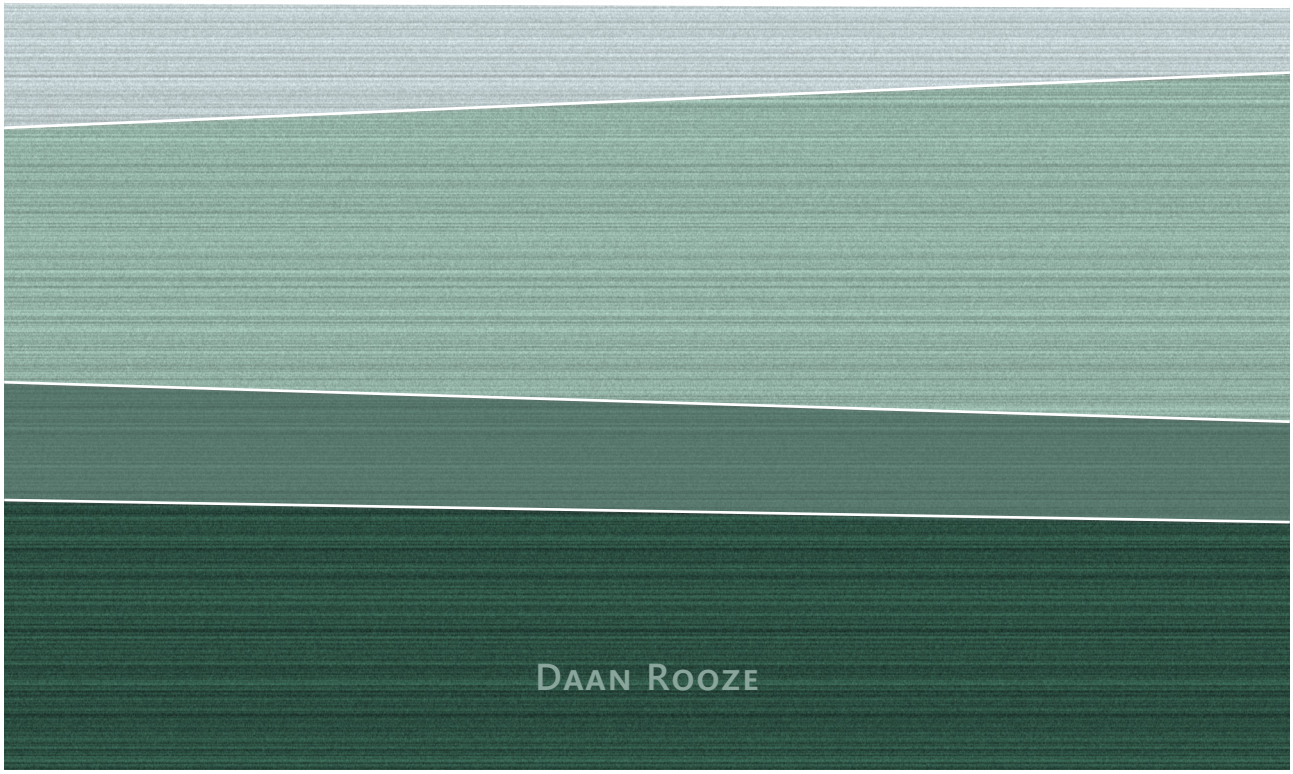
BORROWED LAND

Reframing the relation between flood and drought adaptation efforts with the built environment in New Orleans.



Daan Rooze

Colophon

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flood and drought adaptation efforts
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Master Thesis report

MSc. Architecture, Urbanism and the Building Sciences
Specialization: Urbanism
MSc. Civil Engineering
Specialization: Water Management

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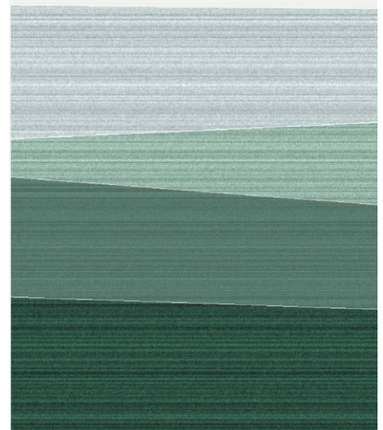




Figure 1 - Hurricane Katrina (source: NASA, 2005).

Abstract

The purpose of this thesis is to conduct research on increasing flood resilience and, albeit to a lesser extent, drought resilience of New Orleans, Louisiana, United States of America. Focusing on the Orleans Lakeside sub-basin, this project builds on previous work through a joint design-engineering approach. This project seeks to address two shortcomings of existing proposals such as the Greater New Orleans Urban Water Plan: consideration for extreme weather events in the design framework as well as focusing on the integration of technical adaptation measures with the built environment. Hence, the main research question answered in this report is "How can Orleans Lakeside be made more flood and drought resilient by integrating multi-layered resilience capacities of the built environment, whilst safeguarding consistent design of technical adaptation measures within the urban space?".

The development of a design framework and detailed design interventions follows from a synthesis of earlier proposals, supplemented with a vulnerability analysis that focuses on the different capacities of the built environment in dealing with weather events of various magnitudes. For this analysis, the threshold (preventing damage), coping (mitigating damage), recovery (recovering from damage) and adaptive (flexibility to change) capacities of the built environment are investigated.

The multidisciplinary approach taken in this project culminates in an urban water management design for Orleans Lakeside which is focused on introducing open water in the urban environment. This design proposal offers a high potential of meeting the required water storage capacity, with the intention to reintroduce the lost identity of wetlands to the suburbs of New Orleans. Typological and urban design across scales aim to integrate water system elements into the urban fabric, and to merge a new water-based urban environment with traditional desired American neighborhood qualities.

Key words – New Orleans, flood resilience, drought resilience, climate vulnerability, urban regeneration.

Preface

This report is the embodiment of the joint graduation thesis for two master degrees at the Delft University of Technology: **Urbanism** at the faculty of Architecture & the Built Environment and **Water Management** at the faculty of Civil Engineering and Geosciences.

Instead of writing a separate thesis for both studies, this project aims to combine elements from both studies and integrate them into an urban water management design for New Orleans. Although parts of this report are more relevant to one study field than the other, there is no separation in chapters between both disciplines. In contrast, the thesis is constructed in such a fashion that the two disciplines contribute to each other and support each other's arguments and narrative.

Unless otherwise indicated, all figures and drawings are by the author.

Acknowledgements

Writing this thesis would not have been possible without the support of many, whom I would like to thank in this section.

First, I would like to thank my mentors from both the faculty of Architecture and Civil Engineering for their guidance throughout the project. Leo, Kristel, Frans, Roelof and Miriam, your expertise really enriched this thesis and your enthusiasm made the process an enlightening journey.

I would like to thank Deltares for enabling me to visit New Orleans twice and giving me access to their extensive network.

Also, I would like to thank the kind people at Waggonner & Ball Architects for constructive input and their hospitality during the two field trips to New Orleans.

I would like to thank the municipality of New Orleans as well as the Sewerage & Water Board for providing helpful input and data.

Furthermore, I would like to thank Bhuban Ghimire (Adrurra Group) for providing the SWMM model, Rik van den Oever for assisting during the first fieldwork trip, and Aron Chang from The Blue House for allowing me to get in touch with New Orleans residents.

Finally, I would like to thank my family and friends, as well as my student colleagues in Delft for their informal feedback and helpful suggestions.

Executive Summary

This thesis focuses on the Orleans Lakeside basin within New Orleans, which is bounded by the extents shown in Figure 2.

Problem field

New Orleans, located in the Mississippi River delta, was hit severely by Hurricane Katrina in 2005 and remains vulnerable to future extreme weather events. In addition to hurricanes, New Orleans is exposed to severe precipitation which overwhelms the city's storm drainage system. Through constant groundwater pumping, and especially during periods of drought, low-lying neighborhoods subside due to oxidation of organic soil matter. The resulting poor state of drainage infrastructure further exacerbates this issue. This process worsens the climate vulnerability of Orleans Lakeside and sets a grim outlook for the sustainability of the urbanized area.

In addition to environmental threats, New Orleans faces socio-spatial issues that relate to vacancy, inequity, poor spatial quality and spatial segregation. New Orleans has double the vacancy rate of the United States average, which is due to stalling repopulation efforts since Hurricane Katrina and repetitive flooding losses. Patterns of inequity lead to issues such as minimal access to amenities, homogeneous housing offer and limited evacuation opportunities. The general quality of public space is low, with water hidden behind tall floodwalls and little diversity in streetscapes. The use of automobiles is encouraged by the hierarchy of infrastructure, as there is a total a lack of pedestrian and bicycle-friendly corridors.



Figure 2 - Project location: Orleans Lakeside sub-basin.

Findings

A vulnerability analysis looking into the threshold (preventing damage), coping (mitigating damage), recovery (recovering from damage) and adaptive (flexibility to change) capacities exposed multiple weaknesses and starting points for design.

Threshold capacity

Hydraulic modelling exercises using SWMM underline the extent of flooding across Orleans Lakeside and show clearly weak spots where the drainage system fails the most often. Regarding the quantification of the water assignment, an urban water balance model yields a total required storage capacity of 1,700,000 m^3 (1378 acre-foot), in contrast with the total storage capacity of 1,289,000 m^3 (1045 acre-foot) determined in the Urban Water Plan. Figure 3 shows the most problematic areas in terms of pluvial flooding, as well as the required water storage capacity per pumping station catchment. Current green infrastructure projects in the city do not significantly contribute to the water assignment. Per catchment their respective contribution is less than one per cent of the required storage capacity.

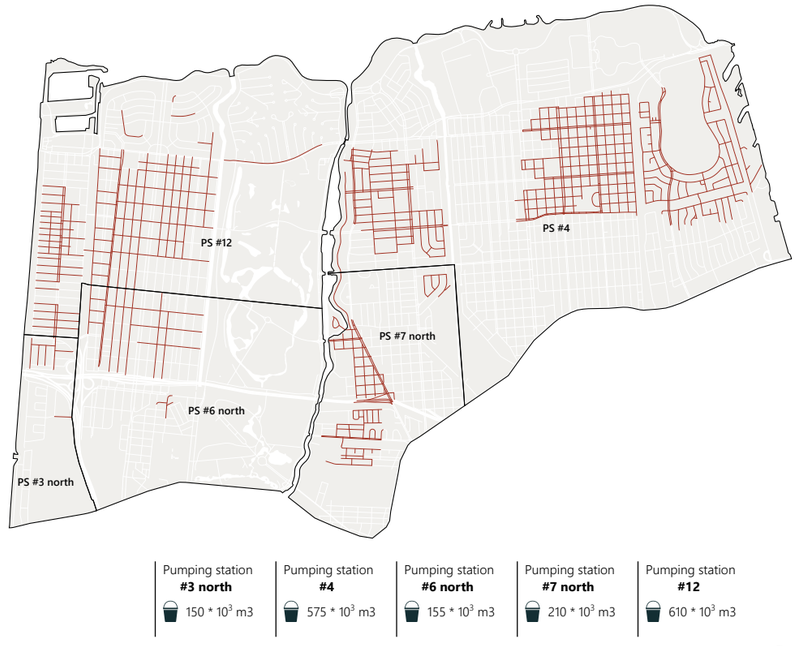
Coping & Recovery capacity

Evacuation is problematic; major access roads flood and in Orleans Lakeside there are no safe shelters for residents that are unable or unwilling to leave. Furthermore, although an elevated first living floor is common, most buildings do not have a first living floor that is above Katrina-flood level. This becomes apparent in Figure 4, which shows a longitudinal street profile of Elysian Fields Avenue and the elevation of first living floors and roofs of buildings along this axis. Furthermore, heavy reliance on the federal levees for protecting against a 100-year hurricane leaves the city vulnerable should the levee system fail. As the levees are already found to not meet the 100-year storm norm, vertical evacuation in buildings and on mounds holds a large potential.

Adaptive capacity

Homogeneous zoning and a lack of a spatial strategy to reaching municipal goals of 'resilience' and 'equity' leaves the urban environment inflexible to future change. It is advised to diversify programming and decentralize employment to make Orleans Lakeside more viable in the long term. On the other hand, wide street profiles and an abundance of public space, albeit of low visual quality, do provide room for interventions in the public domain.

Figure 3 - Most vulnerable parts of Orleans Lakeside to pluvial flooding. A red line signifies flooding above the street curb.



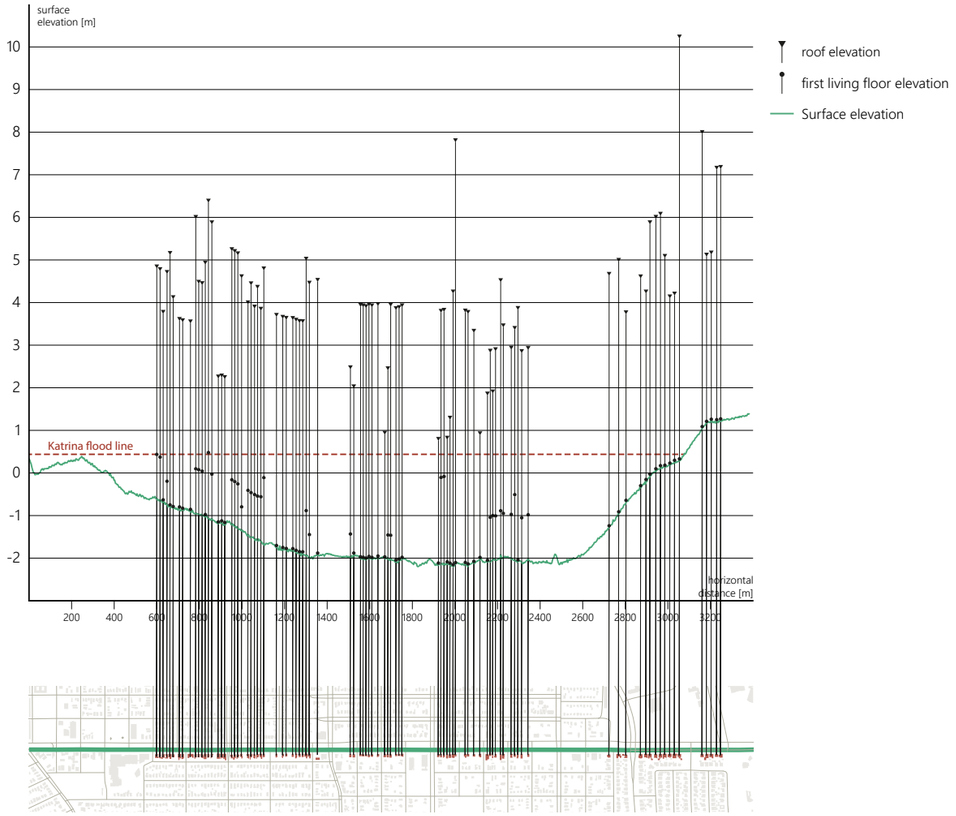


Figure 4 - Longitudinal street profile of Elysian Fields Avenue with living floor elevations of adjacent buildings.

Recommendations

The proposed design for Orleans Lakeside (Figure 8) deploys a reimagined water system not only as a way to increase flood and drought resilience, but also act as accelerator for spatial development. Boundary conditions derived from the water assignment calculations result in a heavy presence of open water in the urban environment. With a system of canals and permanent retention ponds, complemented by green infrastructure projects, the design aims to provide the required storage capacity and stabilize groundwater levels for drought and subsidence mitigation. Hence, the designed system moves towards the natural state of wetlands.

As a way to create added value (merger of interest) and address the coping, recovery and adaptive resilience capacities, the design connects improvements to the area's connectivity, quality of public space, programming and evacuation system to the new water system.

The proposed design conceives a new form of urbanization in Orleans Lakeside, one that is much more centered around water. Moving away from homogeneous, rigid suburbia, the proposed design introduces living environments that are offer high quality public space and accessible amenities. These interventions imply consequences for residents' living environment. The proposed plan aims to successfully fuse the new water-based urban environment with desired traditional American neighborhood qualities. Figure 5, Figure 6 and Figure 7 show urban qualities that the new water system brings to New Orleans.

The leading recommendations for further research are to expand this thesis with studies on social and financial feasibility. Integrating bottom-up initiatives and resolving trust issues between residents and government departments is key for the implementation of measures. In addition, this thesis recommends to study design implications for using a more severe (T25) rainstorm and to carry out extensive tests on green infrastructure to determine the actual contribution to the water assignment.

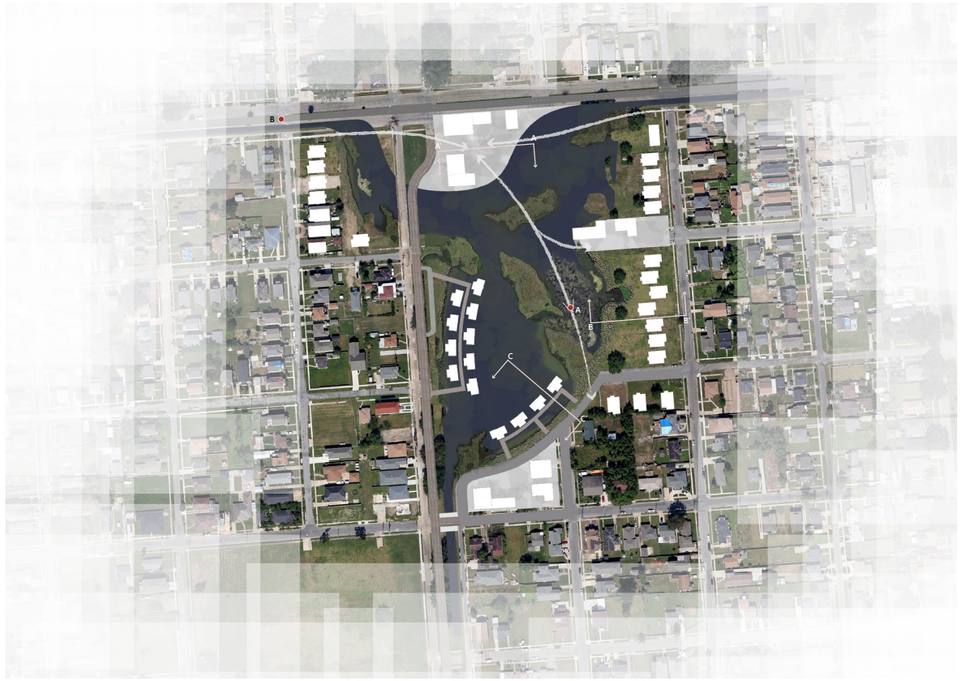


Figure 5 - Impression of the proposed design on a smaller scale.



Figure 6 - Impression of the newly introduced urban qualities.



Figure 7 - Impression of the newly introduced urban qualities.

Lake Pontchartrain

Improved connectivity with recreational routes.

Enriched programming decreases functional homogeneity.

Permanent open water storage on low ground for significant buffering capacity (retention).

Temporary water storage on high ground and educational campuses (detention).

New living enrivonment typologies that are centered around water.

Vertical evacuation on mounds in lower areas.

250 m 500 m

Figure 8 - Proposed urban design of Orleans Lakeside.

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Manifesto

A place of contrast

Too important and too unique to forsake. Threatened on all fronts but determined to prevail. New Orleans is a place of contrast, a contrast that expresses itself throughout history and space.

Human engineering triumphed the swamps and allowed for sprawl into previously unhabitable land. These extensions of engineering ingenuity are now the most vulnerable parts of the city.

Identity of its deltaic location has diluted; only visible outside of the floodgates. A complete reliance on bigger, better pumps has starved the lower neighborhoods from its geographical location. An identity that only sporadically returns in the form of havoc caused by extreme weather events.

Regarding the city as a work of art, Jane Jacobs (1961) argued, is a mistake of attempting to substitute art for life. New Orleans cannot be made safe by engineering bigger drains and pumps alone. The city must recognize its context and embrace the uncertainty inherent to its location.

Figure 9 - Natural & built environment interface (source: Google Earth, 2018).

1 Exploration

1.1 Context
1.2 Problem field
1.3 Starting point: after Katrina
1.4 Motivation





Figure 10 - Local context of New Orleans. Satellite backdrop by Google Earth (2018).

