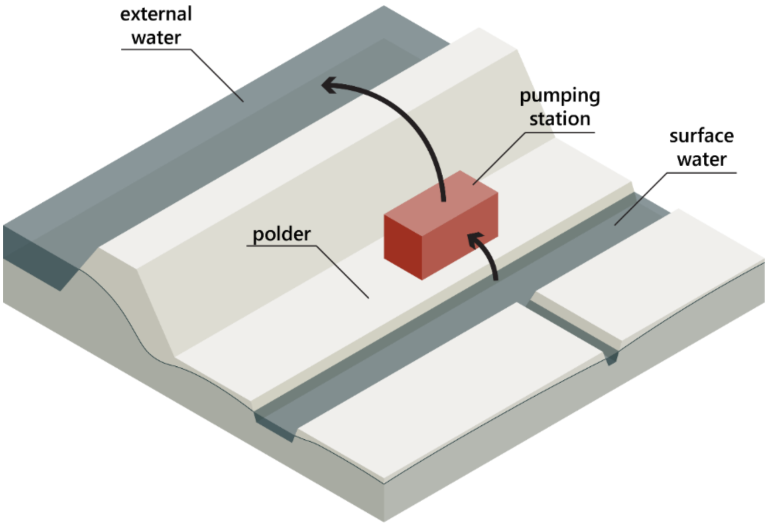


*Figure 4.2: An illustration of an improved Dutch-like type of polder. Adding open water to create storage.*

## 4.2 Water assignment

New Orleans is often exposed to severe precipitation which overwhelms the city's storm drainage system. The amount of water that should be stored to prevent flooding is defined as **the water assignment**. Through an (urban) water balance model, the water assignment can be calculated for rainfall events of different return periods. The catchment of Pumping Station 4, which encompasses Gentilly, has an estimated water assignment to prevent flooding by rainfall that statically occurs every 10 years( 10 inch in 24 hours) of 466 acre-foot, or 575,000 $m^3$ (Rooze, 2020). This is equal to 230 Olympic-size swimming pools.

Now, water storage in Gentilly is much too low. The existing storm drainage pipes possess minimal storage. During serious rain storms the pipes will be completely filled with water in short time (figure 4.3). Therefore, the construction of surface water is needed.

In the case of an intense rain event, a traditional drainage system consisting of pipes would quickly fill with rainfall runoff. With nowhere for the water to go but up, flooding would take place almost instantaneously. Because the system is filled, even upstream parts can vulnerable to flooding. Introducing (small) canals creates more surface storage for runoff. A narrow canal can hold a significant amount of water before it overflows. Even if its limits are reached, the extent of flooding is more manageable than a system consisting only of overflowing pipes. The wider the canal, the more water can be accommodated before overflow occurs.

Although part of the solution, green infrastructure facilities in the form of rain gardens, bioswales and permeable pavement alone are insufficient to cover the full water assignment. For reference, a large, lot-filling rain garden has a typical storage capacity of 80,000 gallons (~360 $m^3$). To account for the full water assignment, the catchment of Pumping Station 4 alone would need about 1600 lot-size rain gardens such as the one on the intersection of Wildair Drive and Filmore Avenue. Smaller rain gardens at street corners usually have a capacity that is 10 times smaller than lot-size rain gardens.

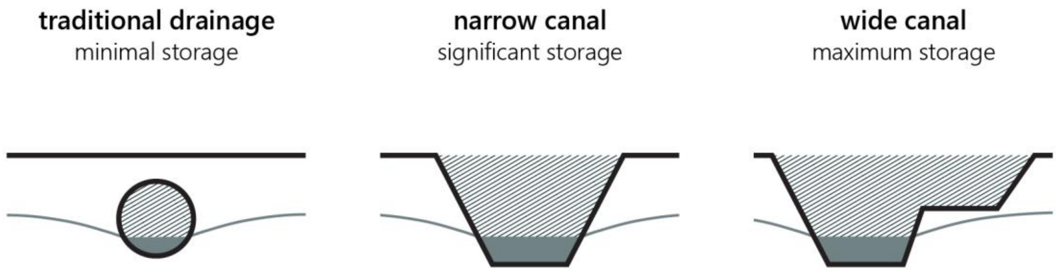


*Figure 4.3: Illustration of creating extra storage capacity when replacing pipes with surface storage and drainage.*

## 4.3 Large-scale interventions

Introducing well-managed open water into the polder catchments of New Orleans would greatly contribute to managing the water assignment. Relative to their size, surface water bodies have the highest water storage capacity. Most New Orleans neighborhoods have streets with a wide right-of-way and could host significant surface water bodies. At vulnerable, low spots, extra surface water can be added to the system. Figure 4,4 shows an example of a surface water network integrated in Gentilly's urban fabric.


*Figure 4.4: introducing surface water into the New Orleans Polders would greatly contribute to the water assignment.*

**Handling extreme events**

A Blue-Green drainage system can handle larger storm events than traditional drainage pipes. With climate change scenarios, the intensity of rain storms is only expected to increase. When using space flexibly, the water system can be adapted to meet future rainwater detention norms. However, every system has its limit. It is (nearly) impossible to design for hurricane-like storms. For these situations, the focus should be on effective evacuation and damage mitigation.

## 4.4 Sub conclusion

- Small Green infrastructure interventions cannot solve pluvial flooding in Gentilly for larger rain storms. To manage future rain storms and meeting the water assignment, the construction of a surface water network is needed.
- Individual Green Infrastructure facilities do play a role in accommodating smaller rain storms and related (very) local flooding. It also helps in creating awareness. Therefore, it can help to encourage the construction of interventions for local rainwater retention in the capillaries of the storm water system (especially private properties).

# 5 Distribution of existing blue green infrastructure in New Orleans

## 5.1 Mapping existing blue green infrastructure

The open source citizen science platform ClimateScan (Restemeyer & Boogaard, 2021) shows over 200 locations where Green Infrastructure is implemented on private and public areas (figure 5.1). Most location are concentrated in the low-lying areas (below sea level), or in areas with relatively little green zones (e.g. Central City)

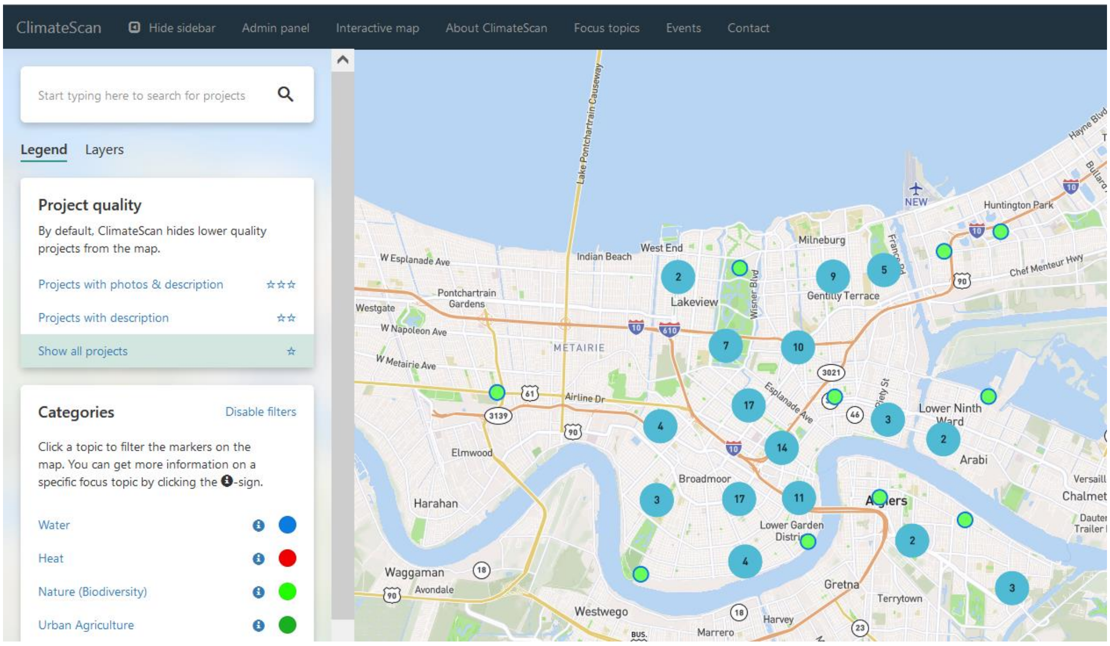


*Figure 5.1 over 200 Locations are mapped in New Orleans (raingardens, permeable pavement, bioswales) at public and private properties*

### 5.1.1 Increasing number of private initiatives

Already many individuals, schools and companies installed green infrastructure at their properties. From simple and cheap designs to more elaborated designs (figure 5.2). The City of New Orleans (Inc. NORA) and SWBNO also subsidized private property green infrastructure projects. The number of locations, size and effectiveness is not clear. When every property retains, and perhaps re-use, rain water at their property a big step in storm water resilience will be made. Managing storm water starts at these capillaries of the storm water drainage system.

*Figure 5.2: Example of a more elaborated rain garden in the neighborhood Irish Channel*

## 5.2 Opportunities to transform existing green space into blue green infrastructure

Next to the often-small private rain gardens, and the somewhat larger “empty lots” rain gardens many other and better opportunities exist to create large surfaces of water storage.

- Existing parks. The situation in Audubon Park is explained in 3.4.1. But many other parks of different sizes could be transformed in blue green infrastructure to store water from the surrounding areas. Of course, starting to not drain storm water in the public storm drainage system.
- City park: Because of its size and location s special opportunity. In 2019 already a project was granted to study and re-design the water system in the park to retain storm water, but also store water from the Lake Vista neighbourhood, to reduce urban flooding in Lakeview.
- Street car network: this network with a length of approx. 24 miles (approx. 30 feet wide) possesses an enormous opportunity to store storm water from the adjacent streets (e.g. in the Garden district and Uptown), or only retain rain water in the more impermeable areas (city centre). In these impermeable areas parts of the network could be transformed into lawns, also adding green into “petrified” area (figure 5.3). The idea is not the removal of street cars but trying to find a combination of street car network and green infrastructure. The best cost-effective solution is creating linear shallow swale depressions. An alternative could be the installation of IT (Infiltration-Transport) drains[4].