1.1 Context

1.1.1 Introduction

The agglomeration of Greater New Orleans, popularly known as New Orleans, is a coastal city, located in the Mississippi Delta in Louisiana, the United States of America. The agglomeration consists of four parishes that together form Greater New Orleans, which are the Jefferson, Orleans, St. Bernard and Plaquemines parishes. The city is bordered by wetlands connected to the Gulf of Mexico on the western, southern and eastern side and Lake Pontchartrain in the north. New Orleans is traversed by the Mississippi River, to which the city owes its rich history and economic and cultural relevance. Figure 11 shows the general surroundings of New Orleans.

New Orleans has frequently been confronted with extreme weather events, with Hurricane Katrina in August of 2005 being the most notable event. An estimated 1833 people lost their lives to Katrina across all affected states, with 1577 reported casualties in Louisiana (Knabb, Rhome, & Brown, 2005). In addition, Hurricane Katrina is estimated to have caused $108 billion worth of damage to property (Knabb et al., 2005). In addition to Atlantic hurricanes, New Orleans also faces pluvial flooding due to high-intensity precipitation on a regular basis. On 5 August 2017, large parts of the city received around 300 mm (10 inches) of rain, causing heavy flooding (Woodward, 2017).

Ever since the early settlement in the 18th century, the population of New Orleans has grown steadily up until the 1960s, when the city saw a sudden decline in population. Fussell (2007) attributes this to a lack of generative power of the oil, port and tourism industries in attracting and retaining population. Hurricane Katrina caused widespread evacuation of the city and large parts of the population did not return after the storm. As of the 2010 census, Greater New Orleans has a total population of 835,320 inhabitants (U.S. Census Bureau, 2010). This is significantly lower than the pre-Katrina census in of 1,034,126 inhabitants in 2000 (U.S. Census Bureau, 2000).

Fussell (2007) identifies three distinctive periods of the population history in New Orleans. The first period is characterized by a migration-driven population of African slaves, which lasted until the end of the 19th century. The second period revolves around the consolidation of the biracial society, during which poor descendants from the enslaved population were spatially segregated from the wealthy white population. The third (and current) period is informed by the influx of largely undocumented Latino migrant workers that helped rebuilding New Orleans in the wake of Hurricane Katrina.

New Orleans has a high degree of climate injustice: low-lying neighborhoods with a majority of low-income black residents were disproportionately hit by the Katrina storm, while wealthier, whiter neighborhoods stayed mostly dry (Fussell, 2007). Many of the poorer residents did not return after the storm, reducing the share of the black population. Instead, Latino migrant workers that helped rebuild New Orleans became a part of New Orleans's society (Fussell, 2007).

Before Katrina in 2005, New Orleans had a notoriously high poverty rate of 24.5 percent of residents living below the poverty level (United States: 13.3 percent) and a median household income of $30,711 (United States: $46,242) (Fussell, 2007).

Parish	2000 census	2010 census
Jefferson	455466	432552
Orleans	484674	343829
St. Bernard	67229	35897
Plaquemines	26757	23042
Total for Greater New Orleans	*1034126*	*835320*

Table 1 - Population before and after Katrina (source: U.S. Census Bureau (2000), U.S. Census Bureau (2010)).



Figure 11 - General location of New Orleans.

1.2 Problem Field

The problem field introduces the fundamental boundary conditions that are relevant to this thesis. It discusses the impact of Hurricane Katrina on New Orleans, in addition to currently significant anthropogenic and environmental issues at play.

1.2.1 The Katrina Precedent

On 29 August 2005, the fifth deadliest hurricane ever to strike the United States made landfall in New Orleans. Hurricane Katrina caused widespread damage across the northern Gulf of Mexico coast, with an estimated $108 billion in damage directly related to the storm (Knabb et al., 2005). In addition to the estimated 1,833 casualties, some 445,000 residents were forced to evacuate from New Orleans (Adams, Van Hattum, & English, 2009).

Katrina produced a storm surge that entered the outfall canals of New Orleans via Lake Pontchartrain. According to Knabb et al. (2005), the levee system of New Orleans failed on multiple locations at different times. Some of the levees collapsed due to erosion caused by overtopping of the walls, while some levees gave way before the water reached the top of the walls. Roughly 80% of New Orleans flooded, with varying depth up to 6 meters (20 ft.) (Knabb et al., 2005). Figure 12 shows how the advancing storm surge struck New Orleans, in addition to all levee breach sites and the recorded flooding across New Orleans.

The recovery of New Orleans in the aftermath of Katrina was slowed by Hurricane Rita, which made landfall in late September the same year and reflooded parts of the city (R. Campanella & Koritz, 2009). It was not until 11 October 2005, 43 days after Katrina made landfall, that all floodwaters were pumped out of the city (Knabb et al., 2005).



Figure 12 - Development of storm surge through the canals, levee breaches and extent of flooding (source: U.S. Department of Housing and Urban Development (2005), Marshall (2015), elaborated by author).

1.2.2 Socio-Spatial Concerns

1. Inequity

New Orleans suffers from high levels of inequity, in both employment and access to housing (Seicshnaydre, Collins, Hill, & Ciardullo, 2018). Seicshnaydre et al. (2018) conclude that blacks are disproportionately affected, stating "blacks on average remain more physically isolated from jobs than members of any other racial group". Furthermore, housing segregation results in more exposure to environmental hazards and crime.

Spatial segregation has roots stemming from the early 20th century, when local governments in Southern states prohibited the integration of races in a neighborhood though so-called "neutral zoning" (Seicshnaydre et al., 2018). Although racial zoning policies were overturned in 1927, state-incentivized development of middle-income single family zoning continued to exclude blacks from desirable and safe neighborhoods, forcing them to settle in more vulnerable places (Seicshnaydre et al., 2018).

Racial segregation resulted in unfair exposure to the Hurricane Katrina disaster, with 68% of African Americans facing displacement, as opposed to 43% of whites (Seicshnaydre et al., 2018). After Katrina, recovery policies only amplified racial segregation instead of reversing the trend. Displacement is currently further reinforced by gentrification processes (Seicshnaydre et al., 2018).

2. Homogenous zoning

New Orleans saw a major expansion of its built footprint in the 20th century with the introduction of the Wood screw pump, which allowed the Sewage and Water Board to drain nearby cypress swamps (Waggonner & Ball Architects, 2013). These expansions have taken shape as classical American suburbs, having a predominant "single family residential" zoning and boasting few other functions. Functional homogeneity and a lack of diversity is often associated with a low resilience to disturbances (Tyler & Moench, 2012).

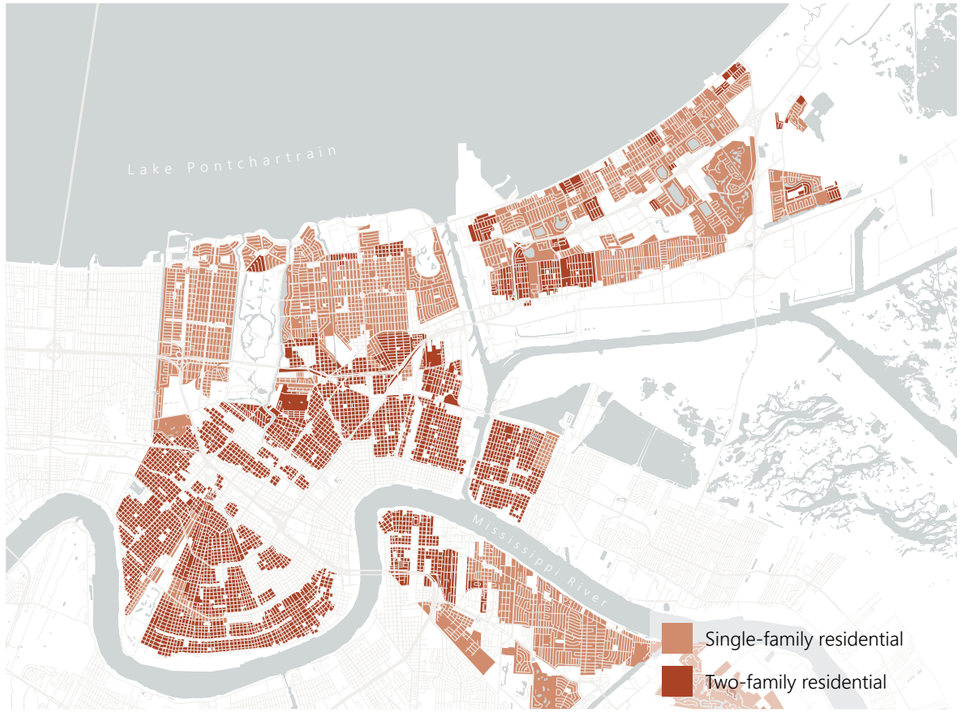


Figure 13 - Homogenous, single family residential zoning in New Orleans (source: City of New Orleans, 2019).

3. Vacancy

Vacancy is a persistent problem in New Orleans, which was exacerbated by Hurricane Katrina. According to the City of New Orleans (2018c), New Orleans had around 26,000 vacant dwellings (21.6% of the concurrent housing stock) in 2000, which jumped to 59,000 vacant dwellings in 2009. Although vacancy has dropped in recent years, it remains high. A survey in 2012 found an estimated 35,700 vacant dwellings, while a survey in 2014 concluded 40,901 vacant dwellings (21.4% of the concurrent housing stock).

4. Deteriorated spatial quality

Public space in the suburbs of New Orleans has a poor spatial quality, as shown in Figure 14. Disinvestment over a long period and inadequate repair efforts after Katrina resulted in roads in disrepair and an overall desolated image (City of New Orleans, 2018c).

In regards to water management, water is not available as an amenity in public space. Rather, drainage infrastructure is hidden from view by box culverts and tall floodwalls (Waggonner & Ball Architects, 2013). Figure 15 shows an example of this. By relying on an engineered drainage system of pipes and pumps, New Orleans has lost the connection to its geographical location of wetlands and floodplains.



Figure 14 - Poor spatial quality in the Gentilly neighborhood.

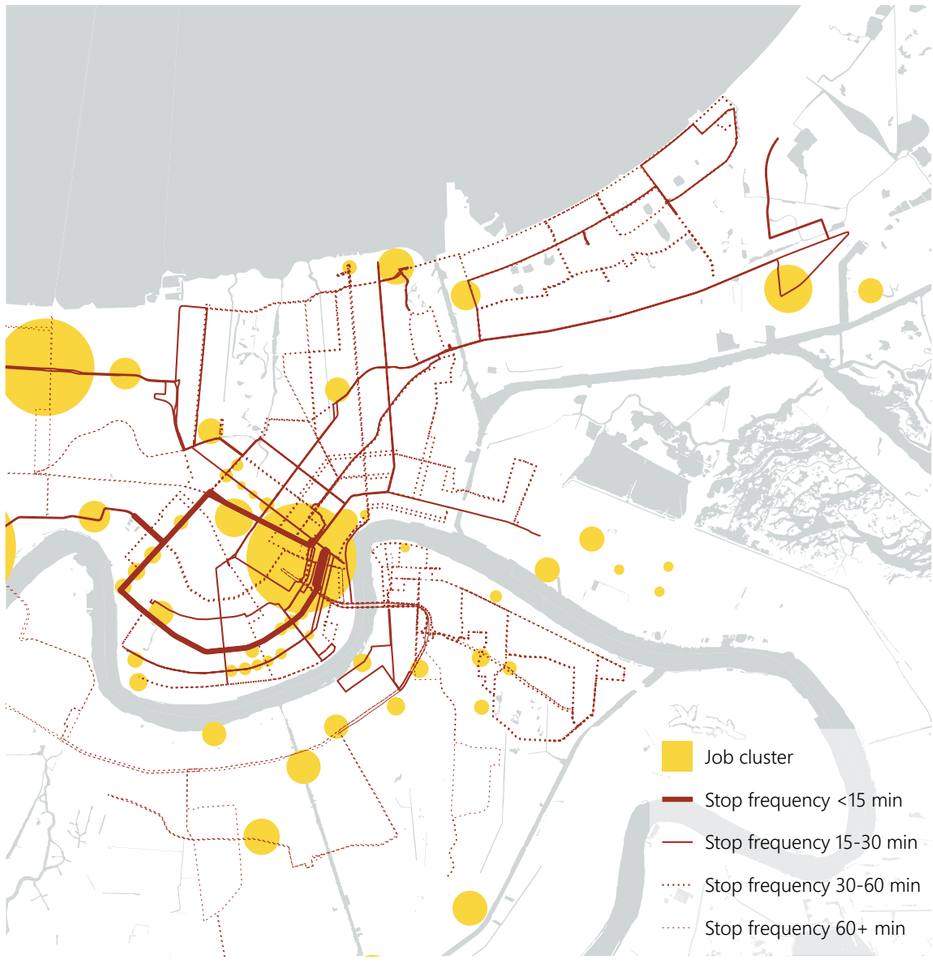


Figure 15 - Openwater is hidden behind tall floodwalls.

5. Poor accessibility; dependency on automobiles

Like many American cities, New Orleans is reliant on automobiles for transportation. The city is a regional provider of jobs, but has a severely limited public transport system (City of New Orleans, 2015). The budget for public transport was cut by almost 40% after Katrina, which further crippled its capacity (City of New Orleans, 2015). Figure 16 shows the public transport lines and major job clusters in New Orleans. It shows that there are few lines extending into the suburbs, and a disappointing stop frequency for lines that do. This connects with the earlier made point of inequity, with less affluent neighborhoods having a poor connectivity and accessibility for residents without private transportation.

Figure 16 - Job accessibility and public transport (source: City of New Orleans (2015), elaborated by author).



1.2.3 Environmental concerns

Independent environmental concerns

1. Sea level rise

Across the globe the sea level is expected to rise, but there are spatial variations. Assuming a medium climate scenario, there is a predicted sea level rise on the Louisiana coast of 63 cm (2.07 ft.) over the next 50 years (Coastal Protection and Restoration Authority of Louisiana, 2017).

2. Increasing peak precipitation

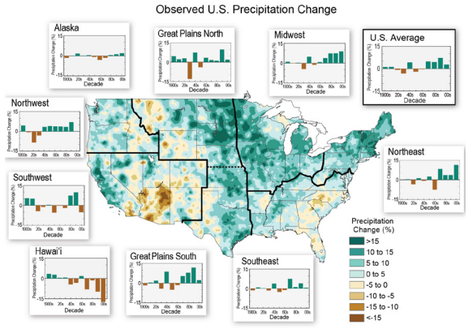
Over the past century, precipitation in New Orleans has increased, although not as significantly as in other parts of the United States (see Figure 17). According to Carter et al. (2014), both daily and five-day rainfall intensities have increased. High-intensity precipitation, a key factor of urban flooding, is expected to increase substantially over the next century (Carter et al., 2014). Figure 18 shows the projected precipitation change by season.

3. Longer dry spells

The length of dry spells is projected to increase across the United States, with the southern part of the country (including New Orleans) having to bear the highest burden (Melillo et al., 2014). Together with an increase in frequency of high-intensity precipitation, this raises the issue of water res management in the city. In the future, the city will have to deal with more extremes than it is currently capable of managing.

4. Increasing frequency of Atlantic hurricanes

The frequency of Atlantic hurricanes has increased steadily since the 1980s and this trend is projected to continue (Melillo et al., 2014). In addition, measures of intensity, duration and number of strongest storms (Category 4 or 5) have increased since high quality satellite data became available. Melillo et al. (2014) state that models project an increase in number of category 4 or 5 hurricanes by the end of the 21st century.



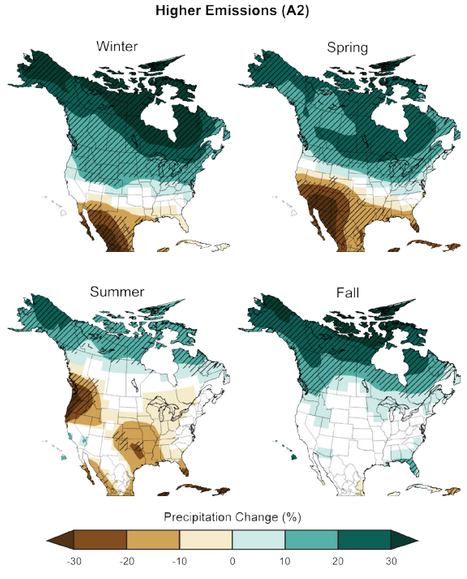


Figure 17 - (left) Observed precipitation changes in the United States (source: Melillo, Richmond, and Yohe, 2014).

Figure 18 - (right) Projected precipitation change by season (source: Melillo et al. (2014).

Human-induced environmental concerns

1. Disappearing wetlands

The construction of levees alongside the Mississippi River has disturbed the natural resupply of wetlands with fresh sediments (Coastal Protection and Restoration Authority of Louisiana, 2017). Instead, sediments are now carried to the deep water of the Gulf of Mexico. Combined with subsidence and the sea level rise as discussed earlier, there is a high potential for extensive land loss (see Figure 19). Under the medium climate scenario, inaction would result in an expected land loss of over 5800 km^2 (2254 square miles). Natural wetlands act as a barrier against storm surge. Therefore, a loss of wetlands makes the city more vulnerable to coastal flooding. In an attempt to save wetlands from completely disappearing, initiatives have started to dredge sediments from the Gulf of Mexico and transport them to sediment-starved wetlands via a pipeline.

2. Subsidence

Continuous drainage of groundwater exposesorganic layers in the soil, resulting in subsidence due to oxidation and shrinkage processes. Figure 20 shows current subsidence rates for New Orleans.

3. Crippling infrastructure

Subsidence due to pumping of groundwater undermines the structural stability of buildings and damages infrastructure (Waggonner & Ball Architects, 2013). As a result, the drainage infrastructure is in a poor state and does not function reliably. This exacerbates subsidence rates, as broken pipes effectively function as drains that lower the groundwater level across the city. Furthermore, Waggonner & Ball Architects (2013) blames decades of deferred maintenance as one of the primary causes of failures in the modern system.

4. Unsustainable urban development

The deterioration of the wetlands can party be attributed to urban development in vulnerable areas. The administration of George W. Bush abolished a policy that was in place to ensure 'no net loss' of wetlands, encouraging developers to expand the city's footprint (Pelling, 2011).

As Figure 21 shows, large parts of the city's expansions are below sea level; they rely on pumps to get rid of excess water. In addition to having an adverse impact on wetlands, the urbanized areas themselves are at danger of flooding. The city's subdivisions have a poor relation with their geographic location in the swamps. The built environment is surrounded by a concrete levee that forms the primary defense against storm surges.

"Last century's infrastructure enabled widespread urbanization in a wet delta environment, but the principles underlying that infrastructure are no longer adequate to sustain the region" (Waggonner & Ball Architects, 2013, p. 8).

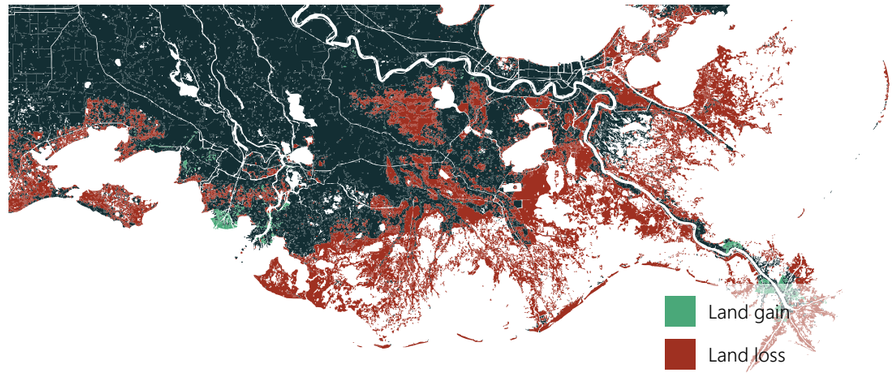


Figure 19 - Extensive land loss is predicted for the Louisiana coast (source: adapted from Coastal Protection and Restoration Authority of Louisiana (2017), elaborated by author).

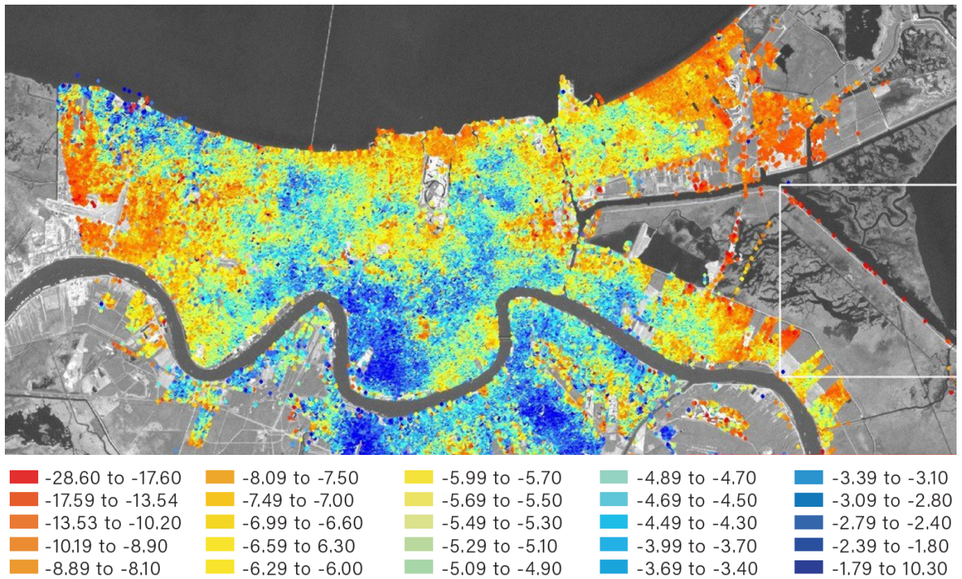


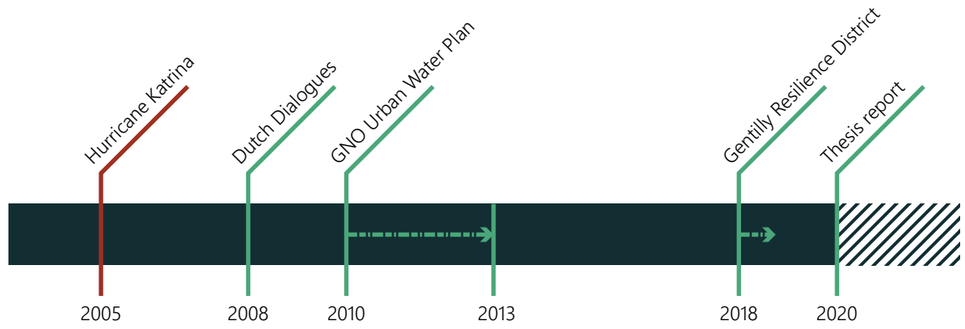
Figure 20 - Subsidence in New Orleans based on InSAR images. Values indicate the vertical velocity in mm per year (source: van Asselen, Jaimerena, and Stuurman, 2019).



Figure 21 - Elevation map of New Orleans (source: National Oceanic and Atmospheric Administration, 2017).

1.3 Starting Point: After Katrina

Figure 22 - General timeline of events after Katrina.

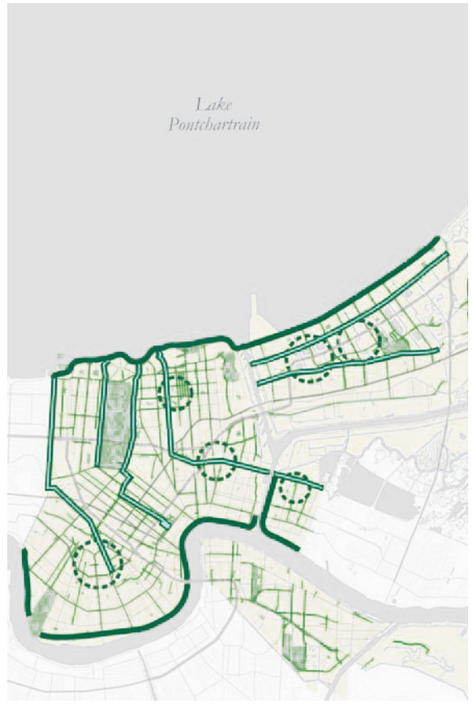


1.3.1 Initial response

The initial response after the Katrina disaster was a unified pledge of rebuilding the city and ensuring that the city would overcome the extensive damage caused by the storm. Speaking to the public on Jackson Square, then-president George W. Bush declared the following:
"I also offer this pledge of the American people: Throughout the area hit by the hurricane, we will do what it takes, we will stay as long as it takes, to help citizens rebuild their communities and their lives. And all who question the future of the Crescent City need to know there is no way to imagine America without New Orleans, and this great city will rise again."
- George W. Bush, September 2005.

However, when the Bring New Orleans Back Commission (BNOB Commission) in 2006 presented their desire to shrink the city's footprint and return many of the geographically low-lying neighborhoods to the wetlands, a public outcry followed. While residents living on higher ground argued that New Orleans should return to its early development patterns along the Mississippi river and natural ridges, residents of low lying areas, although underrepresented in public hearings, strongly pleaded for a full recovery of New Orleans (R. Campanella & Koritz, 2009). Eventually, the BNOB Commission proposed a plan as shown in Figure 23, with the green circles indicated as suitable future parkland. The general public interpreted the circles as representing exact geographic boundaries of land that would be turned into wetlands, instead of dimensionless abstractions of parkland (R. Campanella & Koritz, 2009). This made the discussion about the footprint of New Orleans a sensitive topic.

Figure 23 - Green dot plan. The green circles denote the areas destined for future parkland. (source: Bring New Orleans Back Commission, 2006).



1.3.2 Dutch Dialogues and the Urban Water Plan

Early 2006, an American delegation led by U.S. Senator Mary Landrieu was invited by the Dutch government to visit the Netherlands to experience the Dutch approach to urban water management. In 2008, with funding from the Dutch Embassy and American Planning Association, two separate workshops were organized engaging Dutch experts in the development of a new vision on water management in New Orleans.

After receiving funding from the Office of Community Development - Disaster Recovery Unit, architecture firm Waggonner & Ball led a team of local and international experts to produce the Greater New Orleans Urban Water Plan. The Greater New Orleans Urban Water Plan, completed in 2013, proposed a variety of measures and strategies to redefine New Orleans' relation with water and regard water as an opportunity rather than a threat.

Key components of the proposed measures in the Urban Water Plan

This section elaborates on key proposed measures as outlined in the Urban Water Plan that are relevant to this thesis. Rather than an in-depth review of the plans, each aspect is briefly explained. When applicable, this thesis will refer back to the Urban Water Plan more in-depth later in this report.

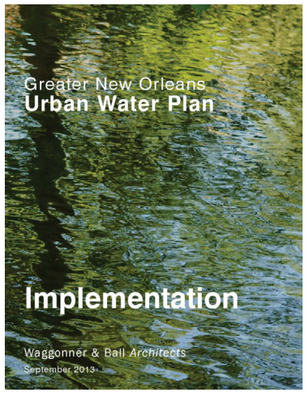
A restructured water system

In the existing water system, all runoff is eventually drained to Lake Pontchartrain in the north. The Urban Water Plan proposes a significant change in water system to intercept water flowing from the Mississippi River backslopes and drain it to the river. Furthermore, it proposes to move the pumping stations towards Lake Pontchartrain to reduce the length of the primary flood defense.

Water systems on the neighborhood scale

The Urban Water Plan proposes a network of open canals to allow for more storage capacity and use open water as a public amenity. In addition, the Urban Water Plan advocates for tearing down the canal floodwalls and using the water in the urban fabric. Having flood gates near the lake would disconnect the canals from the Gulf of Mexico in case of a storm surge, making the water level in the canals easier to control. Figure 25 up to and including Figure 29 show designs from the Urban Water Plan. Figure 25 and Figure 26 show a schematic analysis of the urban drainage system and the proposed new system. Figure 27 shows a schematic drawing of how the water system should be integrated in the urban environment. Figure 28 and Figure 29 show more detailed parts of the design, including a design for dry weather conditions.





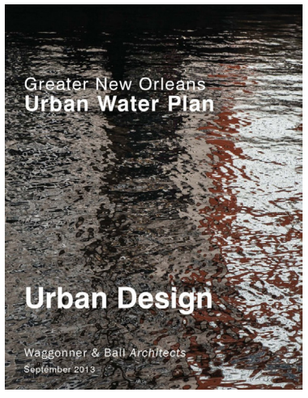


Figure 24 - Covers of some key Urban Water Plan reports (source: (Waggonner & Ball Architects, 2013).

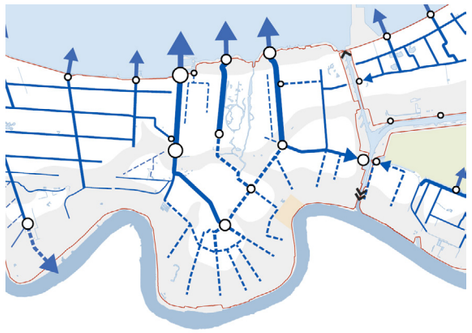


Figure 25 - (left) Existing water system (source: Dolman (2013).

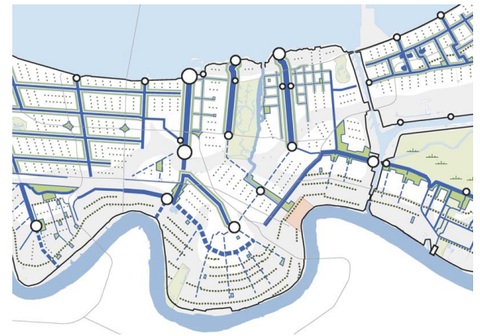


Figure 26 - (right) Proposed water system (source: H+N+S Landscape Architects, 2013).

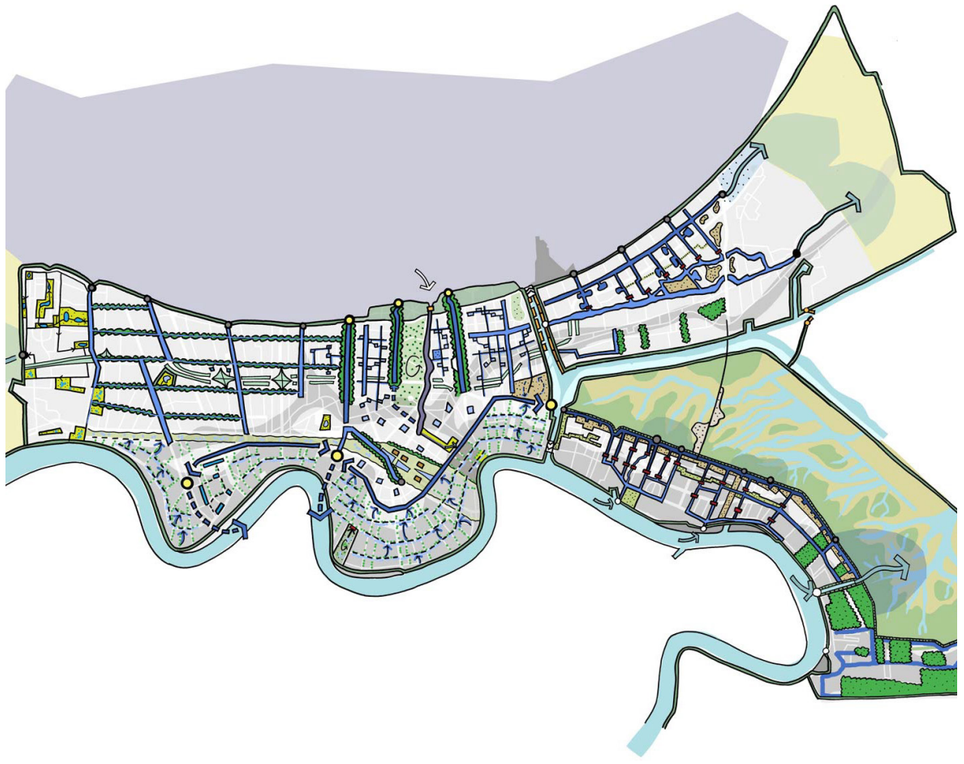


Figure 27 - Water system design (source: H+N+S Landscape Architects, 2013).



Figure 28 - (left) Dry weather flow (source: H+N+S Landscape Architects, 2013).

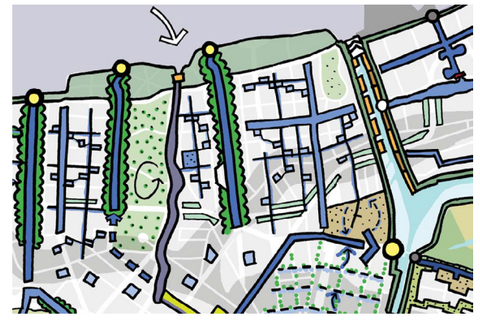


Figure 29 - (right) Water system design for Orleans Lakeside sub-basin (source: H+N+S Landscape Architects, 2013).

1.3.3 Gentilly Resilience District

The Gentilly Resilience District, the city's first resilience district, constitutes twelve projects in one of the most vulnerable sections of New Orleans. The measures aim at reducing flood risk, slowing subsidence, improving energy reliability and stimulating neighborhood revitalization. At the time of writing this report, none of the projects have been completed; they are still in the design phase. The National Development and Reform Commission (NDRC) awarded New Orleans $141 million to complete the Gentilly Resilience district projects. Amongst others, the Gentilly Resilience District encompasses a water garden, blue-green corridors and greener neighborhood streets. An overview of the projects is presented in Figure 30.



Figure 30 - Gentilly Resilience District plan (source: City of New Orleans, 2018).

1.3.4 Taking the Urban Water Plan framework forward

It is clear that since Hurricane Katrina there has been more attention for alternative ways of dealing with stormwater than simply relying on grey infrastructure. The Greater New Orleans Urban Water Plan sets a solid precedent for regarding water infrastructure as a fundamental part of the built form and provides useful analyses and design proposals. The Gentilly Resilience district operates on a smaller scale and considers how blue and green infrastructure would work on a neighborhood scale.

However, there are two fundamental shortcomings in all plans and proposals that have been developed recently. Both shortcomings are individually described below and form the starting point of this thesis.

Shortcoming 1: No consideration for extreme events

The proposals by the Urban Water Plan and Gentilly Resilience District are entirely focused on preventing damage due to moderate precipitation. There is no consideration for making the built environment less vulnerable in case of an extreme event, which could include levee or pump failures. Consequently, merely the "low-hanging fruit" is addressed by the design principles.

Although it is simply not possible (or feasible) to design an urban water system that is capable of dealing with extreme events such as Hurricane Katrina or the 5 August 2017 precipitation, ample opportunities lie in the urban planning and design domain to reduce the vulnerability of the urban environment. The Urban Water Plan does not address these issues, leaving the city still unprepared for extreme storms.

This shortcoming relates to a vulnerability framework developed by de Graaf, van de Giesen, and van de Ven (2009), which is elaborated in section 2.6 (Theoretical Framework). In short, the vulnerability framework identifies four capacities of the built environment in dealing with the consequences of climate change: threshold capacity (preventing damage), coping capacity (minimizing damage in case of failure), recovery capacity (the ability to recover from a traumatic event) and adaptive capacity (reshaping the urban system to future changes).

Shortcoming 2: Poor integration of adaptation measures with the built environment

Many of the current proposals lack detailing on how adaptation measures are integrated in the urban fabric and how they relate to the built environment on different scales. Often, a blue-green corridor is drawn simply as a blue line on a map, without considering what this might mean for the surroundings. Figure 25 up to and including Figure 30 serve as examples for this point. Finished projects in the city, such as rain gardens, are isolated entities and do not adhere to a spatial strategy. Furthermore, the lack of spatial integration of these designs is reflected in improper maintenance and questionable performance.

1.4 Motivation

A critical event such as Hurricane Katrina often triggers an urge for change. There is widespread support for contributing towards a redesigned, safer system. Wagner and Frisch (2009) describe the moment of urgency after a natural disaster or other traumatic event as a 'design moment'. In New Orleans, the design moment after Katrina initiated the development of various plans, including the prominent Greater New Orleans Urban Water Plan.

Regrettably, a design moment loses steam over time and development becomes deadlocked in legislative, cultural and practical objections. In the case of New Orleans, few far-reaching interventions were carried out. Systematic changes that were executed did not take full advantage of their potential to set a solid precedent for change.

The New Orleans case study is not virgin ground; there already is a wide body of reports and articles on how the city has dealt with the fallout of the Katrina disaster. Therefore, this thesis will avoid reiterating general commentaries on which direction the city should take but rather add to established proposals such as the Greater New Orleans Urban Water Plan and Gentilly Resilience District. In fact, the maturity of the plans allows for an interesting analysis of their effectivity and general adoption amongst the public.

The added value this thesis seeks to achieve lies in the combined engineering and urban design approach. The thesis will build on existing proposals and fill knowledge gaps between the urban design and water management disciplines that could lead to more tailored and feasible plans. Therefore, the intended outcome is a design framework with demonstration projects, supported by an engineering perspective.

1.4.1 Motivation for choice of location

This thesis will focus on the Orleans Lakeside sub-basin, wedged in between the Gentilly Ridge, Lake Pontchartrain, 17th Street Canal and the Inner Harbor Navigational Channel. This project area allows for a more spatially focused approach, whilst still dealing with the myriad of issues that New Orleans is dealing with. Below are listed the main arguments for choosing this area over other areas in the city.

- Orleans Lakeside is characterized by homogeneous zoning, mainly consisting of single family residential suburbia. The lack of diversity makes it an economically and socially vulnerable area.
- Much of the land in Orleans Lakeside lies below sea level, making it completely dependent on pumping capacity to get rid of excess water.
- Orleans Lakeside is a sub-basin, meaning it is hydrologically separated from surround parts of the city. This is relevant for water calculations.
- There is a large contrast in income of the population in this projects area. Gentilly, in the eastern part of the project area, is home to predominantly low-income households, while Lakeview, to the west of City Park, has much wealthier households.
- Vacancy is a persistent problem in Orleans Lakeside.
- The Gentilly Resilience District is a pilot program on creating more resilience in the New Orleans suburbs, with multiple projects on green and blue infrastructure underway or planned. It is the first program of its kind in New Orleans. A critical evaluation of the proposed projects results in a thesis that is more connected with the current course of action.

Figure 31 - Project location: Orleans Lakeside sub-basin.



2 Methodology

2.1 Project Backbone
2.2 Methodological Framework
2.3 Research Approach
2.4 Research Outcomes
2.5 Theoretical Framework

Chapter roadmap

New Orleans faces a myriad of perils that relate to social, spatial and technical misalignments and sectorial approaches. In order to successfully and sustainably improve the current system, this thesis proposes an integral approach which is elaborated in this methodology chapter.

The spatial delimitation of this thesis, focusing on the Orleans Lakeside sub-basin, allows for a more concentrated and in-depth approach to creating more flood and drought resilience. The choice of this project area does not suggest that other parts of New Orleans do not require attention. It merely is a representative location for further research and exploration of an integral approach to water management.

Section 2.1: Project Backbone

Section 2.1 forms the backbone of the thesis through a thorough analysis of the problem field as laid out earlier. By providing a summary of the project field and identifying the main issues facing Orleans Lakeside sub-basin, a knowledge gap is formulated which this thesis seeks to address. The research gains more focus through the problem statement, which leads to the research aim explaining the wider goals of this thesis. A hypothesis and main research question, supported by sub-questions, formulate the key aspects on which the research should focus to achieve its goal. Finally, the intended research outcomes are explained. The outcomes form the basis to which the research framework is designed to contribute.

Section 2.2: Methodological Framework

In section 2.2, the conceptual framework provides the first insight in how the problem field, aim and theoretical themes relate. The relevant research themes are deducted from the knowledge gap. The conceptual framework is followed by the methodological flowchart, which shows the various phases of this research and how methods are related to each phase.

Section 2.3: Research Approach

Section 2.3 lays out the general research approach using an analytical framework and an explanation of the methods used in this thesis. Furthermore, the analytical framework describes the relation between the (sub) research questions, theoretical research themes and the methods. The interdisciplinary approach taken in this research requires a variety of methods, including modelling and research by design. In addition to an individual explanation of the methods, this section elaborates on the differing perspectives of both disciplines on the proposed methods.