[4] In the Netherlands the material costs are: (1) concrete tubes (Ø 500 mm) Eur 500/meter, (2) PVC (Ø 200 mm) Euro 75/meter,

*Figure 5.3: The street car network possesses potential of store rain water from the adjacent streets.*

- ❑ Currently unused green locations like Mirabeau
  Good examples of recently constructed larger green infrastructure interventions are (1) the Storm water park at Southern University (Emmett W Bashful Blvd, 217,000 SF storage) and (2) the long Planted bioswale parallel at Prentiss Ave, near Press Dr. (145,000 SF storage).
- ❑ Median strips (“neutral grounds”): The median strips of main roads (e, g Elysian Fields Ave, Paris Ave) possess great opportunities to retain and store water. These grounds are often of cultural significance in New Orleans and therefore is this solution perhaps an unpopular suggestion. But a shallow depression (approx. 1 foot) would not really change the landscape. Figure 5.4 visualizes the opportunities in using the neutral grounds. Each alternative is briefly explained below.
  1. The current situation: all stormwater is drained into the catch basin and transported towards a pumping station. There is very little storage in the system and even a minor flooding event causes damage.
  2. Alternative 1: only rain that falls on neutral grounds is stored and can infiltrate or evaporate over time.
  3. Alternative 2: as alternative 1, but also water from the streets is discharged to and stored in the neutral grounds. Therefore, the slope of the streets needs to be adapted. This is a major intervention, but it becomes feasible when coupled with planned road maintenance/reconstruction. This alternative store the most amount of water.
  4. Alternative 3: Installation of an IT-drain. Depending on the existing underground infrastructure this IT-drain can be installed below the neutral grounds, or below the street or sidewalks. The slope of streets stays as it is. Although this system allows for stormwater infiltration, it still does not meet the storage demand. Figure 5.5 shows the installation of an IT-drain in Amsterdam. Figure 5.6 explains the operation of such a drain.

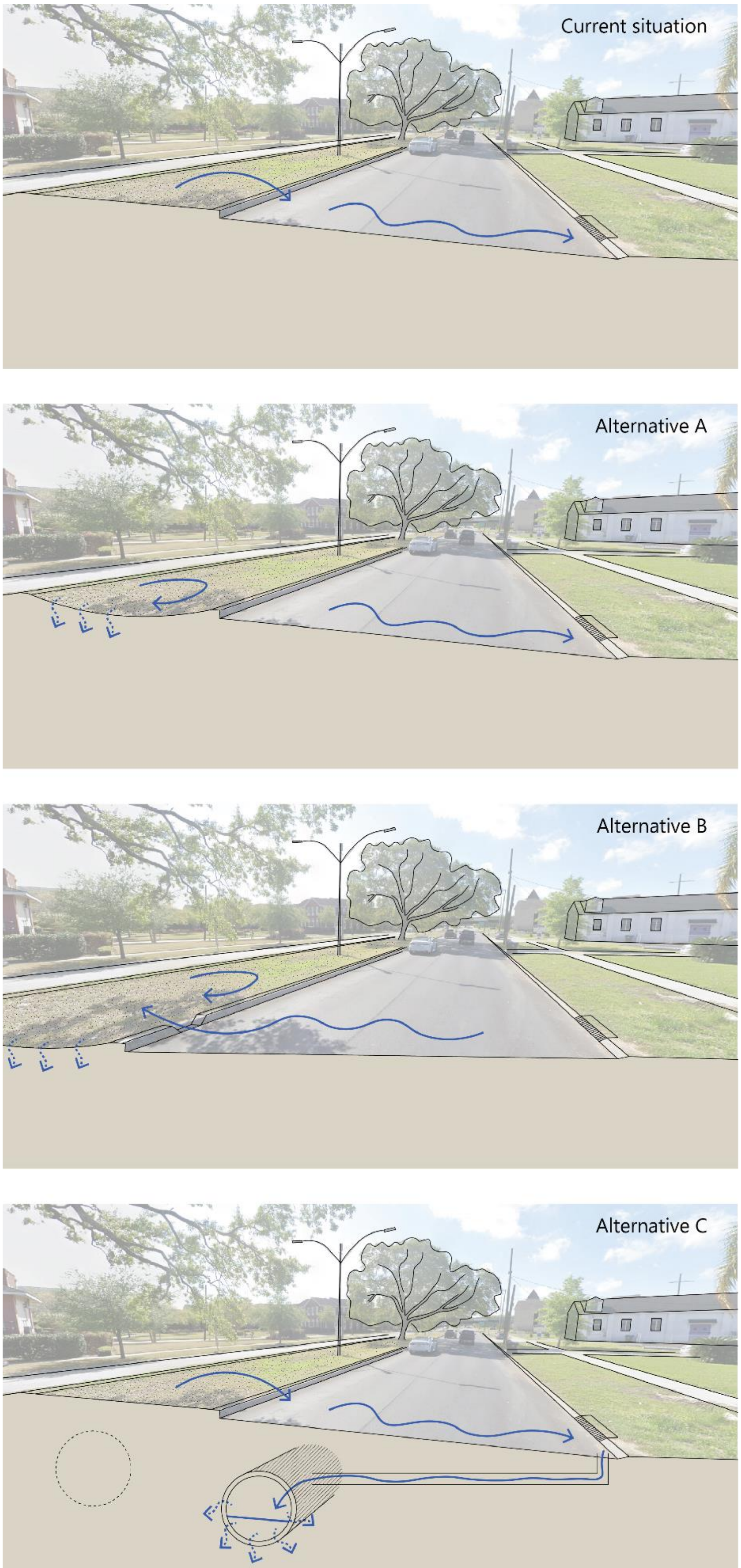


*Figure 5.4: Example of neutral grounds storage opportunities*

Figure 5.5: Installation IT-drain in Amsterdam (Amsterdam Rainproof)

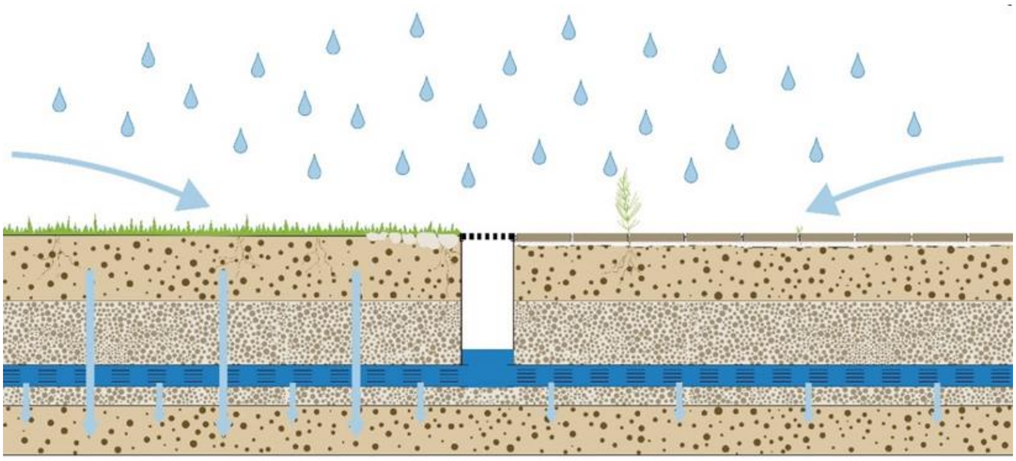

Figure 5.6: Schematic cross-section IT drain (source Amsterdam Rainproof, Atelier Groenblauw). Stormwater from roads is transported towards the catch basins and into the IT-drain. When the groundwater level drops below this drain, infiltration will take place.

## 5.3 Public opinion and community involvement?

### 5.3.1 Awareness and (mis-)understanding

In order to effectively promote climate adaptation an understanding of the role of community in Green Infrastructure development is essential. In most cities there is a lack of understanding about climate change and the interactions of technical and non-technical factors that promote or hinder Green Infrastructure implementation. Community participation should be embedded in collaborative partnership efforts for design, building and maintenance of Green Infrastructure. Community education addresses the challenge of resistance to change, hence community education plays a role in its development and implementation. For this reason, the testing in New Orleans was set up as a *ClimateCafé* involving different stakeholders in design, building and maintenance of Green Infrastructure. ClimateCafé is a field education concept involving different fields of science and practice for capacity building in climate change adaptation. For ClimateCafé New Orleans we involved Groundwork.

During testing a few residents that live near Green Infrastructure approach us to get more information about the raingardens or swales. Information boards can help to give an understanding of the Green Infrastructure and how it should function. However only in 4 of the 22 test locations provided an information board for communication purposes.

An example of misunderstanding is the discussion around the storm water emergency storage in City Park to reduce urban flooding in Lakeview. Lake Vista residents (living on high grounds) are concerned believing that this intervention could create risks for their property and oppose to it (Figure 5.7). They would rather see improvements to existing pipes and pumps (NOLA.com, Ben Myers, May 2022). For us is unclear what the objections of these residents are.


*Figure 5.7: Protest in Lake Vista against stormwater storage in City Park. Note: Storm water from Lake Vista is drained by gravity into Allen Toussaint Blvd.*

### 5.3.2 Health and safety

Green Infrastructure (GI) can pose challenges for urban planning and public health & Safety. The integral and proper design, construction and maintenance of green infrastructure can minimize risks. Frequently asked questions about raingardens and bioswales concert mosquitos and the risk of children drowning. Design guidelines such as a minimum depth of 1-1,5 feet (30-50 cm) and side slopes not steeper than 1:3 help to keep the green infrastructure safe for getting out of the storage volume and accessible for maintenance.

An empty time within 48 hours is advised since mosquitos need several days as incubation time. In addition, the New Orleans Mosquito, Termite and Rodent Control Board in general advises to control the mosquito population by:

- Remove trash and clutter like old tires, buckets, and tarps.
- Empty standing water from containers like pet dishes, children's toys, and flowerpots.
- Keep water fresh in containers like bird baths and kiddie pools.
- Clean gutters and catch basins.
- Call 311 to report illegal dumping, abandoned swimming pools, and water leaks.

If these advises are applied to Green Infrastructure, especially the catch basins and overflow constructions should be monitored. Also, trash, like empty bottles, should often be removed.

In general, during the designs of Green Infrastructure the use of (biological) predators of mosquito larvae should be included like creating favorable conditions (trees, worms) for birds and, according to New Orleans Mosquito etc. Board, in case of surface water bodies, fish (Gambusia affines), turtles, copepods, Toxorhynchites (cannibal mosquito), bacterial lavicides. Also, dragonflies are natural predators for mosquitoes. In fact, they eat them at all stages of life. An individual dragonfly can eat hundreds of mosquitoes each day.

*Figure 5.7: Explaining groundwater, geology and subsidence.*

## 5.4 Costs

Design, construction and maintenance costs are important aspects that determine the success in upscaling green infrastructure projects and contributing to the water balance. This report does not cover an elaborate cost-benefit analysis of green infrastructure facilities but provides a quick overview of available cost figures. This assessment only considers rain garden

A distinction is made between initial costs (design & construction) and recurring costs (annual maintenance). The goal of this assessment is to obtain insight in which types of green infrastructure with a certain set of features has the lowest cost (expressed in $/m3 of storage). The cost figures in this comparison are provided by the facility designers, developers and via the NOLA One Stop App permits database (https://onestopapp.nola.gov/).

Table 5.1 gives an overview of the construction costs and costs per cubic meter of storage for the NORA rain gardens. It appears there are large differences between the cost-efficiency between the various lots. One explanation is that NORA lots usually have secondary goals next to stormwater detention, mostly educational or cultural. Still, given the large water assignment for New Orleans, it is desirable to move towards a rain garden model that maximizes storage capacity for every dollar invested. For maintenance costs, it is estimated that NORA lots are maintained roughly 16x per year, for a total of $700 per maintenance run. This equals a total maintenance budget of $11,200 per year for all facilities. All NORA facilities combined have a design capacity of 832.7 $m^3$; total maintenance costs per $m^3$ of storage per year is 13.45 $\$/m^3$/year.

The storage costs in $\$/m^3$ of storage and maintenance costs in $\$/m^3$/year for various projects found on the NOLA One Stop App are given in Table 5.2. The design and construction costs vary greatly; maintenance costs are around 100 $\$/m^3$/year, with a few exceptions.

The overall average storage costs are 1960 $\$/m^3$ of storage; the average maintenance costs amount to 82.57 $\$/m^3$/year.
Based on these numbers, filling up of the total water assignment of Gentilly (575,000 m3) will cost approx. 1 billion dollars. The yearly maintenance costs will then be 47 million dollars per year.

*Table 5.1: features and construction costs of NORA rain gardens.*

| Location | Surface area [m2] | Storage capacity [m3] | Design and construction costs [$] | Storage costs [$/m3] | Maintenance costs [$/m3/year] |
|---|---|---|---|---|---|
| 5703 N Claiborne Ave | 367.9 | 76.1 | 32615 | $428.66 | $13.45 |
| 1728 N Deslonde Street | 408.8 | 15.6 | 23689 | $1,521.14 | $13.45 |
| 5302 Wildair Drive | 1035.9 | 336.9 | 37909 | $112.52 | $13.45 |
| 1338 Nunez Street | 538.2 | 22.4 | 24931 | $1,114.40 | $13.45 |
| 1925 North Rochblave Street | 2029.5 | 24.2 | 101500 | $4,189.61 | $13.45 |
| 5019 Press Drive | 623.4 | 159.0 | 23879 | $150.19 | $13.45 |
| 2222 N Broard Street | 655.3 | 8.6 | 111213 | $12,874.40 | $13.45 |
| 2427 South Galvez Street | 328.9 | 117.6 | 30204 | $256.74 | $13.45 |
| 8641 Forshey Street | 354.1 | 24.2 | 23236 | $959.11 | $13.45 |
| 1601 Oretha Castle Haley Blvd | 187.3 | 10.2 | 97000 | $9,490.63 | $13.45 |
| 4759 Sandalwood Street | 628.0 | 37.9 | 69490 | $1,835.73 | $13.45 |

*Table 5.2: Construction and annual maintenance costs per cubic meter of storage for projects retrieved from One Stop App.*

| Location | Storage costs [$/m3] | Maintenance costs [$/m3/year] |
|---|---|---|
| 510-550 N. Carrollton Avenue | $1,506.02 | $19.86 |
| 3403 Freret St, 2500 Louisiana Ave, 2520 Louisiana Ave, 2526 Louisiana | $1,014.65 | $85.83 |
| 3943 St Bernard Ave | $488.07 | $64.87 |
| 1902 St Bernard Ave | $3,141.87 | $112.46 |
| 1102 City Park Ave, 5691 Marconi Dr, 1 Stadium Dr, 2 Stadium Dr, 4 Sta | $463.03 | $21.37 |
| 4401 N Robertson St | $2,949.75 | $823.19 |
| 1508 Orleans Ave, New Orleans, LA 70116 | $1,067.22 | $80.01 |
| 3815 St Bernard Avenue | $656.46 | $101.02 |
| 1917-1923 Mirabeau Ave | $387.30 | N/A |
| 4400 General Meyer Ave | $1,564.48 | $51.08 |
| 1102 City Park Ave, 5691 Marconi Dr, 1 Stadium Dr, 2 Stadium Dr, 4 Sta | $92.60 | $28.74 |
| 6750 Freret St, 6811 Freret St, 6823 St Charles Ave, 6401 Willow St, 1 | $366.52 | $178.36 |
| 3108 St Thomas St | $3,298.05 | $290.26 |
| 1800-1892 Wilton Dr, 4951-4953 Warrington Dr, 1801-1893 Mirabeau Ave | $265.49 | $40.04 |
| 1100 Milton St | $3,552.06 | $87.02 |
| 2228 Gravier St | $785.39 | $24.66 |
| 1601 Lafitte Avenue, New Orleans, Louisiana | $912.19 | $72.80 |
| 1730 Tchoupitoulas St, 427 Celeste St, 428 St James St | $1,386.04 | N/A |

## 5.5 Sub conclusions

- The construction and maintenance costs of Green Infrastructure to accommodate the water assignment of New Orleans, based on costs of already existing NGI will be very high.
- But existing and new ones can help to create awareness. In that case communications needs extra attention.
- To reduce storm drainage large simple, cheap interventions are needed (figure 5.6). For example, miles-long (minimal engineered) raingardens in the median strips of roads, or in the street car network.

*Figure 5.6: An example of a simple and cheap vegetated storage pond (constructed wetland) in Amstelveen (the Netherlands). Maintenance: mowing reeds once a year. Construction: digging a depression connected with parking of local hospital.*

# 6 Testing of New Orleans Green Infrastructure facilities

## 6.1 Introduction

A total of 27 tests have been carried out across 23 unique Green Infrastructure facilities: 16 rain gardens/bioswales and 7 permeable pavement facilities. Figure 6.1 shows an overview of the test locations across New Orleans. The planning organization is available in appendix A. All locations, including pictures are visible on the website “Climatescan”. (https://www.climatescan.nl/map/legacy)

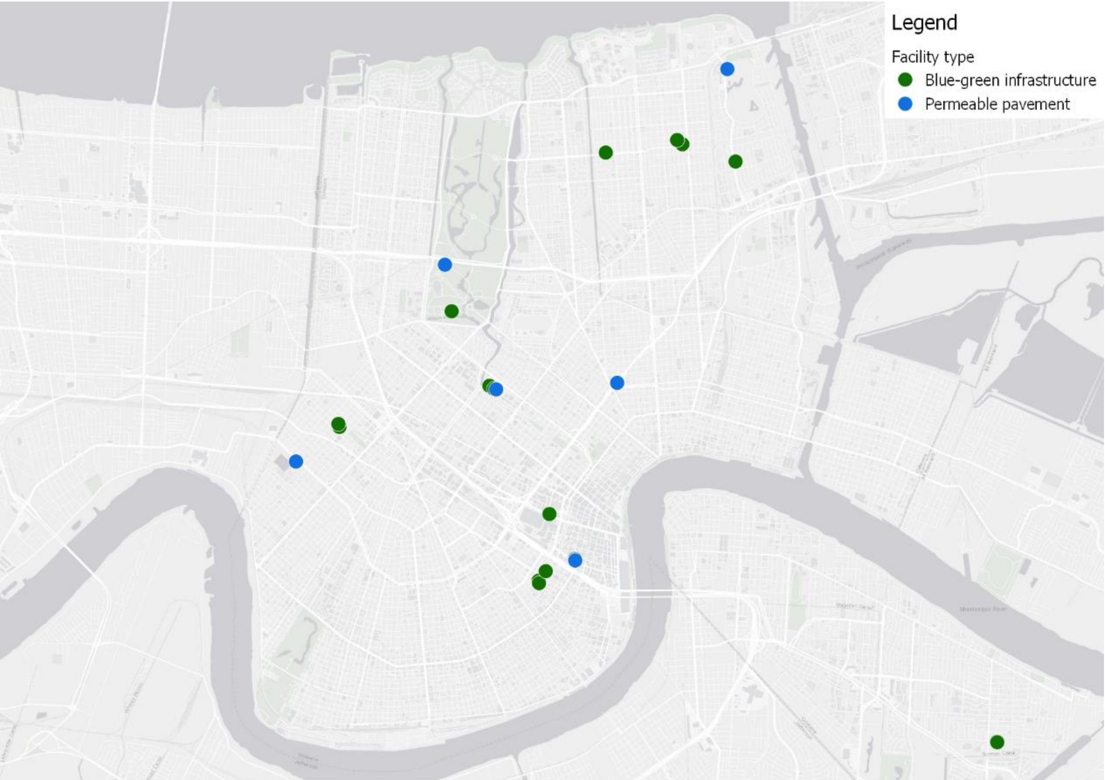


*Figure 6.1: Test locations across New Orleans. Most facilities tested are located on the northern bank of the Mississippi river.*

The performance of the 23 tested facilities were determined using two main methods: ring infiltrometer and full-scale testing. Section 6.3 provides a detailed description of the testing methods. Some facilities were tested using both methods.

Table 6.1 and Table 6.2 show an overview of all tested locations and information regarding their design.

*Table 6.1 Rain gardens, bioswales and bioretention cells.*

| Facility number | Name | Owner | Construction year | Type of test | Design capacity [cf]* |
|---|---|---|---|---|---|
| **GI1** | City Park Tricentennial parking lot | City Park | 2011 | full-scale | 4680 |
| **GI2** | Wildair | NORA | 2014 | full-scale | 11898 |
| **GI3** | Milne - eastern bioswale | | | full-scale | |
| **GI4** | Milne - northern bioswale | | | full-scale | 7214 |
| **GI5** | Press Drive | NORA | | full-scale | 4694 |
| **GI6** | NORA OC Haley - rain garden | NORA | | full-scale | |
| **GI7** | Groundwork OC Haley, next to no.1520 | NORA | | full-scale | |
| **GI8** | Groundwork OC Haley, next to no.1307 | NORA | | full-scale | |
| **GI9** | GNOF rain garden | GNOF | 2016 | full-scale | |
| **GI10** | Aurora rain garden | SWBNO | 2017 | full-scale | |
| **GI11** | Aurora swale | SWBNO | 2017 | full-scale | |
| **GI12** | Greenline pavilion swale | SWBNO | 2016 | full-scale | 6345 |
| **GI13** | Hollygrove - Forshey St | | | full-scale | 855 |
| **GI14** | Lafitte rain garden (Toulouse & N. Lopez St) | | | full-scale | |
| **GI15** | Lafitte rain garden (Toulouse & N. Rendon St) | | | full-scale | |
| **GI16** | City Hall rain gardens | City of New Orleans | | infiltrometer | 800 |

*Table 6.2 Permeable pavement sites.*

| Facility number | Name | Owner | Construction year | Type of test |
|---|---|---|---|---|
| **PP1** | City Park Administration building | City Park | 2011 | full-scale & infiltrometer |
| **PP2** | SWBNO parking lot | SWBNO | 2014 | full-scale & infiltrometer |
| **PP3** | Hunters field | | | full-scale & infiltrometer |
| **PP4** | SUNO permeable pavement | City of New Orleans | 2019 | full-scale & infiltrometer |
| **PP5** | NORA OC Haley | NORA | | full-scale & infiltrometer |
| **PP6** | GNOF permeable pavement | GNOF | 2016 | full-scale & infiltrometer |
| **PP7** | Lafitte permeable pavement (Toulouse & N. Lopez St) | | | infiltrometer |

*1 cubic foot = 0.028 cubic meters

## 6.2 Weather circumstances before and during the tests

Our test period was October 17-22, 2022. During September and early October, New Orleans received a total of 46 mm (1.82 inches) of rainfall (NOAA-NCEI, 2022). Compared to over the average climate during this period, September 2022 was exceptionally dry. A few days before testing began some rainfall occurred, but the preconditions were mostly dry. Over the testing period, no additional rainfall occurred (see Figure 6.2). This makes the test results more comparable and illustrative.