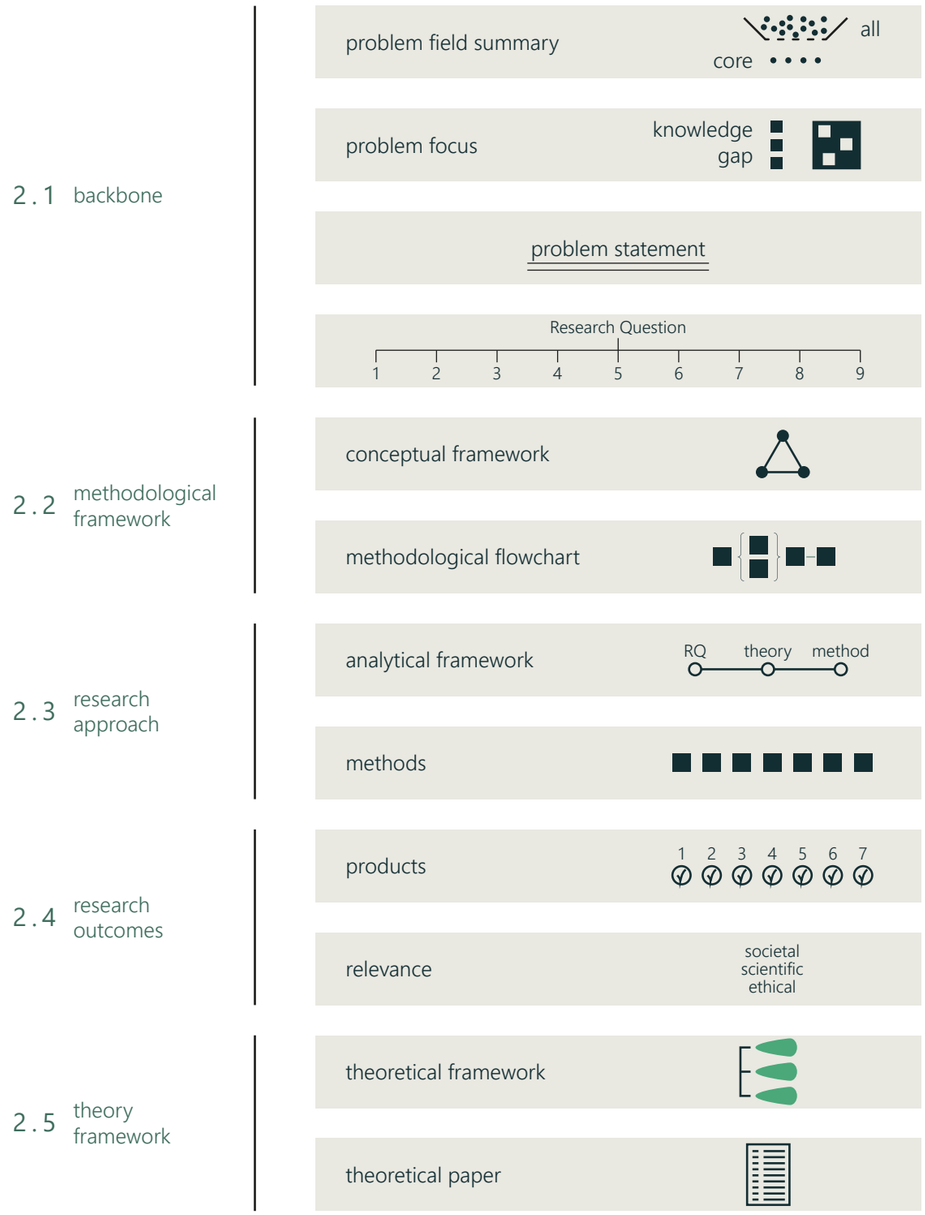
Section 2.4: Research Outcomes

Section 2.4 provides an overview of the expected products and elaborates on the societal and scientific relevance, as well as the ethical dimension of this research. Furthermore, a clarification of the limitations of this thesis describes the awareness that this research project cannot solve all of New Orleans's flood and drought related problems. It, however, seeks to actively contribute to provide a fresh perspective on alternative approaches to creating flood and drought resilience.

Section 2.5: Theoretical Framework

Section 2.5 elaborates on the theoretical framework that forms the general theoretical domain in which this thesis navigates. It explores key themes and relevant authors related to those themes. The theoretical framework concludes with a theory report on the interrelation between two themes, which will be used to gain more in-depth knowledge on innovative approaches.

Figure 32 - Methodology roadmap.



2.1 Project Backbone

2.1.1 Problem Field Summary

This section opens with a distillation of the most pressing issues facing New Orleans, focused on the Orleans Lakeside sub-basin.

Socio-spatial Concerns

- New Orleans suffers from high levels of inequity, with racially biased zoning policies from the previous century still contributing to unequal flood risk. Hurricane Katrina displaced a disproportionate part of the black population, with the process of gentrification continuing to displace low-income households.
- New Orleans is struggling with vacancy. While the city already had extensive vacancy issues before Hurricane Katrina, the amount of deserted plots has skyrocketed since the storm.
- The built environment of Orleans Lakeside is homogeneous and ill-suited to dealing with flooding and drought.
- New Orleans has a diluted identity. The city's geographical location in wetlands is not visible in the urban space.
- Orleans Lakeside is reliant on automobiles for transportation, making the suburb poorly accessible by other modes of transportation.

Environmental concerns

Independent environmental concerns

- Exposure to increasing environmental extremes, including hurricanes, peak precipitation & drought.
- Rising sea levels.

Human-induced environmental concerns

- Disrupted sedimentary processes in combination with sea level rise have resulted in extensive loss of wetlands, therefore weakening natural defenses against coastal flooding.
- Decades of mechanical drainage caused severe subsidence of the polder suburbs.
- Poor maintenance of infrastructure has led to a crippling drainage system.
- Sprawling suburbs into the Mississippi floodplains are the most vulnerable parts of the city.

Shortcomings of proposed frameworks

- The strategy proposed by the Greater New Orleans Urban Water Plan (GNO UWP) fails to address the interaction between the built environment and the proposed adaptation measures.
- The GNO UWP is not consistent in translating strategy-level aims into implications for smaller scales of the urban form.
- The GNO UWP does not provide a holistic view on vulnerability of the built environment. The framework only considers a threshold capacity (preventing the problem).

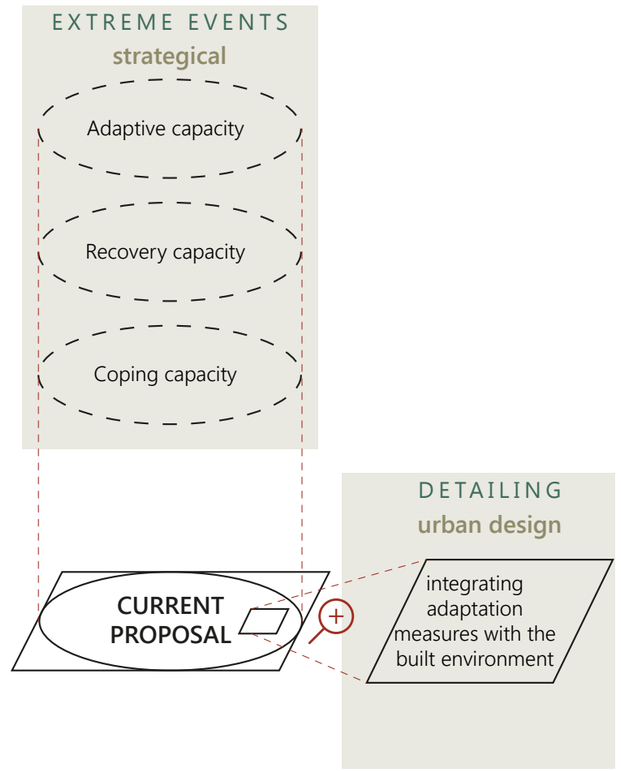
2.1.2 Problem Focus

From the myriad of issues that New Orleans is facing, the knowledge gap, problem statement and research aim narrow down the research field to include both an engineering and spatial task.

Knowledge Gap

The knowledge gap as articulated in the problem field consists of two distinct shortcomings in the current approaches to urban water management in New Orleans. One part of the knowledge gap relates to the lacking consideration of extreme events when prevention of damage is simply impossible and the focus should be to use spatial strategies and design to cope with, recover from and adapt to flooding events. The second part relates to detailing the interaction between adaptation measures with the built environment, as this is currently not a priority. Adaptation measures cannot sustain if they are not integrated in the spatial framework and disregard the local built context. Figure 33 illustrates the knowledge gap this thesis seeks to address, consisting of both a strategical and urban design dimension.

Figure 33 - Knowledge gap.



Problem statement

The aggressive ***expansions of homogeneous, low density suburbia into the wetlands*** of the Mississippi river are now vulnerable and completely rely on pumping efforts to dispose of excess water. ***Changing climatological conditions***, including sea level rise, increasing peak precipitation, longer dry spells and an expected increase of North Atlantic hurricanes demand a ***paradigm shift*** to make the built environment less susceptible to climatological extremes and increase flood and drought resilience. The strategy and measures proposed by the Greater New Orleans Urban Water Plan, while helpful as an indication of desired action, leave out ***key issues concerning the integration of water infrastructure with building typologies and streetscapes***, as well as relating to the stalling rebuilding efforts and pressing inequities across the poorer parts of the city. Furthermore, the performance and effectivity of finished and currently undertaken adaptation projects is poorly understood. Hence, a ***reframing of the interaction between the built environment and adaptation projects*** is required, with consideration for a merger of interests. In addition to the current threshold capacity, a new approach should consider ***multiple capacities of the built environment***, including a coping, recovery and adaptive capacity.

Research Aim

There is a knowledge gap in aligning strategies for integrating adaptation measures with the built environment. The ultimate aim of this project is to improve the flood and drought resilience of the polder suburbs of the Orleans Lakeside basin by aligning strategies and elaborating small scale demonstration projects. This will be pursued from a joint engineering and designing perspective. The focus will be on flood resilience; drought resilience plays a minor role in this thesis.

Intended research outcome

On a meta level, this thesis aims to initiate a new debate on urban planning and water management practices in New Orleans. More practically, the intended research outcomes are two products that are inherently intertwined:

1. The first product is an alignment of strategies for adaptation efforts in the Orleans Lakeside basin, aiming to advocate a holistic vision for the future of the project area.
2. The second product is a demonstration design project on a smaller scale to solidify the integration of adaptation measures with the built environment.

Section 2.4 provides a more elaborate explanation on the intermediate products to arrive at the desired outcomes.

2.1.3 Research Questions

Hypothesis

Current proposals for climate adaptation in Orleans Lakeside disregard a large potential in making the city more climate resilient. The overall lack of strategic consideration for extreme events leaves the city unprepared for next big storm, whilst the missing detailing and integration of technical adaptation measures in the built environment raise questions about the social, economic and environmental sustainability of the interventions. By considering and integrating all capacities of the built environment and detailing urban interventions across scales, Orleans Lakeside can be made more flood and drought resilient.

The overarching research question to be answered in this report is:

How can Orleans Lakeside be made more flood and drought resilient by integrating multi-layered resilience capacities of the built environment, whilst safeguarding consistent design of technical adaptation measures within the urban space?

The research question touches upon multiple aspects, which are elaborated below:

Aim	Improving the flood and drought resilience
Context	... of Orleans Lakeside
Method	... by integrating multi-layered resilience capacities of the built environment
Condition	... whilst safeguarding consistent design of technical adaptation measures within the urban space.

The main research question is split into two encompassing research focus areas that correspond to both disciplines involved in this project. Both focus areas contain research sub questions that elaborate on the discipline-specific challenges.

Urbanism

1. How can Orleans Lakeside be restructured in a way that reduces vulnerability to flooding and drought?
2. How can flood and drought adaptation measures be consistently integrated with the built environment through all scales?
3. How to deal with uncertainty regarding the rebuilding and repopulation efforts in New Orleans?

Water Management

1. Which areas of Orleans Lakeside are the most vulnerable to flooding and drought?
2. How can the existing urban features such as city parks be used in managing the water supply?
3. What is the performance of finished and currently implemented green infrastructure projects such as rain gardens?
4. How can green infrastructure be deployed in managing water surplus and shortage on a small scale?

2.2 Methodological Framework

An integrated interdisciplinary approach at the intersection of urban design and water management provides a challenging methodological basis for the thesis. The methodological framework forms the most fundamental structure of the thesis, describing the main themes, point of departure and general sequence of research.

The water management and urbanism disciplines both delivered domain-specific research questions, as outlined in the previous section. This thesis aims to provide an interdisciplinary outcome, making the integration of the domain-specific research questions from a methodological standpoint a vital concern. In this thesis, the integration of the two domains and their respective research questions takes shape through a synthesis of the leading research themes. As a result, these research themes are a mix of both disciplines and cover the entire spectrum. Reflection moments include a domain-specific reflection, in which the answers to the domain-specific research questions are evaluated, as well as an integrated reflection to assess the success of the interdisciplinary integration.

The knowledge gap brings forth a set of connected topics that form the basis of the main theoretical underpinning of this project. These topics connect a wide variety of related issues and are not well-defined research themes themselves. Through an exploration and synthesis of the most important connected topics, three relevant research themes are derived, with their interrelations capturing the essence of the knowledge gap. This process is schematized in Figure 34.

Climate vulnerability relates to the relative vulnerability of residents and the built environment to different magnitudes of extreme weather. Urban regeneration refers to the premise that any spatial intervention should have beneficial effects for the economic, social and environmental sustainability of the city. The green infrastructure theme encompasses research on the performance of green infrastructure in urban environments, in addition to their integration in the urban fabric. The three leading themes converge into the theoretical framework (section 2.6) by expanding their range and listing relevant authors.

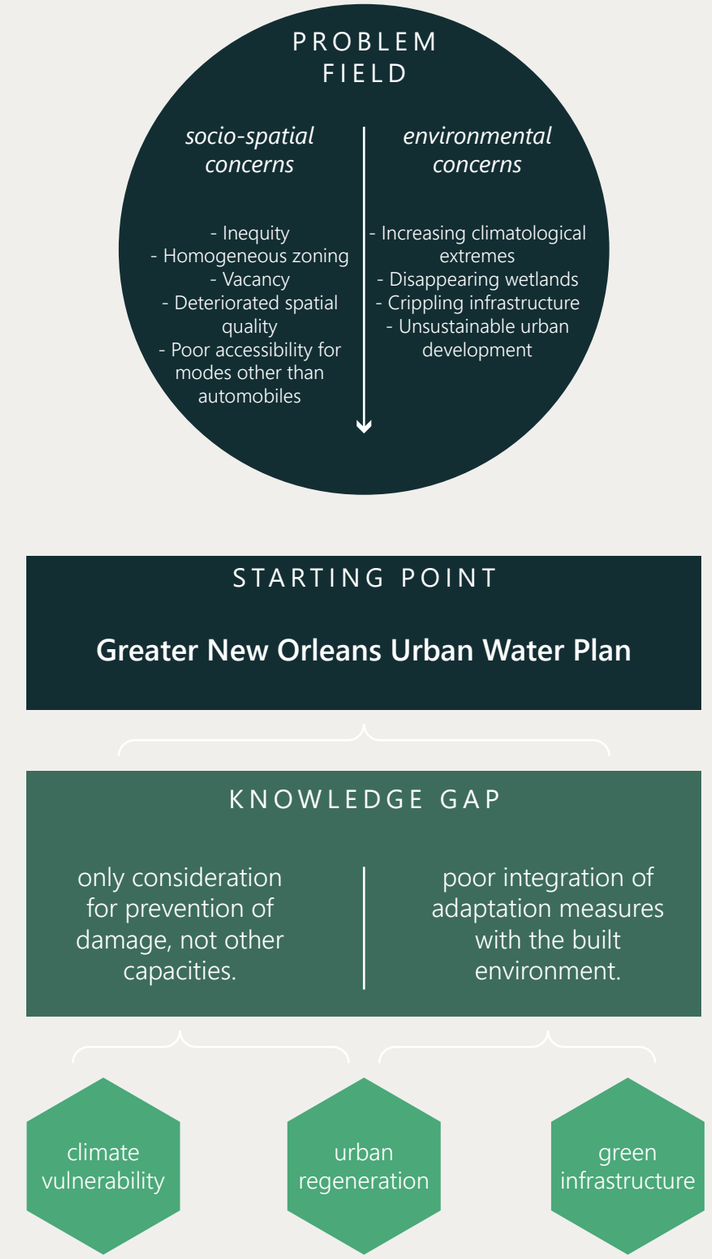


Figure 34 - Process of determining three main research themes from the knowledge gap.

2.2.1 Conceptual Framework

The conceptual framework as depicted in Figure 35 describes the interrelations between the problem field, point of departure, connected theories and the aim of the thesis. It recognizes the anthropogenic and natural parts of the problem field and illustrates the shortcomings of the Greater New Orleans Urban Water Plan (GNO UWP) as the starting point for this thesis. As identified earlier, there are two main instances where the Urban Water Plan fails to contribute to a more flood and drought resilient New Orleans: the lack of consideration of extreme events and the poor integration of green infrastructure with the built environment. The three primary themes, being climate vulnerability, urban regeneration and green infrastructure are associated with the aforementioned shortcomings and are substantiated by multiple key authors. The three themes, to be further explored in this thesis, combine into the aim of improving the flood and drought resilience of the lower lakefront neighborhoods of New Orleans.

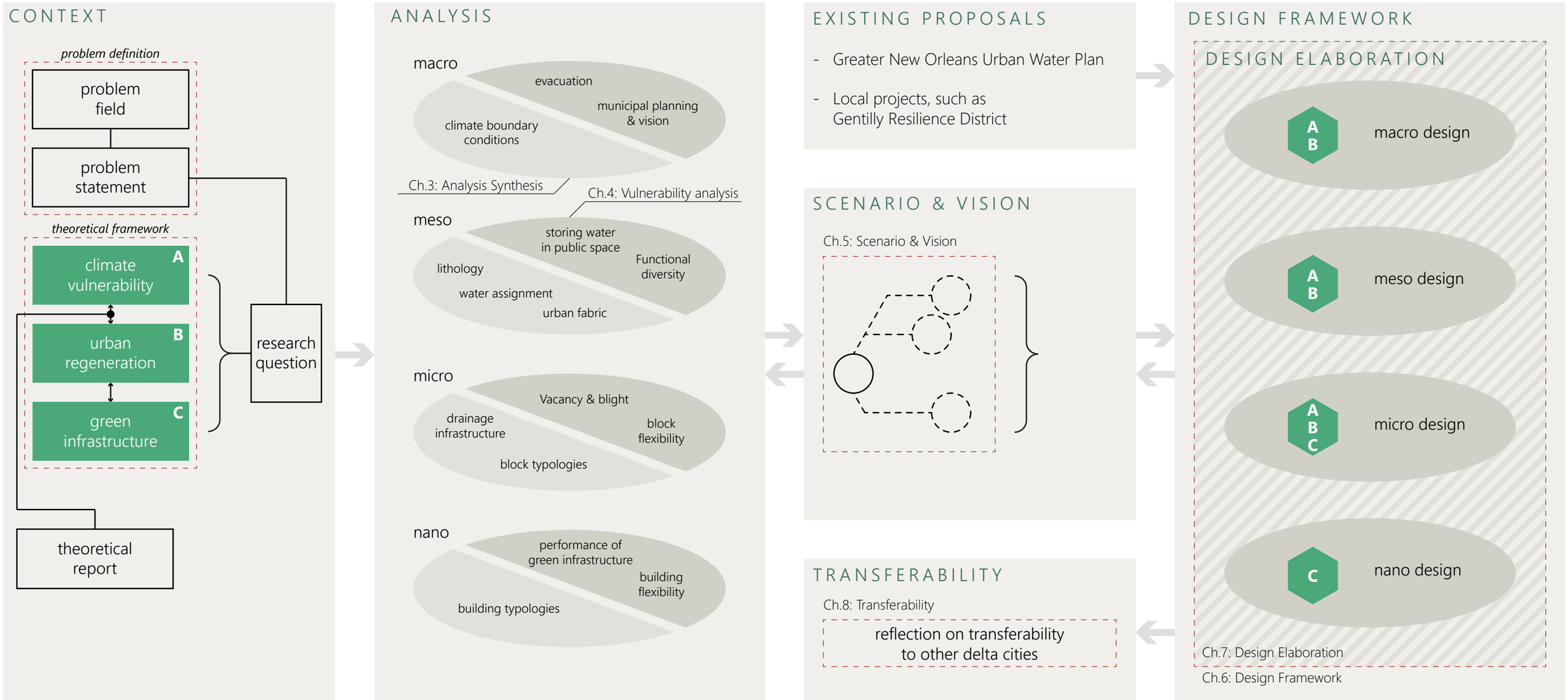
Figure 35 - Conceptual framework.