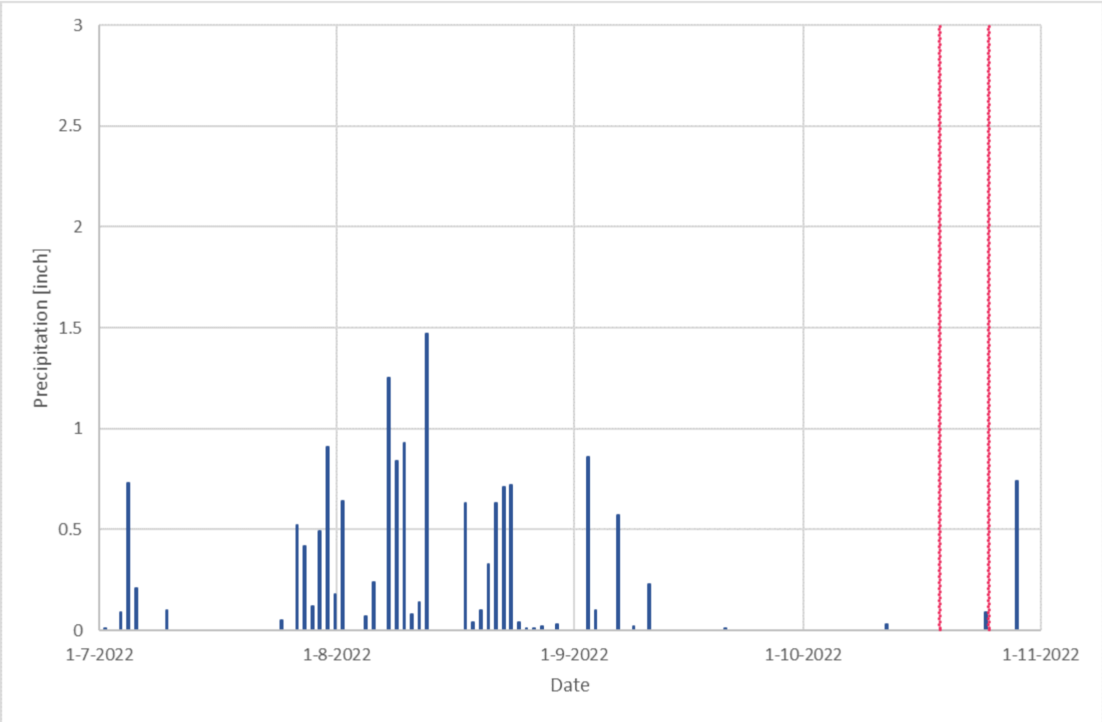


*Figure 6.2: Minimal precedent rainfall to testing (source: NOAA-NCEI, Lakefront Airport). Period between red lines is testing period.*

## 6.3 Testing methods

Measuring infiltration rates accurately in the field is not easy and a variety of infiltration test procedures have been utilized in the past. As previously discussed, the results have shown a large variation in the range of infiltration rates measured. Currently, there is no single standard agreed method for measuring the surface infiltration through permeable pavements, raingardens and swales. Numerous studies have tried to successfully measure the surface infiltration rate of permeable pavement systems done by measuring the infiltration rate of water through a particular section of the pavement surface most are based on some type of modified single- or double-ring infiltrometer test.

A number of ring-infiltrometer tests have been developed in the USA, and these are often used to test the permeability of permeable pavements in American studies. The two main infiltration tests used on pavements in the USA are the ATSM C1781 (*ASTM C1701/C1701M-17a Standard Test Method for Infiltration Rate of In Place Pervious Concrete*, 2020) and NCAT permeameter methods (Li et al., 2013). The ATSM C1781 test method was developed under the jurisdiction of the ASTM Technical Committee and uses the constant head principle. The NCAT permeameter was developed by the National Centre for Asphalt Technology (NCAT) in the late 1990s and uses the falling head principle. The single- and double-ring infiltrometer tests are based on the infiltration rate through a small area of the pavement that is used to represent the infiltration rate of the total pavement area: the area of the inner ring of the ATSM C1781 (2015) test is 0.0707 m2. Using such small areas for testing could potentially lead to erroneous results, as a number of studies have demonstrated a high degree of spatial variability between different infiltration measurements undertaken on the same pavement installation.

A number of studies have demonstrated a high degree of spatial variability between different infiltration measurements performed on the same pavement location (Lucke & Beecham, 2011; Pezzaniti et al., 2009). By inundating a much larger area of pavement during testing, it was shown that any spatial variations in infiltration capacity were effectively averaged-out, and this produced more reliable infiltration data. Therefore the full-scale infiltration testing (FSIT) method was applied in this study to determine the surface infiltration rate of existing permeable pavement installations in the New Orleans as performed on more than 100 existing permeable pavement installations (F. Boogaard & Lucke, 2019; Lucke et al., 2014; Veldkamp et al., 2022).

### 6.3.1 Full-scale infiltration method

For the case study New Orleans some single infiltrometer test are performed for comparison with the full-scale infiltration test where (a large part of) the volume of green infrastructure is filled and the emptying time (falling head) was measured. During the experiments stakeholders are invited in an international ClimateCafe setting (Floris C. Boogaard et al., 2020; Floris C. Boogaard & de Jong, 2020) to raise awareness and capacity building and get information about the lifespan of Green Infrastructure such as year of construction, design criteria and maintenance.

Most green infrastructure such as swales and raingardens have a confined space which can be filled without any additional constructions to prevent water leaving the storage volume during the full-scale infiltration test (figure 3 left). For the testing of permeable pavement, a confined space is made by making a dike of sandbags (figure 6.3 right). For the full-scale infiltration test in New Orleans, a fire hydrant was used if available or a water basin of 110 litres (figure 6.3).

*Figure 6.3 left: full-scale test at raingarden Milne (test number 14, table 1). Right: full-scale test at permeable pavement after building a confined space with plastic and sandbags.*

Wireless, self-logging, pressure transducer loggers (Minidiver. were used in the study as the primary method of measuring and recording the reduction in water levels over time. Loggers were installed at the lowest points of the green infrastructure. The transducers continuously monitored the static water pressures at those locations, logging the data in internal memory. Additional measurements were used in conjunction with the pressure transducers in order to verify the transducer readings: hand measurements, underwater camera and time-lapse photography (movies available at ClimateScan.org). At some locations water quality and soil quality measurements are taken and continuous loggers are installed for follow up research. At some locations drillings of the soil are made to get more information on the soil type and groundwater table (figure 6.4).

*Figure 6.4 measurement with loggers and rulers (left) and additional info by drilling the soil (right)*

### 6.3.2 Ring infiltrometer method

The ring infiltrometer method deploys the same measurement techniques as the full-scale infiltration method. The main difference is the size of A pressure transducer (diver) logs the water depth every 5 seconds. Using a ring infiltrometer to determine the infiltration capacity of permeable pavement is the approved and preferred testing method by the SWBNO.

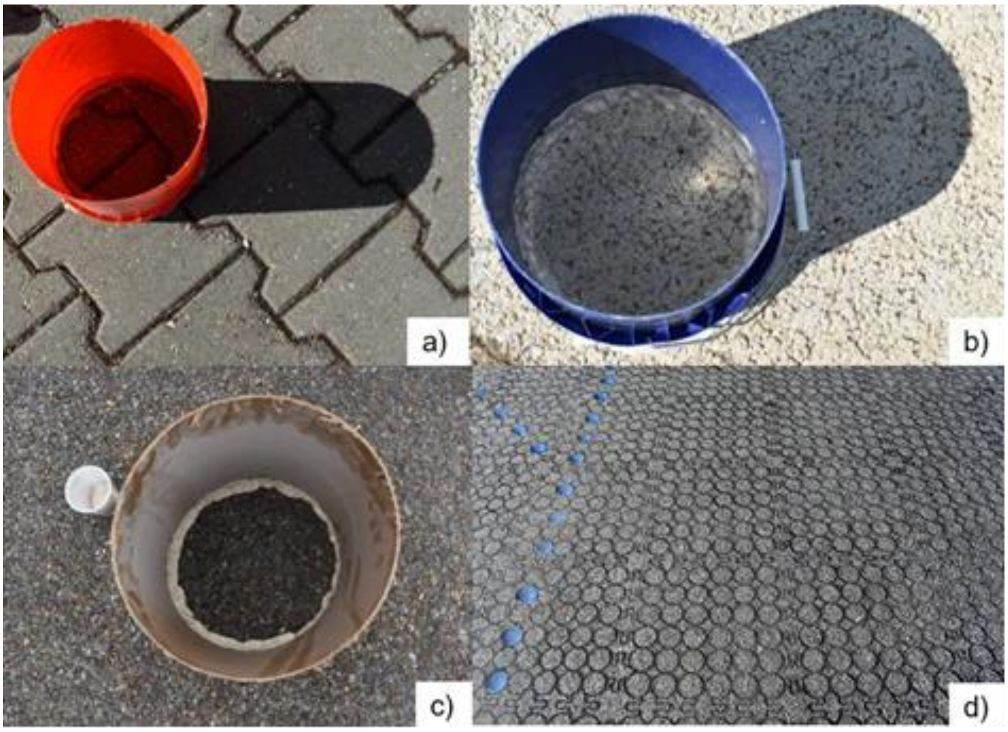


*Figure 6.5: Permeable pavement variants in New Orleans during testing (a) Impermeable concrete interlocking pavers; (b) porous concrete; (c) porous asphalt; (d) plastic grid pavers.*

*Table 6.3: Effects of boundary conditions on permeability (Schönberger et al., 2005)*

| Influencing factor | Effect on water permeability |
|---|---|
| Age | With increasing age, dirt particles are introduced into the pavement, which can reduce water permeability. However, the degree of contamination does not primarily depend on the age of the pavement, but primarily on the use and location (in terms of sunlight and vegetation). |
| Pollution | Dirt particles, such as dust and moss, can significantly reduce water permeability. |
| Use | The type of use, such as driving on the permeable surface with vehicles, can lead to the entry of dirt particles and possibly cause settlement of the pavement. This can reduce the permeability. |
| Vegetation and solar radiation | Surfaces underneath trees or shrubs and in shaded areas often showed increased moss growth or soiling by leaves, flowers, pollen dust or needles. As a rule, these surfaces had lower infiltration rates than the adjacent clean surfaces. |
| Cleaning | The permeability of a pavement can be increased or maintained by cleaning the pavement (including the joints). |
| Wetting of the pavement | The water content of a pavement (i.e., the weather conditions prior to an infiltrometer test) can significantly influence the infiltration rate. |
| Installation (own work/specialist company) | No fundamental differences were observed between installation by a specialist company or a private individual with an effect on the water permeability of a pavement. An installation error in the form of sweeping a fine sand into a pile-porous stone can reduce the water permeability. |

### 6.3.3 Testing of rain gardens, bioswales and bio retention cells

Most green infrastructure have a confined depression which can be filled using a tank truck or fire hydrant without any additional constructions to prevent water leaving the storage volume during the full-scale infiltration test (figure 6.6). Whenever the storage capacity of the facility was too large for reliable testing, a portion of the facility was dammed off to prevent water from spreading into the entire depression.

In addition to infiltration rates, some locations received additional testing:

- Water quality and soil quality measurements;
- Installation of a diver that continuous loggers water depth over a period of 6 months;
- Shallow boreholes to obtain more info on the subsurface and groundwater depth.

*Figure 6.6: Example of rain garden test, making use of fire hydrant.*

#### 6.3.4 Testing of permeable pavement

Permeable pavement facilities were tested by enclosing and waterproofing a parking place-sized area with a dam, and to stage 2-5 cm (1-2 inches) of water (figure 6.7). Using the divers, the pressure at three different spots was logged every 5 seconds.

*Figure 6.7: Example of a full-scale permeable pavement test (parking SWBNO)*

## 6.4 Results

As the construction, norms and design goals of both types of facilities are fundamentally different, test results are analysed separately for rain gardens and permeable pavement. Table 6.4 provides an overview of the test results.

*Table 6.4: Aggregated test results of all tests. Abrieviations: RG = Rain Garden, PP = Permeable Pavement, FS = Full-Scale, IM = Infiltrometer, It. = Iteration.*

| Facility number | Test no. | Test name | Facility type | Type of test | Infiltration speed [meter/day] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | It. 1 | It. 2 | It. 3 | It. 4 |
| **GI1** | 1 | City Park Tricentennial parking lot | RG | FS | 7.52 | | | |
| **PP1** | 2 | City Park Administration building | PP | FS | 0.7 | | | |
| **PP1** | 3 | City Park Administration building - infiltrometer | PP | IM | 0.83 | | | |
| **PP2** | 4 | SWBNO parking lot | PP | FS | 1.73 | | | |
| **PP2** | 5 | SWBNO parking lot - infiltrometer | PP | IM | 2.43 | | | |
| **PP3** | 6 | Hunters field | PP | FS | 1.73 | | | |
| **GI2** | 7 | Wildair | RG | FS | 16 | | | |
| **GI3** | 8 | Milne - eastern bioswale | RG | FS | 12.73 | | | |
| **GI4** | 9 | Milne - northern bioswale | RG | FS | 10.3 | | | |
| **GI5** | 10 | Press Drive | RG | FS | 30.7 | | | |
| **PP4** | 11 | SUNO permeable pavement - infiltrometer | PP | IM | 61.4 | | | |
| **PP4** | 12 | SUNO permeable pavement | PP | FS | 8.72 | | | |
| **GI6** | 13 | NORA OC Haley - rain garden | RG | FS | 10.34 | | | |
| **PP5** | 14 | NORA OC Haley - permeable pavement | PP | FS | 2.16 | 2.2 | | |
| **GI7** | 15 | Groundwork OC Haley, next to no.1520 | RG | FS | 22.2 | | | |
| **GI8** | 16 | Groundwork OC Haley, next to no.1307 | RG | FS | 3.54 | | | |
| **PP6** | 17 | GNOF permeable pavement - full scale | PP | FS | 6.35 | 4.11 | 3.9 | 2.79 |
| **PP6** | 18 | GNOF permeable pavement - infiltrometer | PP | IM | 194.13 | | | |
| **GI9** | 19 | GNOF rain garden | RG | FS | - | | | |
| **GI10** | 20 | Aurora rain garden | RG | FS | 3.31 | 2.37 | | |
| **GI11** | 21 | Aurora swale | RG | FS | 16.27 | 8.86 | | |
| **GI12** | 22 | Greenline pavilion swale | RG | FS | 4.71 | | | |
| **GI13** | 23 | Hollygrove - Forshey St | RG | FS | 39.29 | | | |
| **GI14** | 24 | Lafitte rain garden (Toulouse & N. Lopez St) | RG | FS | 54.44 | 38.93 | | |
| **GI15** | 25 | Lafitte rain garden (Toulouse & N. Rendon St) | RG | FS | 70.81 | 55.76 | | |
| **PP7** | 26 | Lafitte permeable pavement (Toulouse & N. Lopez St) | PP | IM | 58.85 | | | |
| **GI16** | 27 | City Hall rain gardens | RG | IM | 23.84 | 35.625 | 33.135 | 38.05 |

### 6.4.1 Rain gardens infiltration rates

The pressure curves for the tested rain gardens and bioswales are given in Figure 6.8. As can be seen, there are large differences in infiltration capacity. Test number 22, which corresponds with the Aurora rain garden, shows infiltration rates of roughly 3 m/day. In contrast, the well-drained rain gardens near Lafitte Greenway show infiltration rates of over 50 m/day. For the first test iteration, the average is almost 22 m/day.

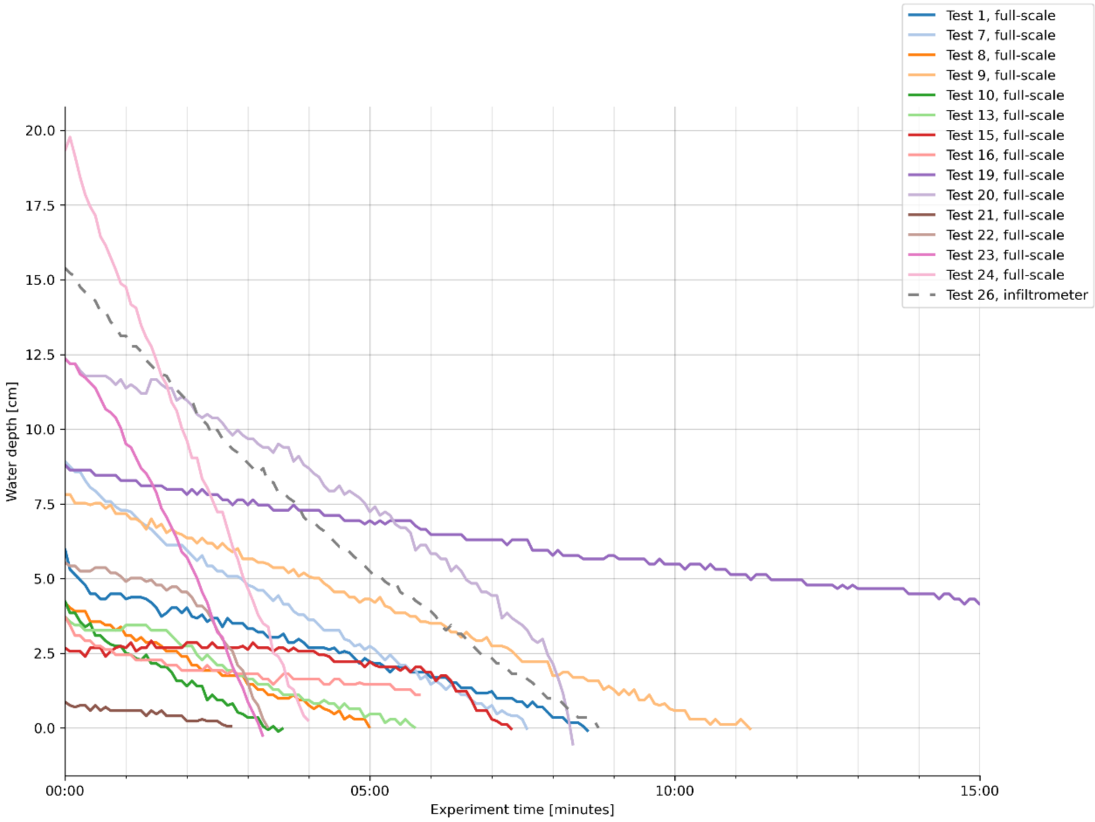


*Figure 6.8: Aggregated infiltration capacity of the tested rain gardens. The number in the legend responds to the test number given in Table 6.1.*

### 6.4.2 Permeable pavement infiltration rates

The difference in infiltration rates for permeable pavement are larger than those for rain gardens and bioswales. Although the average infiltration capacity for the first test iteration is 34 m/day, most permeable pavement systems do not perform this well. The GNOF permeable pavement (Test 18) performs exceptionally well with an infiltration capacity of 194 m/day (infiltrometer test). Permeable pavement at SUNO also performs well, although the difference between infiltrometer (61 m/day) and full-scale test (8.7 m/day) is large. The City Park Administration building (Test 2) only shows an infiltration capacity of 0.7 m/day. Test no. 4, 6, and 14 show a similar infiltration rate of roughly 2 m/day.