2.2.2 Methodological Flowchart

As much of the problem field relates to inconsistencies and deficiencies across scales, the scalar approach remains central to the thesis's methodological flowchart (see Figure 36). The thesis consists of four main phases. The first phase is concerned with contextualizing the problem field and formulating the research foundation. In the second phase, the built environment of New Orleans is analyzed on topics that are relevant to urban design and water management. Phase three draws from the analysis and leads to scenarios and a vision. Phase four consists of research by design on multiple scales. The arrows in Figure 36 indicate progress and reflection between the project phases, which underlines the iterative character of the approach. A final reflection at the end considers the transferability of the results to other delta cities facing similar problems.

Figure 36 - Methodological Flowchart.



2.3 Research Approach

This subsection elaborates on the methods used in this thesis and how they relate to each other. The careful selection of methods ensures a fruitful combination of design and engineering. The thesis uses a total of 6 methods, which are used at different times throughout the thesis:

1. Literature review
2. Mapping
3. Field work
4. Modelling
5. Creating scenarios
6. Research by design

As described in the methodological framework, the concept of scales is pivotal for this research. This concept is also related to the use of methods throughout the thesis, as certain methods are more prominent on a particular scale than others.

2.3.1 Analytical Framework

The analytical framework, depicted in Figure 37, shows the relations between the research questions, connected theories and proposed methods for this thesis. Literature review forms the basis for the report, as it identifies the current state of the art an the most pressing knowledge gaps. It also provides a fundamental theoretical underpinning of the thesis.
Mapping, in its broadest sense, is used to understand the spatial relations and characterize the built environment. An important part of the thesis is field work, where a variety of activities are performed. This includes interviews, measurements and observations. Modelling adds an engineering backing to the proposed interventions and helps understanding the most critical parts of the system. Scenarios are useful for understanding trends and project possible pathways for New Orleans. Finally, research by design combines the engineering and design approach into a design framework with demonstration projects. The following segment elaborates on each method, describing the purpose and procedure in detail.

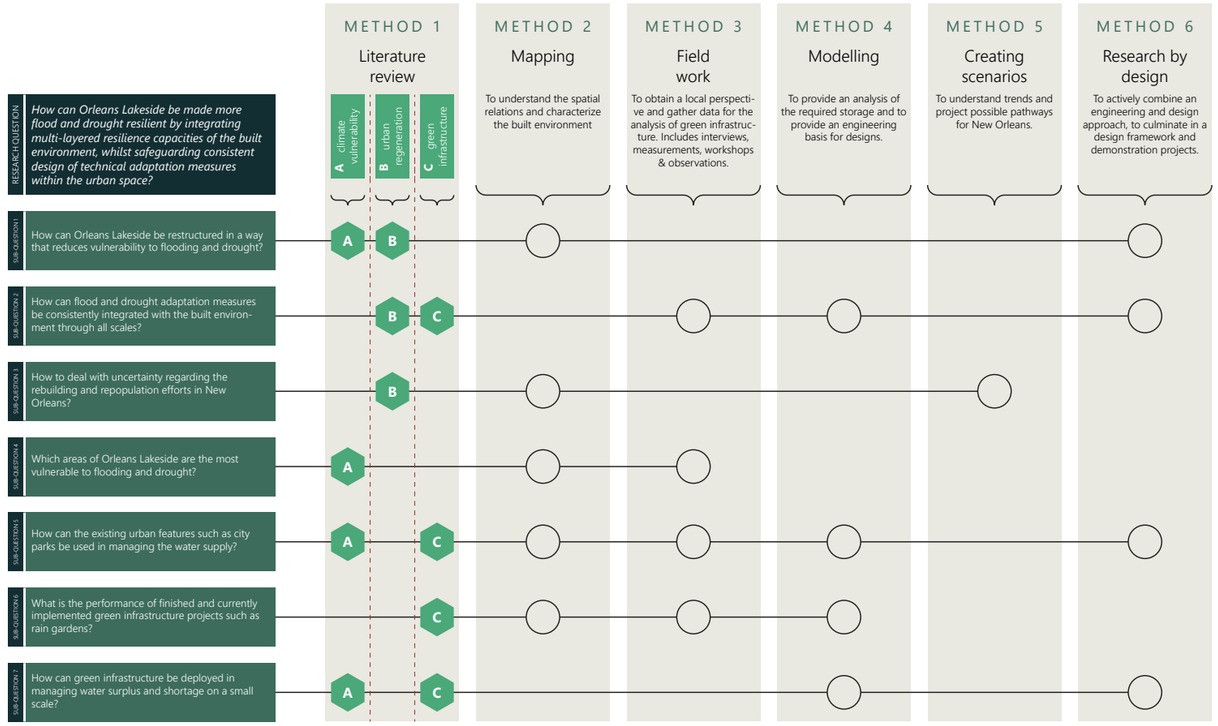


Figure 37 - Analytical Framework.

01: Literature review

Purpose of method

To collect and synthesize theories and concepts relevant to the thesis.
Literature, ranging from conceptual theories to practical reports, forms the theoretical basis for the thesis. This culminates in a theoretical framework, consisting of the three main research themes: climate vulnerability, urban regeneration, green infrastructure. In addition to sharpening the problem focus, it provides an understanding of the state of the art and builds a frame of reference for interventions. A deepening theoretical research is conducted through a theory paper, which explores the relation between the topics of climate vulnerability and urban regeneration in more depth.

Key words

Thesis general:
New Orleans, flooding, drought, climate vulnerability, urban regeneration, green infrastructure, climate adaptation, adaptation measures, urban water management

Theory paper:
New Urbanism, New Orleans, urban sprawl, flood resilience, climate vulnerability

Search engines

JSTOR, Google Scholar, WorldCat Discovery

Document types

Books, book reviews, peer-reviewed journals, (government) reports, newspaper articles.

Procedure

The central research themes as deducted from the knowledge gap (Figure 33) are explored and synthesized into a theoretical framework. The relevant keywords as described above are entered in scientific search engines to retrieve relevant literature connected to the three main themes. Section 2.6 (Theoretical Framework) elaborates further on the content and associated authors of each theme.

02: Mapping

Purpose of method

To understand spatial relations and characterize the built environment.
Mapping and overlaying forms a powerful tool to grasp spatial challenges and identify opportunities for interventions.

Relevant scales

Macro (system)
Meso (neighborhood)
Micro (block)
Nano (unit)

Procedure

The maturity of the flooding issues in New Orleans means a large body of maps already exist on this topic. This thesis draws from previous reports to use those maps, but presents own maps where existing products fall short. Furthermore, relating back to the core goal of this thesis to combine engineering with design, maps will be overlaid to expose core issues and identify novel opportunities. Mapping takes place throughout the project, as elaborated below.

Problem definition
Mapping is the most prevalent at the macro and meso scale in the problem definition phase. Maps contribute to an understanding of general climatological issues and define the spatial boundaries of the thesis.

Analysis
In the analysis phase, mapping occurs at all scales: macro, meso, micro and nano. On the macro and meso scale, mapping is used to fathom the complex system of water flows and the spatial framework of the city. Using tools such as GIS, floods and water shortages are mapped. An analyses of the urban fabric identifies the main challenges and opportunities for interventions. Mapping on the micro and nano scales is used to determine deficiencies and opportunities at the transition from system scale to actual building scale.

Vision
The creation of scenarios and forming of a spatial vision is supported by maps on multiple scales.

Research by design
The design phase sports all mapping scales, building on input from the multi-scalar analysis and vision. This project phase is supported by other ways of visualization, as outlined in ‘method 06: research by design’.

03: Field work

Purpose of method

To obtain a local perspective and gather measurement data for the analysis of adaptation measures.
It is essential to visit the location in order to fully understand the context and locality of the project area. Furthermore, engaging with local residents and practitioners provides valuable insight that is unobtainable through literature review. The complex nature of the problem requires a broad view on the issues at play, drawing from multiple perspectives. In addition to discussing with and interviewing the local residents and practitioners, the field trip is used for data gathering. Essential data for the assessment of adaptation measures is not being made public in the United States due to copyright and liability issues. This requires independent data gathering.

Field work period

Visit 1: 27-03-2019 – 07-04-2019
Visit 2: 05-2019 – 05-2019

Procedure

Visit 1
Colleagues:
- Roelof Stuurman - urban water and soil expert, Deltares
- Rik van den Oever - graduate student, Deltares

Activities:
1. Walking tours with community project groups (Saint Anthony Events)
2. Community workshop on green infrastructure
3. Interviews with local architects Dana Brown & David Waggonner
4. Interviews with representative of Sewerage & Water Board of New Orleans
5. Observing, photographing

The first visit is meant to get acquainted with the city and project area, as well as ongoing community projects. Throughout the field work period, multiple site visits and interviews take place. A complete list of all interviewed people is displayed in Table 2.

Visit 2
Colleagues:
- Roelof Stuurman - urban water and soil expert, Deltares

Activities:
6. Presenting proposed design for multiple groups of stakeholders.

The second visit revolves around presenting the vision and design for Orleans Lakeside to multiple groups of stakeholders, including architects, the municipality, the water board and local residents. This serves to provide valuable feedback for further elaboration of the proposal.

Table 2 - Interviewees in New Orleans.

Name	Company	Function	Date
Andy Sternad	Waggonner & Ball Architects	Architect	3-4-2019
Aron Chang	Blue House (formerly: Waggonner & Ball Architects)	Community group leader (formerly: architect)	29-3-2019
Bhuban Ghimire	Ardurra Group	Senior engineer	14-11-2019
Dana Brown	Dana Brown & Associates	Landscape architect	5-4-2019
David Waggonner	Waggonner & Ball Architects	Architect, CEO	4-4-2019
Delaney McGuinness	Dana Brown & Associates	Junior landscape architect	5-4-2019
Edwin Welles	Deltares USA	Hydrologist/ Director	1-4-2019
Gilad Meron	The Blue House	Co-Founder and Director	14-11-2019
John Kleinschmidt	Waggonner & Ball Architects	Architect	3-4-2019
John Taylor	-	Local resident	2-4-2019
Joshua Lewis	Tulane Universtiy; ByWater Institute	Research Assistant Professor, ecologist	5-4-2019
Julia Kumari Drapkin	Iseechange	CEO	4-4-2019
Mac Ball	Waggonner & Ball Architects	Architect, Director	12-11-2019
Maggie Hermann	Blue House	Community worker	29-3-2019
Mary Kincaid	City of New Orleans	Sustainable Infrastructure Program Manager	14-11-19
Matthew Tarr	University of New Orleans (UNO)	Vice President for Research and Economic Development	14-11-19
Mike Miner	Water Institute of the Gulf	Director of Applied Geosciences	11-11-19
Ramiro Diaz	Waggonner & Ball Architects	Architect	28-3-2019
Sarah Olivier	New Orleans City Park	Director of Planning	1-4-2019
Thorbjörn Törnqvist	Tulane University	Vokes Geology Professor in the Department of Earth and Environmental Sciences	31-3-2019
Todd D. Reynolds	Groundwork	Executive Director	28-3-2019
Tyler Antrup	City planning department	City officer urban planner + resilience	29-3-2019

04: Modelling

Purpose of method

To quantify current flooding and drought issues and testing design interventions for their effectivity.
With this thesis' intention of joining design and engineering disciplines, modelling provides an engineering backing to proposed interventions. From a designer's perspective, modelling can provide insight in the overall effectivity of interventions, while an engineering point of view is more focused on the dimensions and performance of measures. This thesis uses both hydrological and hydro-dynamic models.

Procedure

The procedure for both hydrological and hydro-dynamic modelling is elaborated below.

Hydrological modelling
A hydrological model is used to identify general water management issues concerning flood and drought. Modelling software provided by Deltares will be used for this analysis.

Hydro-dynamic modelling
The Storm Water Management Model (SWMM) computes real-time stormwater dynamics and provides insight in the quantity of runoff. This modelling software, developed by the United States Environmental Protection Agency, simulates the flow through a simplification of the drainage system into catchments, nodes, conduits and outflow points. A SWMM model was already set up for the Greater New Orleans Urban Water Plan and will be expanded in this thesis. For modelling runoff it is essential to use relevant design storms. This thesis will use the design storm with a return period of 10 years (T10) as determined in the Urban Water Plan, accounting for a peak precipitation increase due to climate change.

In the analysis phase, the model is used to identify weak links in the system and determine the most vulnerable parts of Orleans Lakeside. Combined with demographic data, this provides insight in the relative vulnerability of areas.

05: Creating scenarios

Purpose of method

To identify possible paths for the development of the city as a basis for interventions.
The future is unpredictable and depends on a multitude of factors. Instead of extrapolating the current city developments as the starting point for design interventions, this thesis recognizes the most relevant and pressing uncertainties by providing a scenario analysis.

Procedure

Although an extensive scenario review falls outside the scope of this thesis, there are several key factors that can greatly influence the future development of New Orleans. Based on a literature review, this thesis identifies the following uncertain aspects:

Climate projections
Accounting for the effects of climate change is pivotal in developing a solid proposal for Orleans Lakeside. This thesis considers the projected changes in precipitation, length of dry spells and the frequency of Atlantic hurricanes.

Municipal policies and desired development
The municipality can exert influence on the development of the city through policies and incentives. Desired improvements in the drainage system and planned projects have to be taken into account.

Actual demographic trends
New Orleans has had a slow recovery from Hurricane Katrina, with the population count stagnating (U.S. Census Bureau, 2010). Independent of the goals and ambitions of the municipality it is relevant to consider the actual and projected demographic trends. A persistent reluctance of evacuees to return in combination with a low net migration could result in a city whose footprint is too big for its population. Stagnating growth could lead to a removal of a tax base for future interventions.

06: Research by design

Purpose of method

To propose a holistic design framework and location specific designs, supported by engineering evidence.
Research by design is to address the knowledge gap: proposing a holistic design framework, building on existing frameworks, and detailing the interaction of adaptation measures with the built environment.

Procedure

This method combines the design and engineering disciplines through an iterative approach and operates in two phases. The first phase produces a design framework that expands and improves on existing frameworks such as the Urban Water Plan. The second phase is location-specific design, where a couple of representative locations are chosen for further detailing.

Phase 1: design framework
Building on the Urban Water Plan and other frameworks, the first phase proposes a design framework that tackles the strategic part of the design challenge. This phase is mainly concerned with the macro & meso scales. Major implications for the water system are modelled with SWMM and the hydrological model as defined earlier. A representative location for further detailing is chosen, which is elaborated in the second phase.

Phase 2: urban design
Phase 2 consists of a series of urban design projects on the meso, micro & nano scales. These projects focus on detailing the interaction of the built environment with adaptation measures, while considering their implications on larger scales.

2.3.2 Methods and disciplines

Water management and Urbanism deploy methods in different ways. Although both disciplines benefit from all methods described in this section, the interpretation is different. To clarify these differences, Figure 38 elaborates on both discipline's perspective on the methods.

Figure 38 - Differing perspectives on methods.

	URBANISM	WATER MANAGEMENT
METHOD 1 literature review	• Studying US planning culture. • Determining boundary conditions for urban regeneration.	• Defining the technical state of the art. • Investigating ways to analyze adaptation measures. • Defining possible technical solutions.
METHOD 2 Mapping	• Overlaying maps for spatial analyses. • Combining socio-spatial and technical data. • Uncovering the scales of the system and their interrelations	• Simplifying to understand the water system.
METHOD 3 Fieldwork	• Grasping socio-spatial processes. • Studying spatial quality. • Interviewing designers & residents.	• Gathering data. • Understanding the water system through field measurements. • Interviewing engineering experts.
METHOD 4 Modelling	• Determining the relative climate vulnerability.	• Determining dimensions. • Producing a hydraulic & hydrological design.
METHOD 5 Creating scenarios	• Evaluating socio-economic development. • Developing a vision for the future.	• Determining hydraulic & hydrological boundary conditions.
METHOD 6 Research by design	• Deploying urban design in iterative design loops to explore socio-spatial interventions.	• Intensive design process to design effective systems.

2.4 Research Outcomes

2.4.1 Products

The thesis proposes a total of seven intermediate products that together lead to the two main research outcomes as described earlier: an alignment of strategies resulting in a design framework and set of demonstration design projects at smaller scales. Figure 39 shows the seven intermediate products in a logical succession. The first two products are domain-specific, while the products in the following phases join to explore their synergies.

Product 1

The first intermediate product is a synthesis of the analysis done for the Greater New Orleans Urban Water Plan. A synthesis of the most relevant conclusions from the readily available body of morphological and technical analyses forms the starting point of further elaboration.

Product 2

The second product is a vulnerability analysis of Orleans Lakeside by using the vulnerability framework as described by de Graaf et al. (2009). This analysis is designed to build upon existing analyses and contribute to a more in-depth analysis of the situation. All three main research themes are assimilated in this analysis.

Product 3

The products of the first phase, with their primarily domain-oriented approach, combine into the development of scenarios for the Orleans Lakeside project area. These scenarios contain a projection of possible future trends such as demographics, urban development and hydrology.

Product 4

The fourth product is a vision for Orleans Lakeside, based on a synergistic consolidation of both technical and socio-spatial scenarios.

Product 5

Building on the Urban Water Plan and ongoing adaptation plans, the fifth product is a design framework that aligns strategies and proposes improvements on existing programs. This product is largely tied to the larger scales of the project (macro & meso).

Product 6

The sixth product is an elaboration of the fifth product. From the design framework, a representative design location is selected for further detailing. The detailed urban design ties together all scales of the project with the aim of successfully integrating adaptation measures with the built environment.

Product 7

The seventh intermediate product takes shape as a reflection on the transferability of the findings in this thesis to delta cities facing similar issues. This product is to expand the societal relevance of this thesis, although an in-depth review of possible transfer locations falls outside the scope of this project.

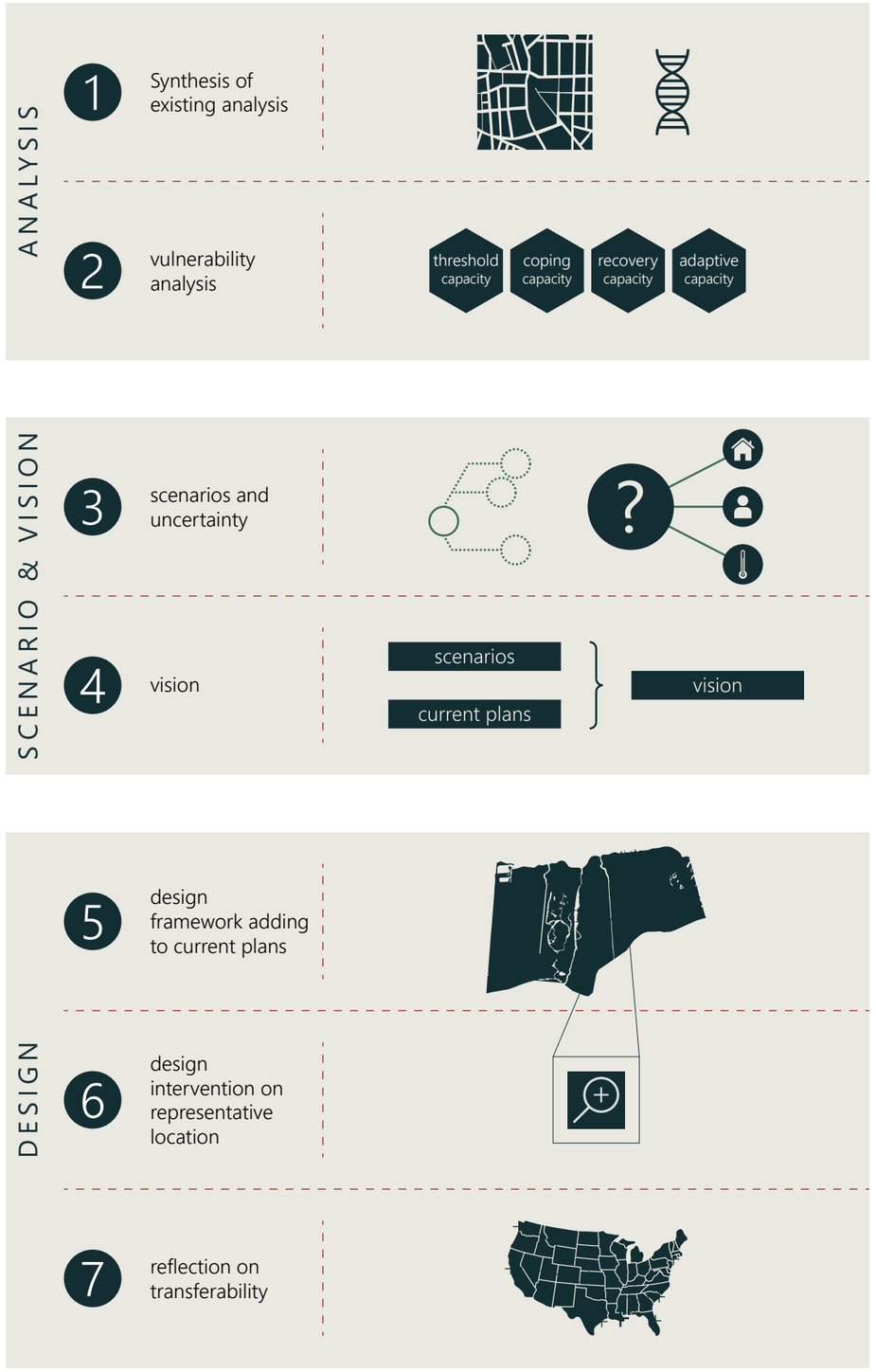


Figure 39 - Research outcomes.