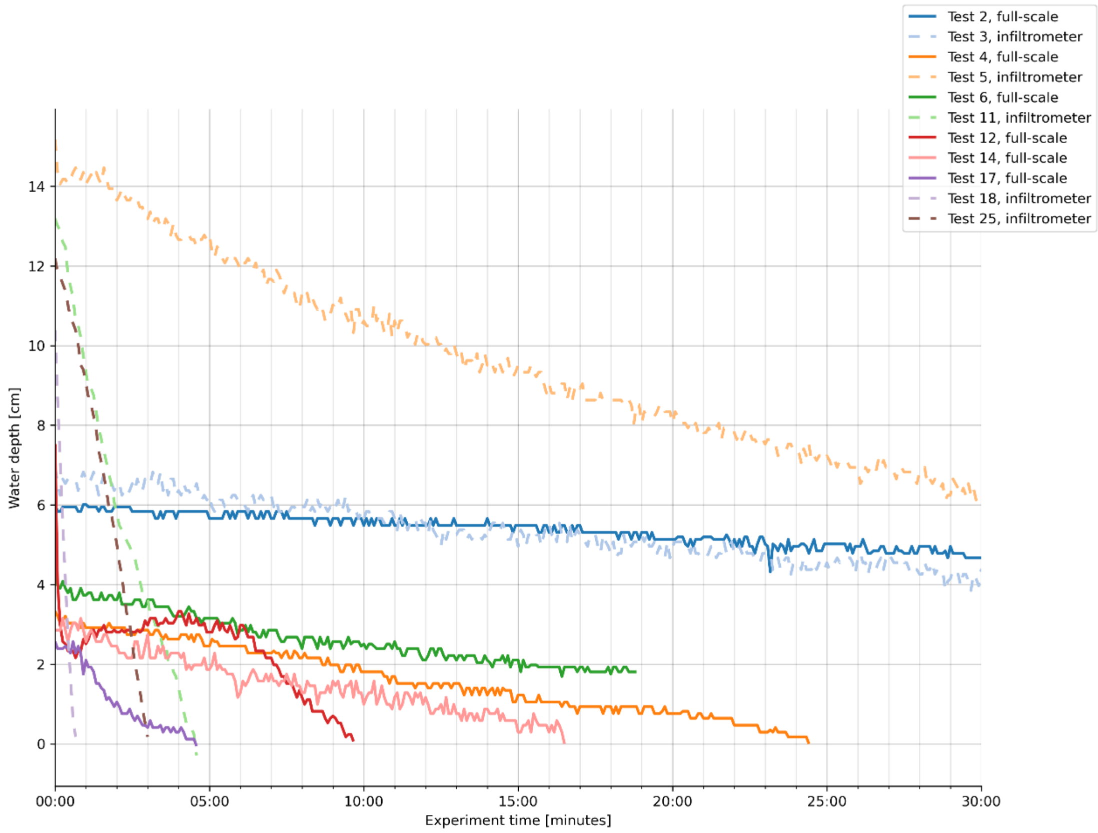


*Figure 6.9: Aggregated infiltration capacity of the tested permeable pavement facilities. The number in the legend responds to the test number given in Table 6.2.*

### 6.4.3 Performance of green infrastructure facilities

The infiltration rate is calculated by determining the tangent of the infiltration curves in Figure 6.8 and 6.9. The results for the first test iteration are shown in Figure 6.10 and Figure 6.11. The large differences in infiltration capacity are notable. A first observation is that infiltration rates determined by a ring infiltrometer are consistently higher than those determined via full-scale testing, even for tests on the same location. This can be due to two main reasons:

1. When testing with an infiltrometer, often a favourable spot is picked. The selected location is usually a flat spot, not in the corner or downstream side of a parking place where sediment would accumulate.
2. A second mechanic that might overestimate the infiltration capacity is horizontal dispersal of water. As is intended with permeable pavement, infiltrated water can freely flow horizontally within the pavement. For a very small test surface area, the amount of water that is 'lost' horizontally is relatively large. Although this water would eventually infiltrate, it does not immediately infiltrate into the soil and therefore results in skewed measurements on short time scales.

Figure 6.11 shows that only two of the full-scale tested permeable pavement facilities conform to the City of New Orleans infiltration criterium of 10 inches/hour. Infiltrometer rates are much more optimistic. Test 18 stands out with an enormous infiltration rate of 194 m/day. Referring back to Table 6.1, this is a ring infiltrometer test on permeable pavement on GNOF property. It is relevant to explain the high infiltration capacity using design and construction drawings provided by Waggonner & Ball. It appears that underneath the permeable pavement there is a drainage system that drains infiltrated water towards an external pipe system.

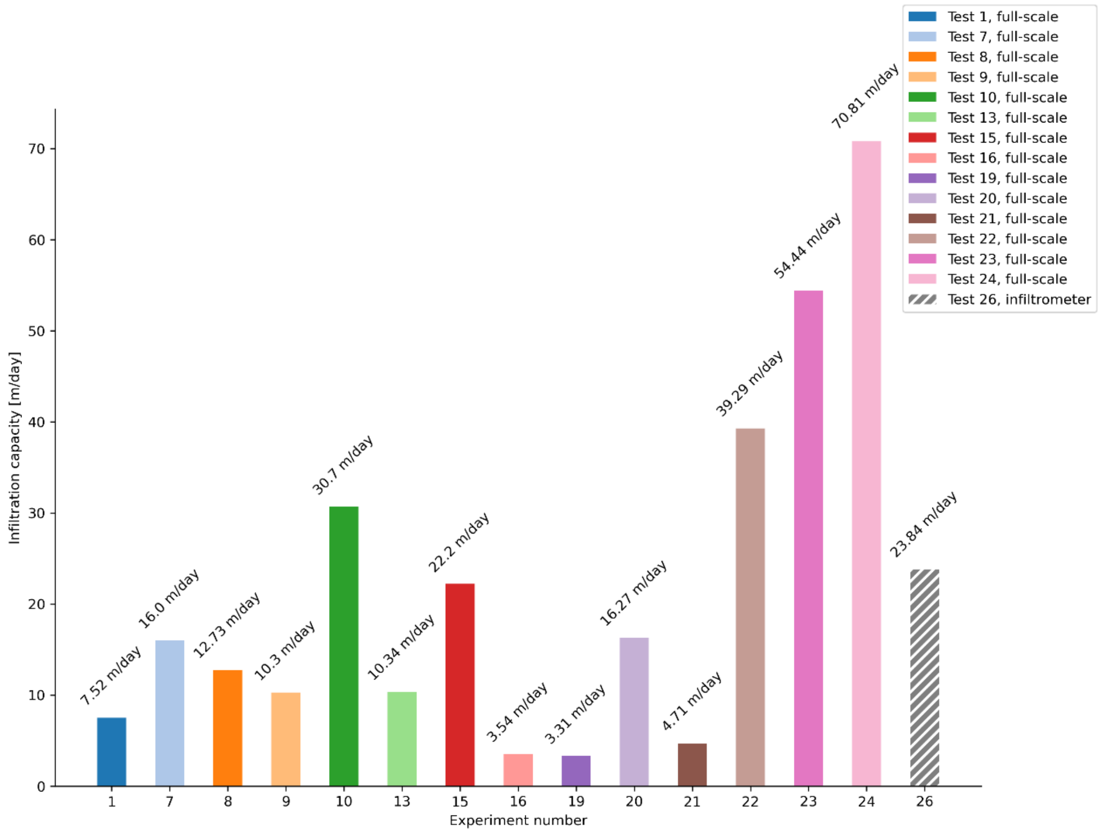


*Figure 6.10: Performance of rain gardens.*

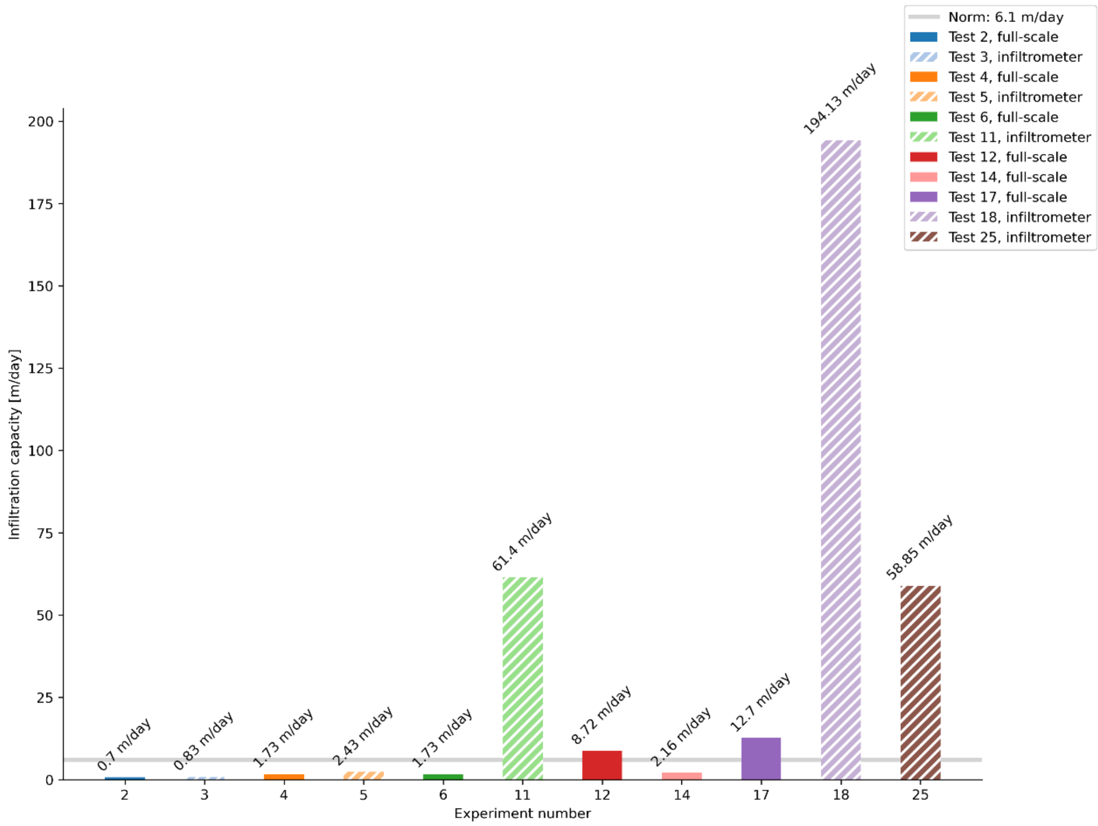


*Figure 6.11: Performance of permeable pavement in comparison to the infiltration criterium of 10 inches/hour (6.1 m/day).*

## 6.5 Field observations and information from local stakeholders

During field testing, all facilities were assessed qualitatively as well. Table 6.5 shows an overview of the tested facilities with the most important aspects concerning design issues, state of maintenance, pollutants and other remarks.

*Table 6.5: Qualitative feedback on tested rain gardens.*

| Facility number | Name | Design issues | Maintenance state | Pollutants | Remarks |
|---|---|---|---|---|---|
| **GI1** | City Park Tricentennial parking lot | Adding deeper storage depression can improve effectivity | Relatively good. Sedimentation before and after inlets | Not badly polluted, but many plastics visible. | Add simple water quality treatment interventions |
| **GI2** | Wildair | Runnel is downstream of catch basin: rain garden is only used as overflow | Well maintaned. | Not badly polluted. | Storage capacity can be optimized greatly. |
| **GI3** | Milne - eastern bioswale | The overflow was unprotected and is damaged during mowing. | Well maintaned. | Not badly polluted. | More diverse planting and correct maintenance adds biodiversity. |
| **GI4** | Milne - northern bioswale | The overflow was unprotected and is damaged during mowing. | Well maintaned. | Not badly polluted. | More diverse planting and correct maintenance adds biodiversity. |
| **GI5** | Press Drive | Runnel is downstream of catch basin: rain garden is only used as overflow. Runnel goes uphill; water cannot enter. | Well maintaned. | Not badly polluted. | Storage capacity can be optimized; slope has to be inverted. |
| **GI6** | NORA OC Haley - rain garden | Runnel is downstream of catch basin: rain garden is only used as overflow. Runnel goes uphill; water cannot enter. | Moderarately maintained; much debris present. | plastics | Inflow needs to be optimized |
| **GI7** | Groundwork OC Haley, next to no.1520 | Inlets are not positioned favourably. | Moderarately maintained; sedimentation at inlets. | Trash in the rain garden. | Inflow can be optimized |
| **GI8** | Groundwork OC Haley, next to no.1307 | Inlets are not positioned favourably. | Moderarately maintained; sedimentation at inlets. | Trash in the rain garden. | Inflow van be optimized. |
| **GI9** | GNOF rain garden | Storage volume can be optimized. | Well maintaned | none | Working unclear. Therefore, to understand better a high freqeunce sensor installed. |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **GI10** | Aurora rain garden | Runnel is downstream of catch basin: rain garden is only used as overflow | Well maintained. | Not polluted | Emptied very slowly. |
| **GI11** | Aurora swale | Favourable position of runnel | Well maintained | Not polluted | Emptied very fast. Most likely due to the drain. Is this desired? |
| **GI12** | Greenline pavilion swale | Storage volume can be optimized greatly. | Badly maintained – most of the structure has been destroyed. | Many pollutants (plastics). Lot needs more mainetnance visits | Great constrcution. BUT, needs restoration |
| **GI13** | Hollygrove - Forshey St | Favourable position of runnel | Moderately maintained, exept sediment removel. | Plastics and others. | Garden well maintained, but needs to be cleanded 9removal of garbage and sediments. |
| **GI14** | Lafitte rain garden (Toulouse & N. Lopez St) | Rain garden drains too quickly to concrete pipes. | Well maintained | none | How can water storage be improved? |
| **GI15** | Lafitte rain garden (Toulouse & N. Rendon St) | Rain garden drains too quickly to concrete pipes. | Well maintained | none | How can water storage be improved? |
| **GI16** | City Hall rain gardens | Storage volume can be optimized. | Well maintained | none | |

*Figure 6.12: sedimentation and (visible) pollutants at bioswale inlet. (source: https://www.climatescan.org/projects/9685/detail)*

*Table 6.6: Qualitative feedback on tested permeable pavement facilities.*

| Facility number | Name | Design issues | Maintenance state | Pollutants | Remarks |
|---|---|---|---|---|---|
| **PP1** | City Park Administration building | Parking lot is surrounded by green zones. | Moderately maintained; lower parking places have much sedimentation | none | Better to drain water into these surrounding green zones. |
| **PP2** | SWBNO parking lot | Surrounded by green zones. | Great (recently construcetd) | none | Better to drain water into these zones. |
| **PP3** | Hunters field | PP not the best solution for this site. | Pavement is damaged, incl. small sinkholes. | Plastics, needels etc. | Design bio swale also accepting drainage water from highway. |
| **PP4** | SUNO permeable pavement | Better to drain water into the adjacent green zones. | Great. Just new. | none | |
| **PP5** | NORA OC Haley | Better to drain water into the adjacent green zones | clean | none | |
| **PP6** | GNOF permeable pavement | Looks great | Clean | none | Water should be drained into swales. |
| **PP7** | Lafitte permeable pavement (Toulouse & N. Lopez St) | Small PP locations. | clean | none | Water is drained to fast into sewer. |

*Figure 6.13: Example of a catch basin next to bioswale inlet. (source: https://www.climatescan.org/projects/9695/detail)*

The observations as outlined in Table 6.5 and 6.6 are summarized in Table 6.7, with suggested action to for improvement.

*Table 6.7 most frequent observations and actions to improve the green infrastructure*

| Challenge | Suggested action |
|---|---|
| **Trash/debris is present.** | Remove the trash/debris. |
| **Erosion or other signs of damage have occurred at the outlet.** | Repair the damage and improve the flow dissipation structure. |
| **The inlet pipe is clogged (if applicable)** | Unclog the pipe and dispose of any sediment in a location where it will not cause impacts to streams or the SCM. |
| **Flow is bypassing pretreatment area and/or gullies have formed.** | Regrade if necessary, to route all flow to the pretreatment area. Stabilize the area after grading. |
| **Sediment has accumulated to a depth greater than three inches.** | Search for the source of the sediment and remedy the problem if possible. Remove the sediment and dispose of it in a location where it will not cause impacts to streams or the SCM. |
| **Inlet is too close to outlet (by passing water quality improvement and storage is not used)** | Higher outlet |
| **Green infrastructure inlet is higher/next to stormwater drainage inlet** | Inlet raingarden lower to make sure the raingarden fills up first |
| **Lack of insight in water and soil quality** | Monitoring advised |
| **Permeable pavement often adjacent to green zones** | On the long-term PP is vulnerable for clogging. So, better drain water into adjacent green zones if available. |

## 6.6 Sub conclusions

**General observations**

During field testing, several observations were made that apply to virtually all tested facilities.

1. For rain gardens, sediment at the inlets is generally not removed properly (see Figure 6.14).
2. Most of the tested rain gardens were quite shallow and did not fully exploit water storage capacity.
3. Communication between landscape designer and construction engineers is often lacking
4. There is a lack of monitoring of both hydraulic performance and water/soil quality.
5. There are no uniform guidelines for maintenance, design and construction.
6. Many Permeable Pavement sites borders on green zones. Better to drain water into these zones.

*Figure 6.14 Water cannot enter the raingarden (blocked or to drain next to inlet raingarden)*

In general, green infrastructure in New Orleans could benefit from switching to an innovative practice, with a focus on participation, training in the field, videos, full-scale testing, presentations and a (short visual) report.

**Conclusions on performance**

- There are large differences in performance between different locations, both for rain gardens/bioswales and permeable pavement (as seen in measurements and visual inspection);
- There are large differences between infiltration rates according to ring infiltrometer versus full-scale test. Most likely this is the result of choosing a favourable location for ring infiltrometer tests and excluding possible impermeable/clogged areas.
- Most permeable pavement facilities do not meet the City infiltration norm of 10 inch/hour.

*Picture Ramiro Diaz*

# 7 Conclusions, recommendations, quick wins and lessons learned

## 7.1 Performance of tested green infrastructure

### 7.1.1 Permeable pavement

- Only two of the 11 full-scale tested permeable pavement facilities conform to the City of New Orleans infiltration criterium of 10 inches/hour. The infiltrometer results are consistently higher.
- Recently constructed permeable pavement functions better (e.g. Southern University).
- Often, permeable pavement is constructed adjacent to green zones. A design transporting storm water from e.g. a parking lot into these green zones can be more effective in terms of costs and stormwater volume detention.
- Maintenance of the permeable pavement sites is necessary but is not yet part of general maintenance plans. In addition, the required machinery for cleaning permeable pavement is not readily available for private parties.

### 7.1.2 Green infrastructure

- All the 15 tested sites conform to the City’s criterium of dry-fall within 48 hours. However, this does not mean that all green infrastructure sites can contain a significant amount of stormwater to relieve the grey stormwater drainage system. Some of the tested facilities have a shallow French drain that rapidly drains stormwater towards the storm drainage pipe below the street.
- In general, given the available surface area, the potential storage volume could be increased by deepening the depression and elevating the level of the overflow.
- Construction and maintenance costs of green infrastructure facilities are high. This can be justified in case of pilots or creating awareness but will make it extremely hard to cover the entire water assignment.
- Large, and cost-effective facilities (simple design and construction with minor maintenance costs) are needed.
- Often curb cuts and runnels for rain gardens are constructed next to catch basins, transporting street runoff into the existing drainage system instead of into the rain garden Figure 7.1).

*Figure 7.1: Example of a catch basin next to bioswale inlet.*

- ❑ The vegetation seemed well maintained at most sites (NORA, SWBNO, City). But, at many locations the inflow runnel was not ideally maintained as it is often (partly) filled with sediment from the streets.
- ❑ Reflecting back on the total water assignment for New Orleans, the most effective measure remains the addition of surface water bodies.

## 7.2 Towards an integrated network approach

Individual rain gardens etc. can help to reduce flooding locally. But to meet the city’s water assignment a more integrated Blue-Green infrastructure network approach is needed. In short, this network consists of a combination of Blue-Green measures (such as rain gardens), surface water bodies and traditional drainage pipes.

### 7.2.1 Retain, store, reuse at multiple scales

This new water management strategy should be based on “retaining” and “storing” water at the location where rain falls (figure 7.2). Only surplus water can be drained into the street and storm water drainage network which should be connected to large public storage areas.
The goal is to create a city as a sponge” system (figure 7.3). Starting at lot/parcel scale, upscaling towards city blocks and neighbourhoods.