2.4.2 Limitations

In order to provide sufficient depth in this research, the thesis is spatially limited to the Orleans Lakeside basin, confined by Lake Pontchartrain, the Gentilly Ridge, 17th Street Canal and the Inner Harbor Navigational Channel. This basin holds some of the most vulnerable neighborhoods, as well as City Park. The low lying Gentilly neighborhood is home to many community initiatives on green infrastructure, making it a suitable location for further research.

This thesis recognizes the pressing social-racial issues in the city, but will not elaborate on these issues due to time constraints. The strategies and designs proposed in this thesis will be sensitive to their surroundings, but will not consider an elaborate analysis on racial issues in the city. This thesis will have a predominantly technical character, in which the focus on combining designing with engineering is key.

2.5 Theoretical Framework

2.5.1 Theoretical Framework Elaboration

The main research themes introduced in section 2.2 (Methodological Framework), presented in Figure 34, form the basis for the theoretical framework. The relevance of a solid theoretical framework lies within a theoretical underpinning the problem focus and proposed interventions. This section elaborates on the main research themes and relevant associated authors.

Although the leading research themes are used throughout the thesis, a separate, more in-depth theory paper is included as part of the theoretical framework. The theory report explores the relation between the climate vulnerability and urban regeneration themes to investigate how different forms of urbanization could positively affect the vulnerability of the low-lying New Orleans neighborhoods, whilst creating conditions for urban regeneration.

Climate Vulnerability

Climate vulnerability refers to the relative vulnerability of residents and the built environment to different magnitudes of extreme weather. Central to this research theme is the work by de Graaf et al. (2009), who developed a vulnerability framework to describe the capacities of the built environment in dealing with extreme weather events. de Graaf et al. (2009) identify four capacities of the built environment: threshold capacity (preventing damage), coping capacity (using spatial planning to minimize damage and optimize evacuation), recovery capacity (recovering), and adaptive capacity (adapting to future changes). This approach relates to the Multi-layer Safety Framework, developed by the Dutch Government in 2015 to actively use spatial planning in reducing flood risk. This theme includes work by Adams et al. (2009), who consider climate injustice issues and the eviction of the poor from New Orleans.

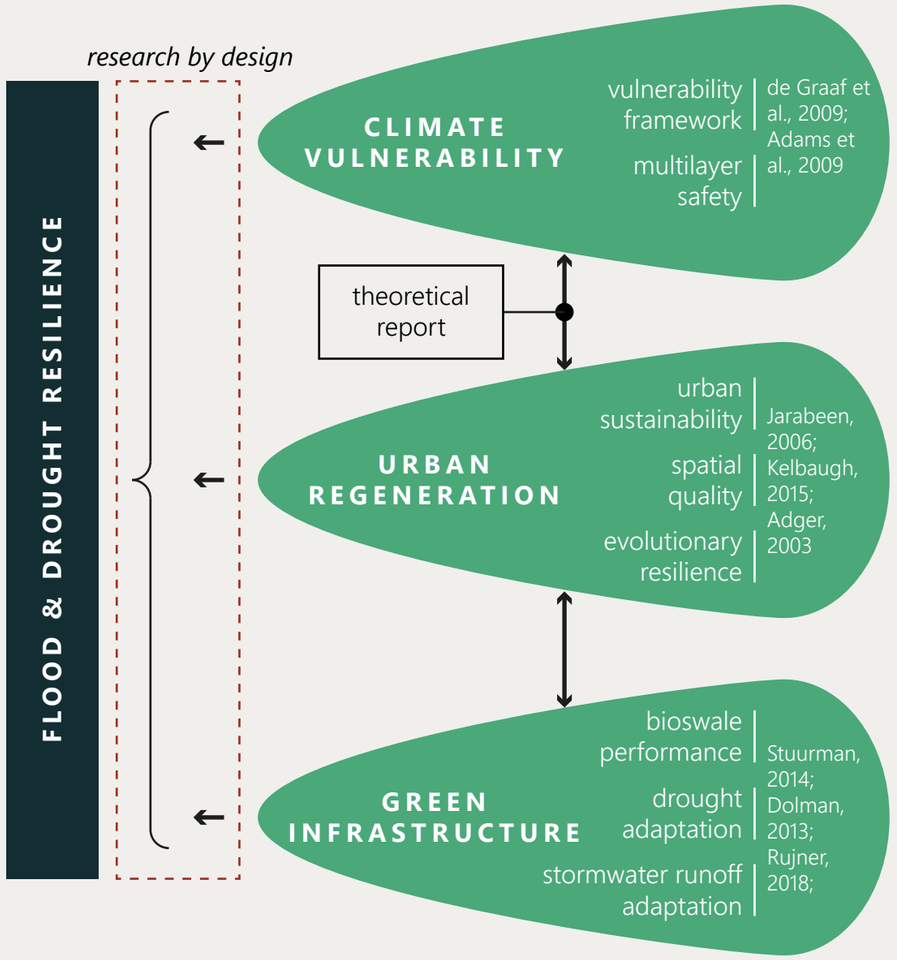
Urban Regeneration

Urban regeneration refers to the premise that any spatial intervention should have beneficial effects for the economic, social and environmental sustainability of the city. This theme covers a range of literature, including theory on alternative urban typologies (Jabareen (2006); Kelbaugh (2015)), evolutionary resilience (Adger (2003); T. J. Campanella (2006);) and the role of public space (Jacobs (1961)). Part of the urban regeneration theme is dedicated to a review of the American urban grid design, with Busquets, Yang, and Keller (2018) providing relevant literature on this aspect. As this thesis builds on the Greater New Orleans Urban Water Plan, the book Dutch Dialogues written by Meyer and Waggonner (2013) is used to guide general strategies in making the water system beneficial to upgrade the main spatial framework. Governmental reports and policies are part of this framework as well, as they are used in defining scenarios for New Orleans.

Green Infrastructure

The green infrastructure theme encompasses research on the performance of green infrastructure in urban environments, in addition to their integration in the urban fabric. For the evaluation of small scale adaptation measures (rain gardens), literature by Warnaars, Larsen, Jacobsen, and Mikkelsen (1999), van Seters, Smith, and MacMillan (2006) and Rujner (2018). For the integration of green infrastructure with the built environment this thesis refers to the book Green-blue Grids by Hiltrud Pötz (2016).

Figure 40 - Theoretical framework.



The potential of New Urbanism in making New Orleans more flood resilient.

Abstract - This paper addresses the potential of New Urbanism development in creating more flood-resilient communities in New Orleans suburbs. It seeks to evaluate the potential benefits, on multiple layers, of flood-risk management and provide arguments against conventional suburb planning. As a grounds for comparison, a vulnerability framework is used which identifies four capacities of the built environment on dealing with extreme weather events: threshold, coping, recovery, and adaptive capacity. For each capacity the paper identifies multiple aspects where New Urbanism performs better than conventional suburb planning, although some capacities are benefitted more than others. For the threshold capacity, a denser city fabric results in a smaller footprint, which reduces the required dike-length and therefore reduces vulnerability to failure. In addition, a more efficient evacuation facilitated by New Urbanism increases the coping capacity of the built environment. New Urbanism advocates a denser built environment, which reduces evacuation travel time and allows for vertical evacuation in taller buildings. Furthermore, the higher diversity of functions encouraged by New Urbanism creates more suitable conditions for recovery, although communal institutions and social networks are found to play a more significant role. Finally, New Urbanism increases the adaptive capacity by proposing a finer grained urban fabric containing a larger mix of functions. This type of urban environment is better able to adapt to future changes than rigid, homogenous suburbia. The limitations to New Urbanism found in this research mainly relate to a planning approach that caused resistance amongst the residents. Hence, New Urbanism design principles hold a strong potential in making New Orleans more flood resilient, although an integration towards a context-sensitive design with regards for local perception is essential.

Key words – New Urbanism, New Orleans, urban sprawl, flood resilience, climate vulnerability

1. Introduction

This paper addresses the potential of New Urbanism development in creating more flood-resilient communities in New Orleans suburbs. It seeks to evaluate the potential benefits on multiple layers of flood-risk management and provide arguments against conventional suburb planning.

After Hurricane Katrina struck New Orleans on 25 August 2005, urban planners seized the opportunity provided by the extensive destruction to put forth their design agenda and use the city as a clean slate for experiments (Wagner & Frisch, 2009). The New Urbanism movement was a prominent player involved from the early stages of rebuilding New Orleans (Michna, 2006). New Urbanism's design principles, cemented by the Congress for the New Urbanism (CNU), can be classified as neo-traditional development, aimed at limiting urban sprawl and inner-city decline by focusing on density and diversity (Jabareen, 2006). These design proposals encountered fierce resistance among New Orleans residents, largely due to the lack of regard to local context and the superimposed, top-down character of the plans. Subsection 4 (Urban flood resilience and the role of New Urbanism in New Orleans) deals with these issues in greater detail.

Generally, it is argued that urban development based on New Urbanism fundamentals is more sustainable than conventional suburb development (Berke et al., 2003). Brody, Gunn, Peacock, and Highfield (2011) found that high-density development patterns, including those prevalent in New Urbanism planning, show significantly less reported property damage than low-density development. This is echoed by Stevens, Berke, and Song (2010), who argue that New Urbanist designs have a potential to reduce losses due to natural hazards. However, all previous studies only considered the influence of New Urbanism development on the causes of flooding with regards to basin-wide implications. The potential of New Urbanism principles in making the built environment more flood resilient is not fully understood.

This paper appraises the potential of New Urbanism in making New Orleans more flood resilient by focusing on the design principles that affect the vulnerability of the built environment. Hence, this paper is not seeking to enter a debate on the aesthetics of New Urbanism, but rather discusses the aspects of compact development that directly influence the spatial vulnerability. The abundance of New Urbanism precedents in New Orleans greatly helps to identify the potential of these design principles in making the city more flood resilient.

This paper provides a comparative research on the differences in flood resilience between conventional suburb development and design guidelines dictated by New Urbanism. For the definition of resilience, theories by Liao (2012) and Davoudi, Brooks, and Mehmood (2013) are used. The potential of New Urbanism in creating flood resilient communities is evaluated on the basis of the vulnerability framework as defined by de Graaf, van de Giesen, and van de Ven (2009). This framework identifies four capacities which determine the vulnerability of the built environment: threshold, coping, recovery, and adaptive capacity. These four capacities provide a representative basis for comparison.

Reading guide

The appraisal of New Urbanism and the argument against conventional suburbia is built up by formulating the context and research question. Then follows an explanation of the methodology used for the comparative analysis. A theoretical framework introduces the main concepts used in this paper, after which the comparative analysis forms the main argument. The paper concludes with a reflection on the potential of New Urbanism in making New Orleans more flood resilient.

2. Context & Problem statement

Suburbs are ubiquitous in the United States; major city expansions often take shape as extensive subdivisions filled with detached dwellings. Large greenfield development, resulting in urban sprawl, converts vast areas of natural landscape to residential districts (Berke et al., 2003). Generally, scholars agree that suburbia creates an environment that is less than ideal and starves the city cores of investment (Kelbaugh, 1997; MacBurnie, 1995). However, suburbia remains immensely popular with investors and residents alike, as this is a typology that is associated with the "good life" (MacBurnie, 1995).

The catastrophic damage caused by Hurricane Katrina triggered a design moment, defined by

Wagner and Frisch (2009) as a period of time in which particular events occur that result in a process of urban restructuring. A design moment, Wagner argues, can result from (natural) disasters or other traumatic experiences. The role of New Urbanism in New Orleans in the design moment after Hurricane Katrina is elaborated in subsection 4 (Urban flood resilience and the role of New Urbanism in New Orleans).

The proposed urban designs were criticized for having little regard to the local context and being too overzealous in their approach to completely reimagine the city of New Orleans (Michna, 2006). However, with the rejection of these plans, interesting ideas and concepts that would increase the flood resilience of New Orleans were discarded as well.

Reconsidering the potential of compact development and New Urbanism principles holds potential in making the lower lying New Orleans more flood resilient. New Urbanism designs have the capacity to reduce losses due to natural hazards and offer a much more promising future than business as usual (Kelbaugh, 1997; Stevens et al., 2010).

This paper aims to answer the following research question:
To what extent can New Urbanism increase flood resilience in New Orleans suburbs?

3. Methodology: Comping New Urbanism with conventional suburbia

Firstly, when assessing the flood resilience of New Urbanism development, a definition of (flood) resilience is required. In this paper, flood resilience is defined by the framework and theory set forth by Liao (2012), complemented by the notion of evolutionary resilience by Davoudi et al. (2013).

An introduction to New Urbanism and its basic principles and concepts follows. Special attention is paid to the properties linked to environmental sustainability and flood resilience. This paper drafts from multiple authors on this issue to compile a holistic view on New Urbanism design ideals.

In order to provide a thorough assessment of the potential of New Urbanism in increasing flood resilience, the vulnerability framework as defined by de de Graaf et al. (2009) is used. This framework identifies four capacities of the built environment in dealing with (natural) disasters: a threshold, coping, recovery and adaptive capacity. The main characteristics of this framework and criteria for evaluation are briefly explained in subsection 4.

The main body of this paper is a comparative analysis between conventional suburbia and New Urbanism on all four layers of the vulnerability framework.

4. Theoretical Framework: Urban flood resilience and the role of New Urbanism in New Orleans

Resilience theory

Despite the increasing prevalence of the term "urban flood resilience", it remains ambiguous (Liao, 2012). Liao (2012) identifies two distinctive interpretations of resilience: ecological and engineering resilience. Engineering resilience is defined as the ability of a system to maintain stability and the capacity to return to the pre-disaster state as quickly as possible. Ecological resilience, on the other hand, describes the ability of a system to survive a disturbance and return to a stable state, not specifically being the pre-disaster state. Davoudi et al. (2013) introduces the concept of evolutionary resilience, which recognizes the ability of a system to change, adapt or transform in response to stresses and strains. Thus, a system does not necessarily have a stable state (Davoudi et al., 2013). This paper draws from both Liao and Davoudi and defines urban flood resilience as the capacity of the built environment to prevent flooding, and to reorganize should physical damage and socioeconomic disruption occur, so as to prevent deaths and injuries (Davoudi et al., 2013; Liao, 2012).

New Urbanism

New Urbanism opposes to conventional suburb development and focuses on reviving traditional typologies and urban patterns (Kelbaugh, 1997). It views the explosive sprawl of low density residential subdivisions in the natural landscape as undesirable and rather sees investment in more traditional, denser urban forms. Kelbaugh (1997) identifies seven principles of New Urbanism that cover the primary goals of the movement: denser communities, fine-grained and diverse land use, priority to 'slow' traffic, conserving existing urban cores, a sense of identity, increased citizen participation and making day-to-day life more energy-efficient and sustainable. Jabareen (2006) describes New Urbanism as an approach to urban planning and design that relies on historical precedents to blend a variety of housing types in the form of communities, rather than superblocks or suburbs. Stevens et al. (2010) underline compactness and walkability as core principles of New Urbanism.

The destruction caused by Hurricane Katrina triggered the development of different rebuilding and design proposals, with New Urbanism playing a key role in the immediate aftermath of the hurricane (Michna, 2006). Wagner and Frisch (2009) argue that the extent of destruction was exaggerated by urban planners to justify using New Orleans as a clean slate to facilitate their own agenda. A wide variety of designs were proposed for the city, including a relocation of the city, constructing super levees and creating an 'American Venice' (Wagner & Frisch, 2009). Most plans had two aspects in common: the rejection of homogenous urban sprawl and limiting the city's footprint. New Urbanism was widely involved in reconstruction efforts along the Gulf Coast, as the Congress for the New Urbanism (CNU) was invited by the then-Mississippi Governor Haley Barbour to develop plans for the rebuilding of the communities damaged by Hurricane Katrina (Talen, 2008).

There was fierce resistance against New Urbanist plans from both professionals and the public. Professionals argue that New Urbanism developments do not live up to their promise of social improvement, but rather provide nostalgic urban communities for the upper-middle class that actually contradicts social improvement and perpetuate an old social order (Michna, 2006; Talen, 2008). Especially in the context of New Orleans, where many vulnerable and poor residents were severely hit, this seems unethical (Michna, 2006). Furthermore, local architects criticize the vastness and top-down character of the plan, which contrasts with the incremental growth and development of the city. New Orleans residents, Michna (2006) argues, do not identify with the New Urbanism plans as they have little consideration of local stories and do not connect with the New Orleans identity.

Despite the backlash, the New Urbanism agenda has achieved some successes in the rebuilding of New Orleans. Talen (2008) describes the design of a small affordable housing unit and new types of zoning as the major contributions of New Urbanism. The "Katrina Cottage", a more permanent alternative to FEMA's emergency trailers, was hailed nationally and received the Cooper-Hewitt National Design Museum's People's Design Award (Talen, 2008). The second significant contribution is the development of the "SmartCode", a zoning plan that thoroughly considers social diversity by allowing a range of dwelling types and price segments for each zone (Talen, 2008).

Vulnerability framework

A framework was developed by de Graaf et al. (2009) that identifies four capacities of the built environment in dealing with (natural) hazards. This framework acknowledges the traditional threshold capacity (1), which is focused on prevention of damage caused by extreme events. This takes shape in building dikes, pumping stations and other infrastructure. In addition, the framework identifies a coping capacity (2), a recovery capacity (3) and an adaptive capacity (4). The coping capacity is defined as the ability to minimize impact on society when the damage threshold is exceeded (de Graaf et al., 2009). The recovery capacity concerns the capability of society to return to a pre-disaster situation. The adaptive capacity describes the ability of society to change over time to a state that is better equipped to dealing with extreme events.

The four capacities of the vulnerability framework operate on different time horizons. The threshold capacity relies on past events, such as using extreme-value statistics based on historic water levels to determine the necessary height of a dike (de Graaf et al., 2009). The coping and recovery capacities are focused on the instant. In contrast, the adaptive capacity is relevant on a long time horizon and involves a high degree of uncertainty (de Graaf et al., 2009). This capacity requires the built environment to have a sufficient flexibility to respond to all possible future trends.

The different time horizons can be represented in three different domains and have a direct relation with the damage involved. In the threshold domain, no damage is perceived. The coping and recovery domain relate to low return periods and relatively limited damage. The adaptive domain, on the other hand, is relevant to extreme events

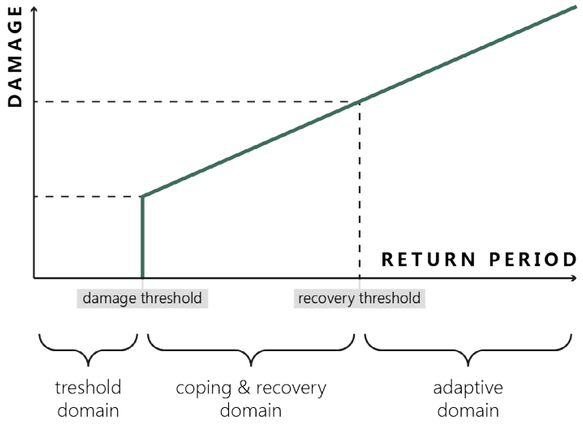
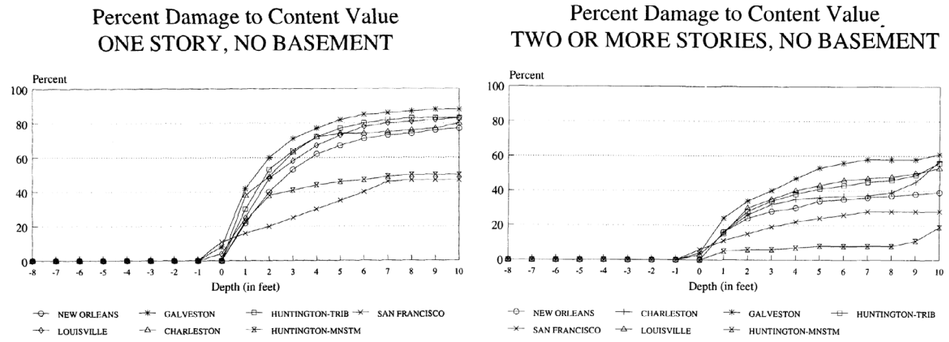


Figure 41 - Vulnerability framework (source: adapted from De Graaf, van de Giesen & van de Ven, 2007).

Figure 42 - Depth-Damage curves for single-story and multiple-story dwellings (souce: US Army Corps of Engineers, 1992).



and a corresponding high potential damage. Figure 41 shows the relation between the return period and potential damage.

5. Discussion: Comparative analysis

With the main theories underpinning this paper explained, this section continues with a comparative analysis between conventional suburbia and New Urbanism development in terms of flood resilience based on the four capacities of the vulnerability framework.

Threshold capacity

There is a variety of literature claiming that New Urbanism development is less likely to contribute to natural hazards than conventional suburbia. High-density development patterns show significantly less reported property damage than low density development (Brody et al., 2011). This is attributed to the alteration of the flow regime by conversion of open space to housing divisions, resulting in more extensive flooding. Furthermore, Stevens et al. (2010) found that New Urbanist designs have a potential to reduce losses due to natural hazards. However, if development takes place in areas prone to natural hazards or when insufficient hazard mitigation techniques are implemented, the risk of damage to natural hazards is exacerbated. For New Orleans, the main detrimental effect of urban expansions on the natural water system concerns the disappearing wetlands. Channelization and confinement of the Mississippi river has disrupted sedimentary processes, threatening the health of the wetlands separating New Orleans from the Gulf of Mexico (Coastal Protection and Restoration Authority of Louisiana, 2017). Wetlands act as a natural barrier during storm surges, and a retreat of the wetland system would put a greater strain on the federal flood defenses in case of a hurricane.

New Urbanism development is inherently more compact than traditional suburb development. By clustering housing demand into a denser typology, the effective footprint of the city shrinks. This implies that a New Urbanism subdivision would be cheaper to protect with a dike than a conventional suburb subdivision. After Hurricane Katrina struck New Orleans, arguments arose in favor of abandoning the most vulnerable parts of the city and limiting the city's extents (Ford, 2007). Such a move would reduce the length of dikes and make the city less vulnerable. However, this proposal was met with intense criticism by residents who were forced to flee the rising waters but insisted on returning (Ford, 2007).

Coping capacity

An important consideration for building in areas that are exposed to extreme weather events is that it is not feasible to make the built environment completely resistant to flooding. When the threshold capacity is exceeded, the city should be well-equipped and designed to minimize damage and facilitate a proper evacuation.

Conventional suburbia has an inherent but limited capacity to dealing with moderate flooding, which is due to the typical architecture in these subdivisions. A small elevation allows the typical urban dwelling to cope with a few feet of water, however, remains extremely vulnerable to severe inundation due to the single-story architecture. New Urbanism typologies, often sporting multiple stories, is less prone to inundation as not the entire property's value is amassed on the ground floor. Depth damage curves, developed by the US Army Corps of Engineers (1992), show damage per feet of water, per building typology. The curves, displayed in Figure 42 for different typologies, give the damage as a percentage of the building's content value. The curves show that denser typologies (40% damage at 10 ft. of flooding) cope better with moderate flooding than single-story dwellings (80% damage at 10 ft. of flooding).

An individualistic approach in American property management focuses on preventing flood damage to private structures. By raising individual parcel, private property is saved from moderate flooding, while runoff from the storm floods the streets and disrupts processes in the city. Those who can afford it save their property, while putting a greater strain on the overall system.

In addition to mitigating damage in case of flooding, evacuation is an important aspect of the coping capacity. Evacuation from conventional suburbia is completely reliant on automobiles due to the vast sprawl of the built environment. During Hurricane Katrina, impoverished residents were unable to leave due to a lack of private transportation (Colten, 2006). New Urbanism can provide vertical evacuation in local shelters as an alternative, as upper floors of buildings would remain dry during floods. Furthermore, concentrating development on naturally higher ridges would reduce the vulnerability in an effective way.

Recovery capacity

The capacity of an urban environment to recover from extreme events depends on a multitude of factors. While urban planning definitely plays a role in the recovery of cities, Campanella (2006) argues urban resilience largely depends on people. Campanella (2006) explains that communal institutions and social networks tend to survive the destruction of their physical environment, recalling the determination of residents of the devastated Lower Ninth Ward to rebuild their living environment. Increasing citizen participation by strengthening the public realm and discouraging to spend time in privatized spaces are one of the prime objectives of New Urbanism (Kelbaugh, 1997). While these principles are significant contributors to social networks, the case of the Lower Ninth Ward shows that social networks can also thrive in urban environments that do not meet these demands. Thus, the potential of New Urbanism is less clear in the aspect of recovery.

In terms of economic damage, the recovery capacity relates back to the threshold and coping capacity, as these capacities determine the amount of damage the built environment sustains in the event of a disaster. If, for instance, the extent of flooded area is limited by a more compact built form, it takes less resources to rebuild flood defenses and inundated infrastructure. However, a higher value of the affected buildings might lead to more expensive

reconstruction.

Adaptive capacity

Conventional suburbia falls into a trap that inhibits the adaptive capacity. Carpenter and Brock (2008) identify two types of traps, of which one is applicable to the New Orleans suburbs. The rigidity trap is described by Carpenter and Brock (2008) as a system where institutions become highly connected, self-reinforcing and inflexible. Furthermore, the lack of diversity is a predisposing factor for a rigidity trap, with Carpenter and Brock (2008) providing an ecological example where only a few shade-tolerant species can survive in an old-growth forest and the entire system is vulnerable to external disturbances such as wild fires. The rigid, top-down planning nature of conventional suburbia with inflexible land uses and segregated zoning matches the features of such a system and falls in the rigidity trap. Turner (2017) elaborates on why the rigidity trap persists in American planning culture, arguing that particularities of land development and finance inhibit other ways of urbanization. Current institutional characteristics and connectivity create a system where there is little incentive to explore alternatives; exposure to stress has led to entrenchment rather than experimentation (Turner, 2017).

As the adaptive capacity operates on a longer time scale with associated uncertainties, flexibility is key. By laying out homogeneous subdivisions across the landscape, suburbia does not take into account possible uncertainties in vacancy, demographic trends and potential urban development along its fringes. New Urbanism has an inherent better adaptive capacity, as its diversity enhances the collective flexibility (Pelling, 2011). In addition to a diverse urban environment, Kelbaugh (1997) describes New Urbanism's aim to achieve a small grain size, making adjustments over time easier. Flexibility can be further increased at the building scale. By integrating attributes such as high ceilings, buildings can more easily change function over time.

6. Conclusions

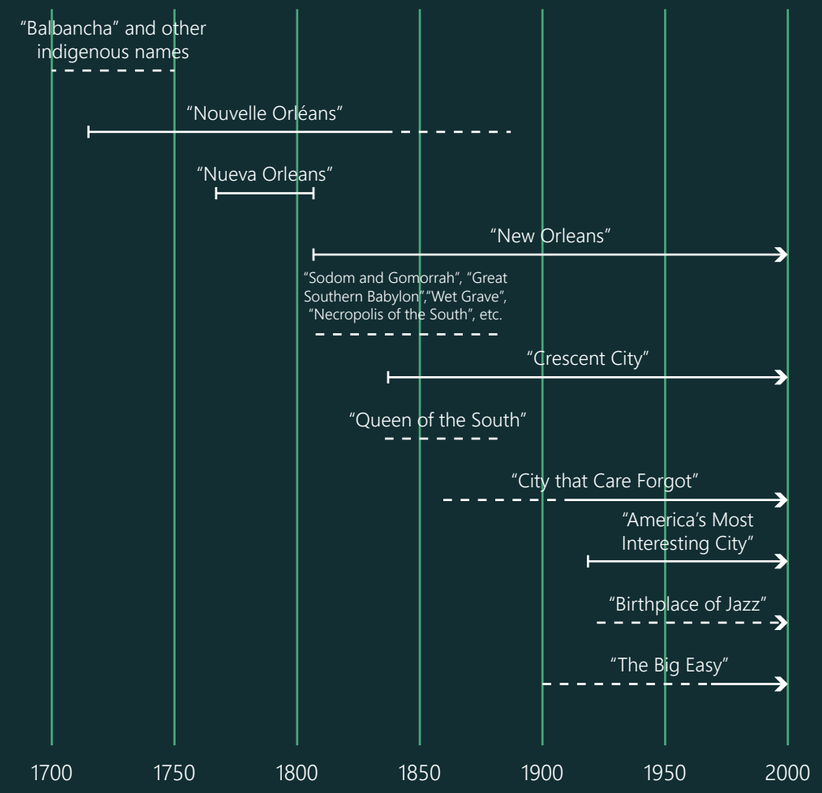
This paper aimed to appraise to what extent New Urbanism can contribute to an increased flood resilience in New Orleans. A comparative analysis with conventional suburbia on the basis of a vulnerability framework showed that New Urbanism holds potential on multiple capacities, underlining the argument of this paper in favor of alternative urban planning.

The core design principles of New Urbanism developments hold merits on all layers of the vulnerability framework, although some capacities are enhanced more than others. For the threshold capacity, a more dense city fabric results in a smaller footprint, which reduces the required dike length and therefore reduces vulnerability to failure. In addition, a more efficient evacuation increases the coping capacity of the built environment. New Urbanism advocates for a denser built environment, which reduces the evacuation travel time and allows for vertical evacuation in taller buildings. Furthermore, a higher diversity of functions encouraged by New Urbanism creates more suitable conditions for recovery, although communal institutions and social networks play a more significant role (Campanella, 2006). These social networks are also found to exist in a conventional suburban environment. Finally, New Urbanism increases the adaptive capacity by proposing a finer grained urban fabric containing a larger mix of functions. This type of urban environment is better able to adapt to future changes than rigid, homogenous suburbia (Pelling, 2011).

The limitations to New Urbanism found in this research mainly relate to a planning approach that caused resistance amongst the residents. The opportunistic behavior of New Urbanism planners after Katrina was widely denounced, making some promising proposals such as reducing the city's footprint now unnegotiable. New Urbanism design principles hold a strong potential to making New Orleans more flood resilient, although an integration towards a context sensitive design with regards for local perception is essential.

3 Analysis synthesis

3.1 Climate Boundary Conditions
3.2 Topography & Flood Susceptibility
3.3 Urban Structure
3.4 Drainage Infrastructure



Names and nicknames for New Orleans (source: based on Campanella, 2008).

This chapter aims to provide insight into the state of the art of current urban analyses and distill the most relevant aspects for this thesis. Rather than rehashing general engineering and morphological analyses, this chapter draws from conclusions made in the GNO Urban Water Plan.

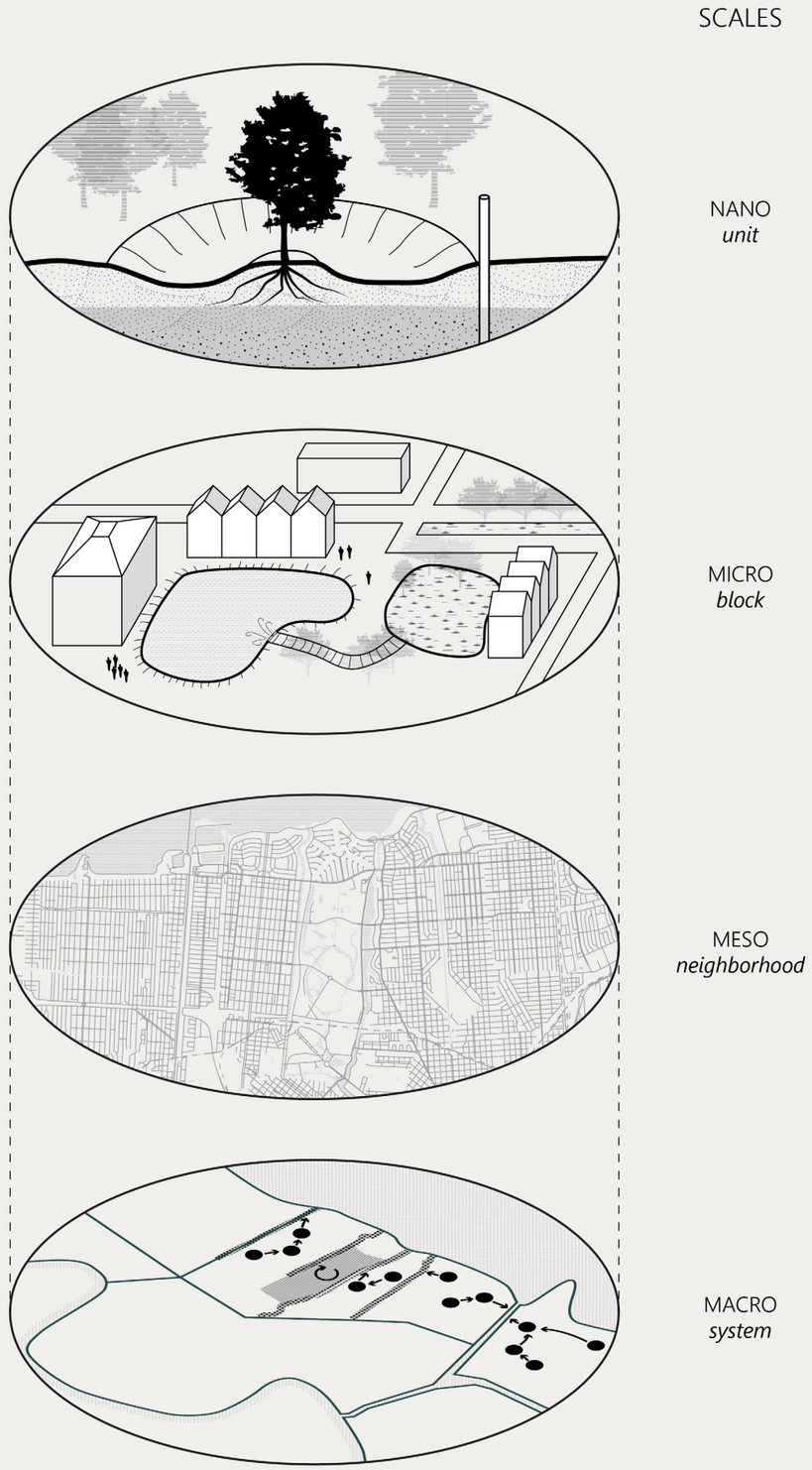
This analysis synthesis chapter provides a general background and precedes the more project-focused vulnerability analysis in Chapter 4.

The analysis synthesis is structured with a set of topics that tie together a series of related analyses. For each topic, the analyses are sorted by scale (macro-meso-micro-nano). Figure 43 shows the relevant scales in this thesis; this classification of scales is valid for the entire report.

This chapter consists of the following topics:

3.1 Climate boundary conditions
3.2 Topography & flood susceptibility
3.3 Urban structure
3.4 Drainage infrastructure

Figure 43 - Scales considered in this thesis.



3.1 Climate Boundary Conditions

3.1.1 General climate

New Orleans has a subtropical climate, resulting in the occurrence of extreme precipitation. South-east continental US has a high annual precipitation (Figure 44), with a large seasonal variability in precipitation intensity (Figure 45).

The Mississippi River drains 40% of the landmass of the lower forty-eight states (Waggonner & Ball Architects, 2013). The extent of its watershed is displayed in Figure 46.

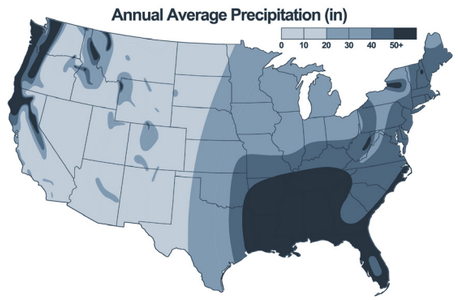


Figure 44 - Annual Average Precipitation in inches (Waggonner & Ball Architects, 2013).

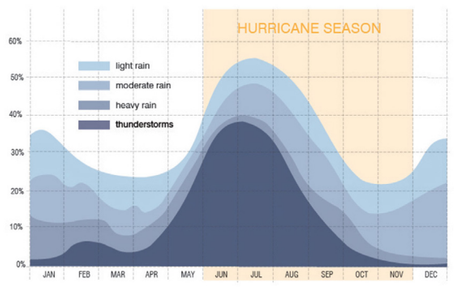


Figure 45 - Seasonal distribution of precipitation (Waggonner & Ball Architects, 2013).

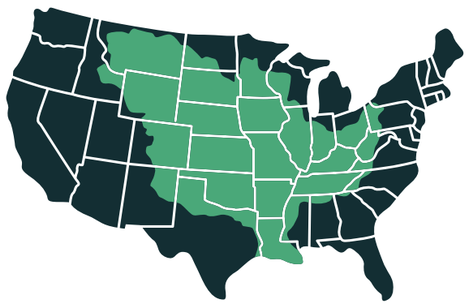


Figure 46 - Mississippi watershed.

3.1.2 Water Assignment

The water assignment method was developed by the Dutch Ministry of Transport, Public Works and Water Management in 2008 to tackle flooding related to urban surface water, sewers and groundwater. Using a water balance model comprising static input (land use) and dynamic input (precipitation & evaporation times series), the required storage capacity is computed.

Dolman (2013) performed a water assignment calculation for New Orleans, which this thesis uses as a guide for the required storage capacity.

Elements of the water assignment

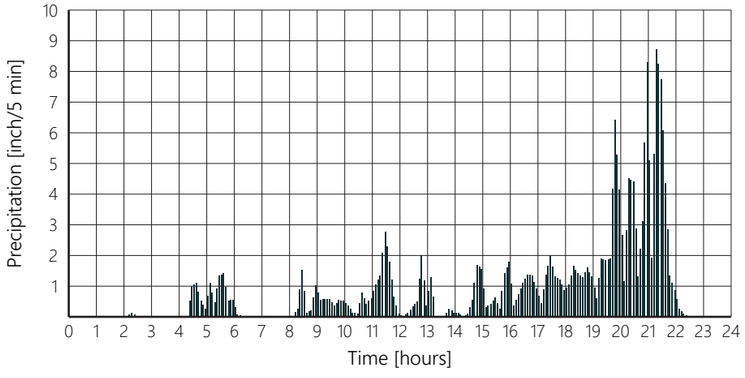
The water balance model used for the water assignment consists of five variables, which are explained below in Figure 47.

Figure 47 - Water balance model for the water assignment (source: Dolman, 2013).

$$P(t) + G(t) = R(t) + S(t) + Q(t)$$

P(t)	Precipitation
G(t)	Groundwater; seepage and infiltration
R(t)	Retention and losses [slow]
S(t)	Storage capacity [store]
Q(t)	Discharge capacity [drain]

Figure 48 - Actual T10 design storm (source: adapted from Dolman, 2013).



Precipitation

Instead of the default Type III Chicago design storm, an actual T10 rainstorm is used for the water assignment. This rain event is given in Figure 48.