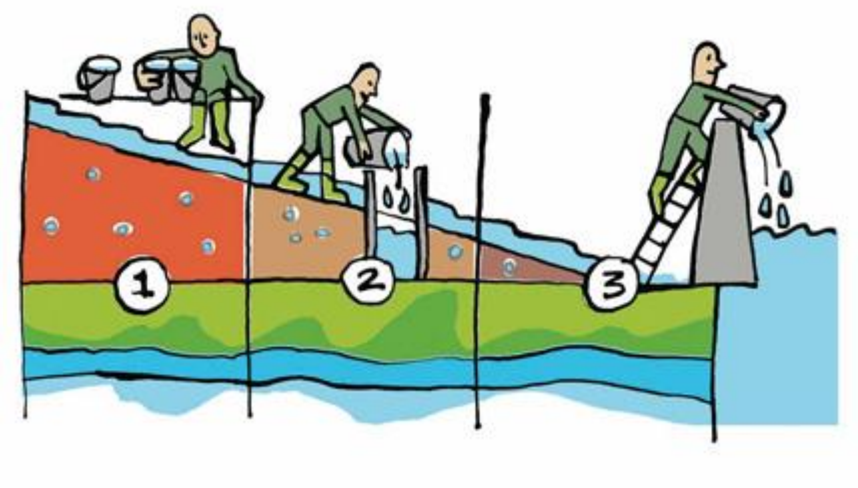


*Figure 7.2: Retain, store and discharge concept.*

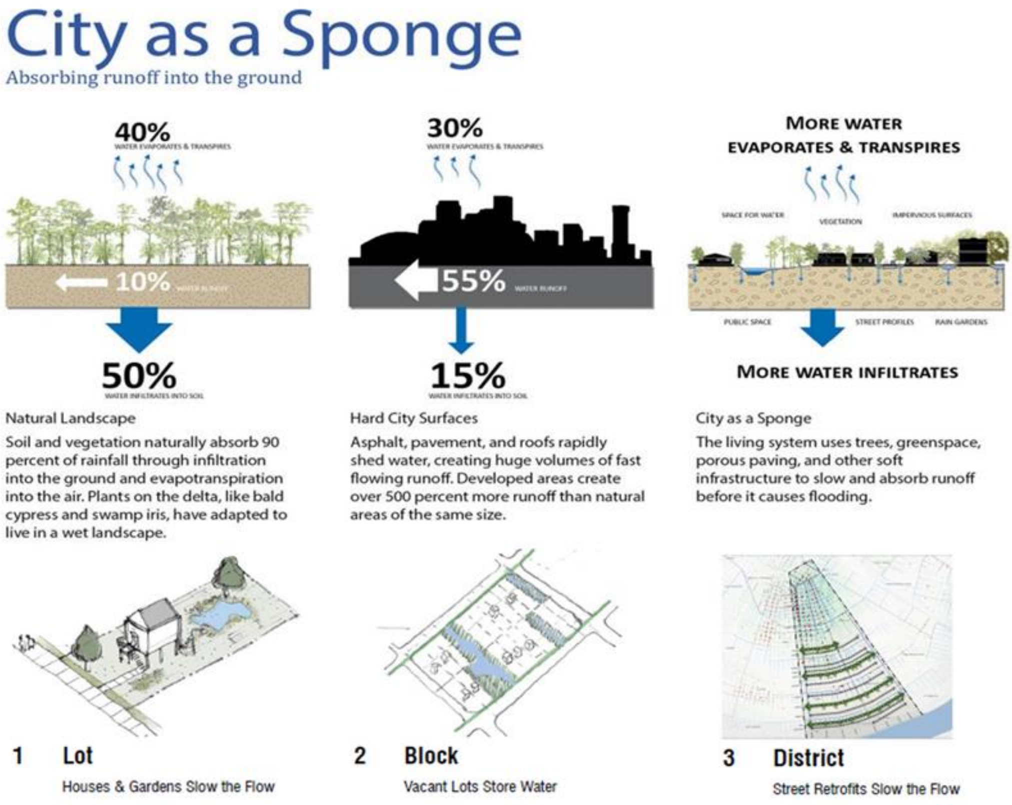


*Figure 7.3: the city as a sponge.*

In table 7.1 these concepts are translated into steps to reduce urban flooding in New Orleans.

*Table 7.1: A step-by-step approach to organize drainage of urban storm water*

| **Towards an integrated storm networks water storage approach** | |
|---|---|
| **1. Start retaining and storing water at lot scale (the capillaries of urban water system)** | Remove tiles, concrete and asphalt where possible. Create simple, well-designed depressions in suitable gardens. Re-construct drainpipes into these bioswales. Rehabilitate cisterns or add rain water barrels (figure 7.4) and use these for irrigation. This helps to reduce drinking water use (and related $CO_2$ footprint) and will increase soil moisture content (helps to reduce shrink-swell damage). Adapt vegetation to climate conditions, so that less irrigation water is needed. Reduce the use of fertilizers and pesticides to support healthy soils. At large buildings try to retain water at the roofs (see also appendix B infographic from Amsterdam Rainproof, in Dutch). |

| | |
|---|---|
| **2. Organize (1) at a block scale (action City and/or SWBNO)** | Wherever possible, upscale the principles of (1) to the city block scale. The larger the scale of the new system, the more awareness is created, and costs are reduced.<br><br>❑ School and churches can help to create awareness. Initiate projects to make them water neutral. Sharing this with pupils, parents and church members.<br>❑ Adapt streets design to handle surplus water that cannot be stored at lots. Water that cannot retained or stored at the lot scales will drain into the public area. If possible, this water should be drained into local green. |
| **3. Start actions at the high grounds** | Drainage from the high grounds impacts the lower areas. The high grounds often have a lower groundwater level and therefore more opportunity for water storage. Often high grounds (e.g. Garden District) have larger gardens, and therefore offer the best opportunities for local storage. |
| **4. Design improvements** | ❑ Improve curb cuts / runnels. Curb cuts and runnels needs maintenance but can also be improved. For example, by adding collectors for plastics, leaves and grass clippings.<br>❑ No curb cuts next to catch basin.<br>❑ Create maximum storage depth.<br>❑ Keep it simple; avoid high costs.<br>❑ Always keep fine grained sediments at the top, potential covering more coarse sediments. In this way pollutants (organics) cannot clog the pores between the sediment grains. With a rake the topsoil can be cleaned.<br>❑ Choice of vegetation |
| **5. Street network** | During intense rain storms the streets transport water from high grounds towards lower areas. Based on understanding of this flow system, streets and streets network can be redesigned. To handle extreme rain storms a selection of streets can get an additional function: emergency surface flow channel, transporting water towards emergency storage areas. |
| **6. No discharge of storm water from parks and green zones** | Stop drainage from these green zones. Store every rain drop, making irrigation unnecessary. Stop, or reduce the use of fertilizers and pesticides to improve (ground)water quality.<br><br>No discharge from parking lots into public drainage network. |
| **7. Design and construct large scale green infrastructure water storage zones** | ❑ Thousands of small rain gardens will not solve the water assignment. Large interventions are needed, such as using the neutral grounds of streets.<br>❑ Design large open surface water bodies (canals, connected ponds). The low areas of New Orleans are polders. Polders need surface water storage. Without open water intense rain storms cannot be managed and repeating flooding will occur. |

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| **8. Adapt City's storm drainage model to analyses and monitor above interventions.** | To support the design of a solid storm water strategy the existing storm drainage model need to be adapted so that the above-mentioned interventions (1-6) can be monitored.<br>❑ Implement a storm drainage monitoring network to calibrate/validate modelling results. A model without supporting monitoring network is not more than a guess.<br>❑ Make use of the City's groundwater model and groundwater monitoring network. The groundwater situation, and therefore the water storage capacity (the zone above the groundwater level) will change because of renovations of the piped system and climate change.<br>❑ Overland street flow needs to become part of this model. |
| **9. Map planned network renovations (drinking water, waste water, storm drainage water)** | These activities can change the water system. When groundwater drainage by leaking waste water and storm drainage pipes will stop, groundwater levels will rise and therefore the water storage capacity of the soil reduces. |
| **10. Map green infrastructure** | Where is the city's green infrastructure? If you do not know where it is, it will be not properly maintained. Publicize locations of green infrastructure in a public database. |
| **11. Try to integrate other functions like ecology and recreation** | Green infrastructure can be used as stepping stones for ecology and recreants. Adding vegetation can help to reduce urban heat. Many streets lost trees during Katrina. Re-introduce native trees. Perhaps in a way that the surrounding area can act as a local water storage area. |
| **12. Improve awareness program** | Essential is that citizens understand and support blue-green interventions (see Amsterdam Rainproof, appendix B). |
| **13. Improve maintenance** | This is about more than landscaping. Remove waste more frequently. Remove sediments at the inlets. Never use fertilizers and pesticides. Use native vegetation. |

*Figure 7.4: Stored rain water to be used for garden irrigation.*

## 7.3 Possible opportunities for improved green infrastructure design

- ❑ Start creating a "best storage opportunities map". Based on elevation (preferred high grounds), groundwater level and soil composition. Therefore, start studying the soil composition and groundwater fluctuation.
- ❑ Optimize the Storage volume. Most GI have just depth of couple of inches, and often only a small part of a lot is used.
- ❑ Organize regular maintenance. Locations will get less stormwater due to sedimentation of the inlet.
- ❑ Handle potential shortcuts. Often, inlets are next to catch basins. In these cases, the preferred option 'raingarden before stormwater drainage' is not utilized.
- ❑ Therefore, improve communication between designers (landscape architects) and contractors (construction and maintenance).
- ❑ In case of planning permeable pavement:
  - Consider the long term → clogging and maintenance
  - Better to make use of adjacent green zones
- ❑ Reduce construction costs to facilitate upscaling.
- ❑ Include pre-treatment and treatment of stored urban water.
- ❑ Organize standard monitoring. Every new site should be monitored for at least 1 year. These data can help to improve new designs and learn about the effectivity in storm drainage management.
- ❑ Publish Open source and share your knowledge. Currently, different organizations do not share their perceptions and results

## 7.4 Large blue green infrastructure projects are needed

The water assignment of New Orleans can only be met by large interventions, such as creating open water, miles-long green infrastructure lines in the median strips of large roads (e, g Elysian Fields) or in the Streetcar network. Parks (Audubon, City Park etc.) should not discharge storm water into public storm drainage system and should be use as emergency storage area.

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# A Test week organization (planning)

| P= permeable pavement, BG= green infra | Monday 17th | Tuesday 18th | Wednesday 19th | Thursday 20th | Friday 21 |
|---|---|---|---|---|---|
| 8:30-10:30 | BG1: City Park bio retention cell. With visit Dana Brown and Jake Webster (NO City Park) | BG2: Wildair Filmore (incl. installation sensors). *Installation groundwater sensor.* | BG4: Haley Blv with Abrina Williams & Charlotte Giroux and Seth Knudsen (NORA). | Office. Data analysis | BG7: Hollygrove BG11: Hollygrove School of Architecture |
| 11:00-12:30 | P1: Administration building City Park. With visit Ramiro Diaz (Waggonner & Ball) | BG6: Milne → 2 tests | BG 12/13: Testing 2 Groundwork raingarden sites along Haley Blv. | BG5a/5b: Aurora, Algiers 2 sites with Abrina Williams (NORA) | BG9: Lafitte Greenway 2 rain gardens, 1 permeable pavement |
| lunch | | | | | |
| 1:30-3:30 | P2: SWBNO Carrolton, with visit Grace Vogel (SWBNO) | BG3: 5019 Press Drive, with Abrina Williams & Charlotte Giroux (NORA). *Installation groundwater sensor.* | P3: GNOF parking, with Dan Favre (GNOF) and Ramiro Diaz | Groundwork car broken. Therefore, planning & visiting Lafitte | BG8: City Hall bioswale |
| 4-5:30 | P4: Hunters Field parking (Claiborne) | P5: Southern University New Orleans | BG10: GNOF rain garden testing (incl installation EC/level sensor) | | Evenings: visits private rain gardens of Tor Tornqvist, Ramiro Diaz. |

# B Amsterdam (www.rainproof.nl)

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