Groundwater

The influence of groundwater is included in the model, although the relative contribution is expected to be insignificant (Dolman, 2013).

Retention

The retention depends on initial and time-dependent losses, including runoff per surface typology and losses in the drainage system.

Storage capacity

The existing storage capacity in parks and canals is considered when determining the required storage capacity. A maximum water level rise of 30 inch is assumed for all open water bodies.

Discharge capacity

For each catchment the specific pumping capacity is used.

Water assignment for New Orleans

The water assignment for each pumping station catchment in Orleans Lakeside is given in Table 3 and visually represented in Figure 49. Depending on properties such as imperviousness, the required depth differs per catchment. While pumping station catchment 4 has the largest water assignment, it has a relatively small required storage depth of 29 mm for a T10 storm. Catchment 12 has a much larger required storage depth of 43 mm for a T10 storm.

Storage-discharge-frequency curves

Storage and discharge capacity are interchangeable. This relation is represented by storage-discharge-frequency (SDF) curves, which show the required discharge capacity in relation to the present storage capacity for storms with different return periods.

The SDF curves computed for a T10 storm and different land uses are given in Figure 50. As the SDF curves show, increasing the pumping capacity becomes exponentially less significant; increasing storage capacity in the built environment is much more efficient. Furthermore, the curves show large differences between high density, multi-family districts and suburban single-family districts. The relative absence of gardens and green space in high-density districts can be attributed to this striking difference in required water storage.

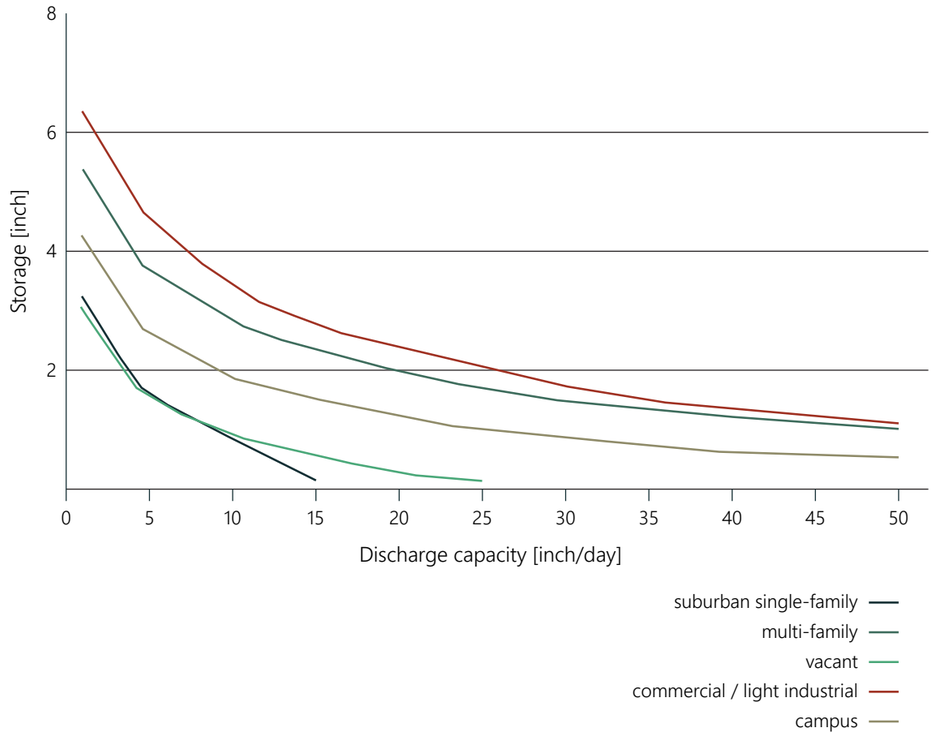
	T10				T100			
	Volume		Depth		Volume		Depth	
Pumping Station	**Acre-foot**	**m^3**	**inch**	**mm**	**Acre-foot**	**m^3**	**inch**	**mm**
3 north	99	122115	1.12	28	242	298503	2.73	69
4	370	456388	1.15	29	862	1063261	2.68	68
6 north	53	65375	1.35	34	120	148018	3.05	77
7 north	190	234362	1.71	43	401	494626	3.6	91
12	334	411983	1.83	46	774	954715	4.25	108

Table 3 - Water assignment for each pumping station for T10 and T100 rain storms (source: Dolman, 2013).

Figure 49 - The water assignment per pumping station catchment in Orleans Lakeside as determined by Dolman (2013).



Figure 50 - SDF curves for a T10 storm for different land uses (source: Dolman, 2013).



2.3 Topograhy & Flood Susceptibility

3.2.1 Land elevation

Much of New Orleans lies below sea level; only the current river banks and old alluvial deposits are above mean sea level. Gentilly Ridge, traversing the city from east to west, separates the northern and southern parts of New Orleans' hydrological system. Furthermore, these elevated areas have a relatively low flood vulnerability.

The federal levee system of New Orleans is designed to withstand a storm surge with a return period of 100 years (US Army Corps of Engineers, 2012). Figure 51 provides insight in the potential flooding depth across New Orleans in the case of levee failure. The maximum potential flooding depth reaches almost 3 meters (10 ft.) in the lowest parts of the city.



Figure 51 - Digital elevation model of New Orleans with levee system and Gentilly Ridge. Elevation data from National Oceanic and Atmospheric Administration (2017).

3.2.2 Lithology

The top layers of the soil New Orleans is built on have a predominantly silty and organic composition, reflecting the alluvial character of the Mississippi River delta. As Figure 54 shows, the current river banks and the Gentilly Ridge have silty soils, while the parts of New Orleans below sea level mainly consist of clay and muck soils.

Sections of the subsoil are given in Figure 53. These sections show that the top soil primarily consists of silt, clay and muck, while deeper layers also contain more permeable sands. The sand layer originates from the Pine Barrier Island, which dates back prior to the formation of the Mississippi River delta (Waggonner & Ball Architects, 2013).

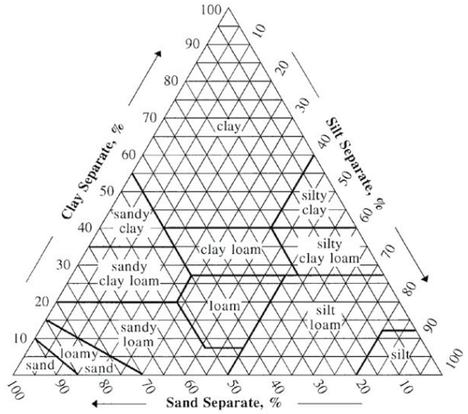


Figure 52 - (left) Soil texture classification (Source: Natural Resources Conservation Service, N.D.)

Figure 53 - (right) Soil section A-A' through Lakeview, soil section B-B' through City Park, soil section C-C' through Gentilly (source: van Asselen, Jaimerena, and Stuurman (2019), elaborated by author).

The soil texture class in Figure 52 provides insight in different soil classifications. As the share of sand is low in the top soils of New Orleans, the classifications on the right side of the graph are applicable.

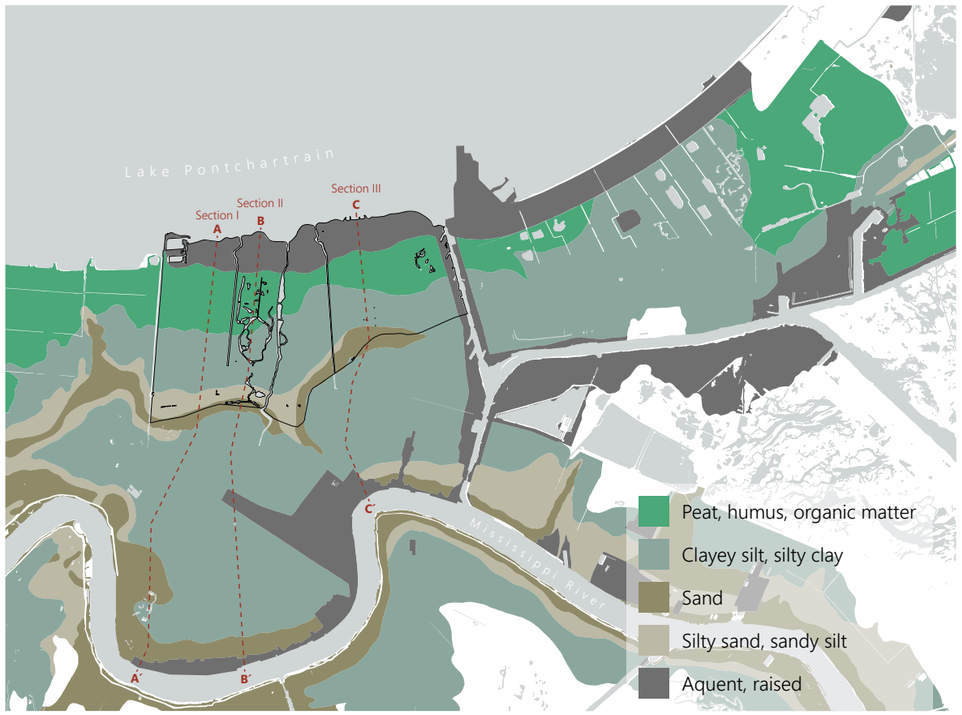
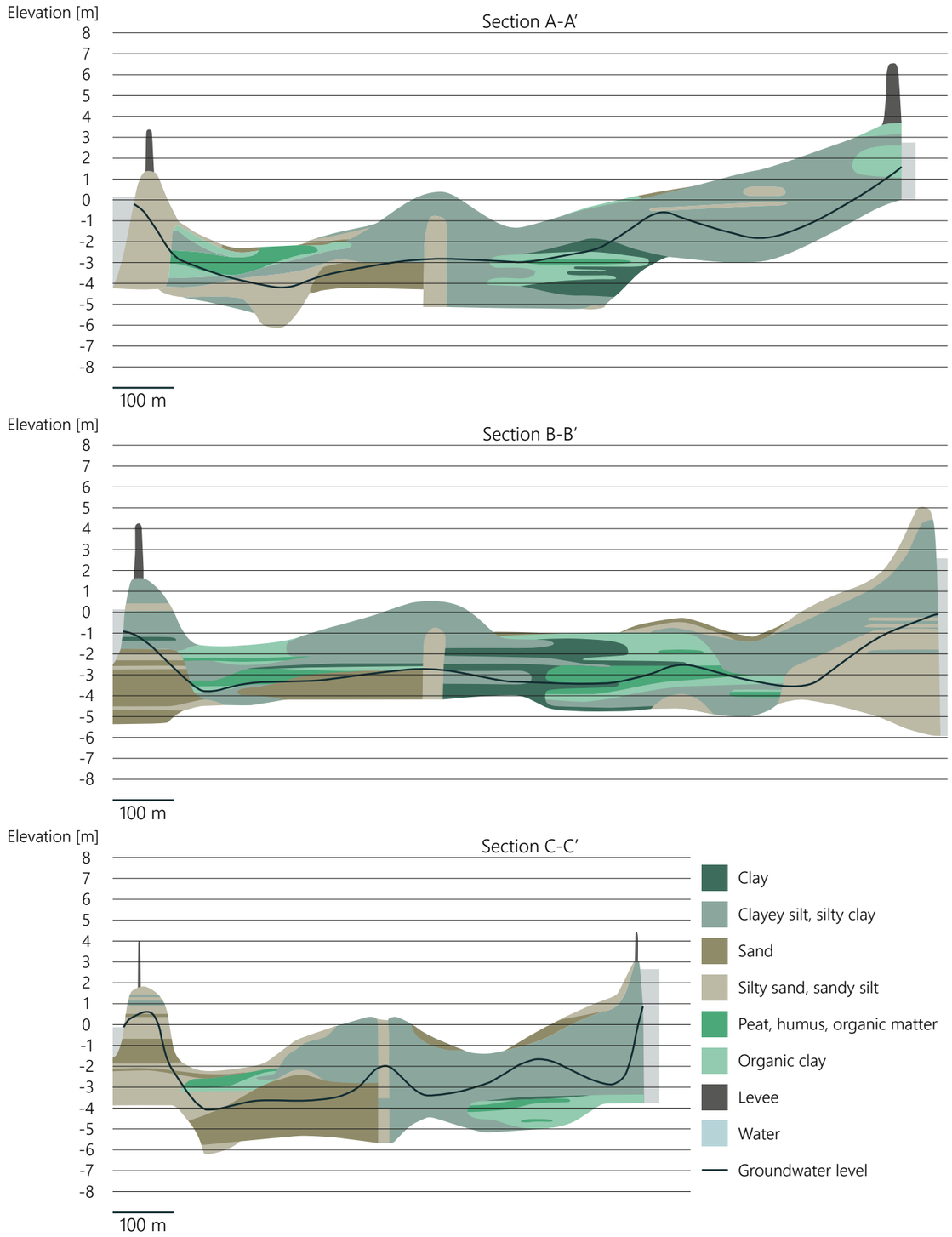


Figure 54 - Lithology with Gentilly Ridge as natural river deposit (source: Natural Resources Conservation Service (2013), elaborated by author).



3.3 Urban Structure

This section presents an overview of the most relevant urban characteristics of Orleans Lakeside, focusing on the relation to water management.

3.3.1 Neighborhood profiles

Figure 55 shows an overview of administrative districts within Orleans Lakeside, along with key statistics regarding population and density.

A comparison of neighborhoods brings to light several striking differences within Orleans Lakeside. With a total population of nearly 70,000 inhabitants, Orleans Lakeside contains a major part of the total city's population of 340,000. Neighborhoods differ greatly in terms of population density, vacancy and percentage of owner/renter, although there seems to be a strong east-west pattern. In short, most differences come forward with City Park being a dividing line between values.

Population density

Neighborhoods west of City Park generally have a lower population density than those to the east of City Park. While Lakeview, Navarre and West End generally have densities of around 180 inhabitants per km^2, Gentilly Terrace, Milneburg and St. Anthony have densities closer to 300 inhabitants per km^2.

Vacancy

Vacancy is inversely related to income; affluent neighborhoods such as Lakeview and Lake Shore – Lake Vista have a low vacancy, while less affluent neighborhoods such as Gentilly Woods and Filmore have a higher vacancy.

Land ownership

Similarly to vacancy, the percentage of land owners follows income patterns. Affluent western neighborhoods see ownership rates of up to 90%, while east of City Park this figure is much lower with 40% to 60%.



Figure 55 - Administrative districts (source: The Data Center (2017), elaborated by author).

District	Population	Density [inh/km^2]	% Vacant	% Owner	% Renter
City Park	2842	41	13.9	43.8	56.2
Dillard	5181	196	17.9	51.6	48.4
Fairgrounds	5612	231	17	42.6	57.4
Filmore	5649	166	19.4	77.5	22.5
Gentilly Terrace	10169	300	15.4	61.8	38.2
Gentilly Woods	3170	154	18	61	39
Lake Shore - Lake Vista	3872	123	10	87.1	12.9
Lake Terrace & Oaks	2098	50	22	77.5	22.5
Lakeview	8043	179	11.8	72	28
Lakewood	1818	72	11.4	92.4	7.6
Milneburg	4659	226	13.9	58.5	41.5
Navarre	2914	159	10.6	60.3	39.7
Pontchartrain Park	2186	78	19	73.8	26.2
St. Anthony	4754	266	12.4	40.8	59.2
St. Bernard Area	2518	256	14	17.5	82.5
West End	4128	186	16.7	54.1	45.9

3.3.2 Character of water infrastructure

The central part of New Orleans can be divided into six hydrological sub basins, which all have a different approach to water management in the urban environment (Figure 56). Based on an analysis by Palmbout Urban Landscapes (2013), the following brief descriptions of each sub basin are given:

Jefferson Lakeside

Contains a network of open canals in both east-west and north-south direction.

Jefferson Riverside

Main infrastructural connections run parallel to the river; secondary lines run perpendicular to the primary connections.

Orleans Lakeside

Contains the primary outfall canals and a set of box culverts that drain stormwater to pumping stations. Open water is barely visible in this sub basin.

Orleans Riverside

Green boulevards run perpendicular to the Mississippi River towards Gentilly Ridge.

Orleans East

Contains a set of open canals that run parallel to Lake Pontchartrain.

Lower Ninth / Upper St. Bernard

Contains open canals that run perpendicularly to the river and drain to the Forty Arpent Canal.

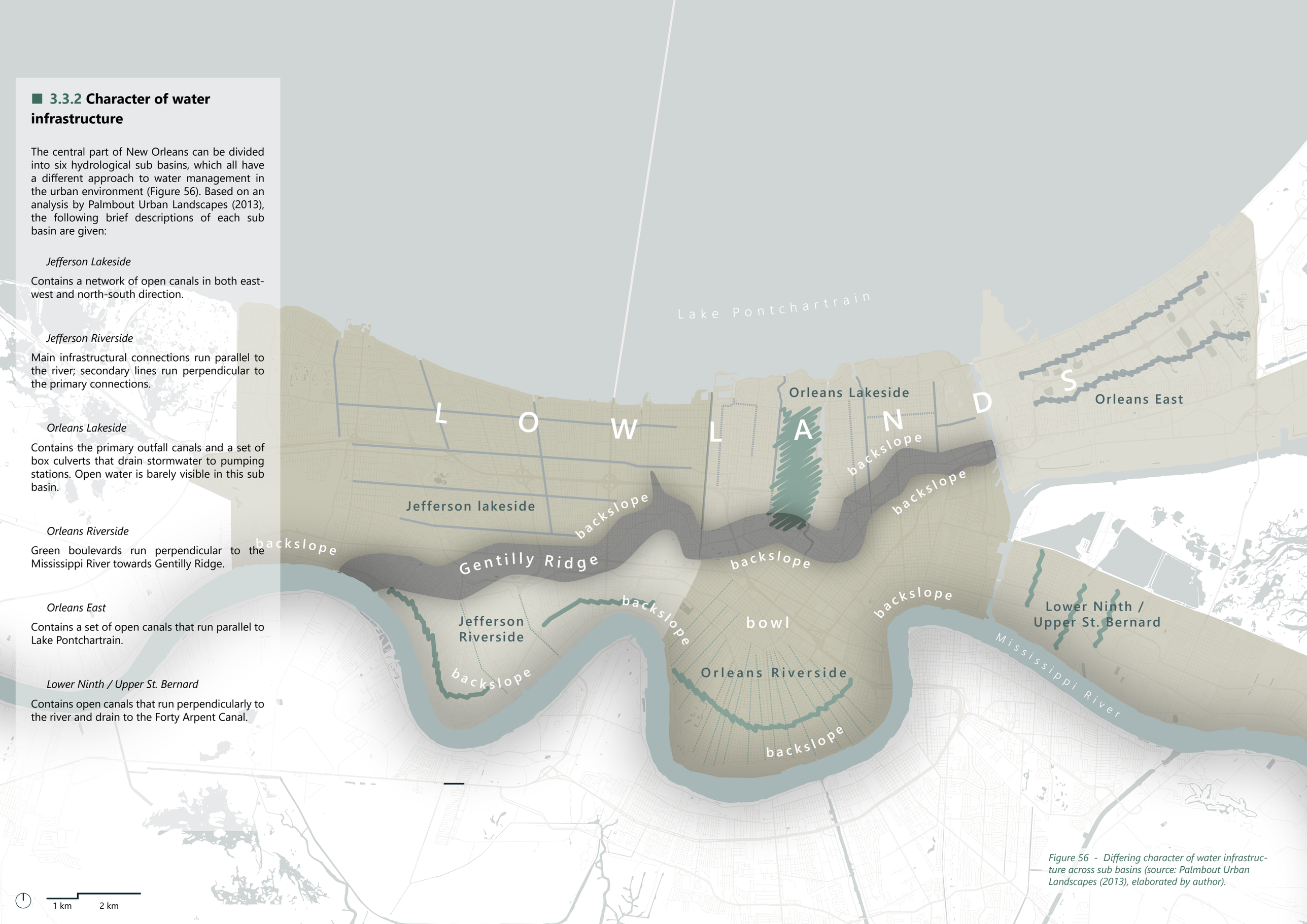


Figure 56 - Differing character of water infrastructure across sub basins (source: Palmbout Urban Landscapes (2013), elaborated by author).

3.3.3 Character of coastal flood protection system

The coastal flood protection system within Orleans Lakeside can be categorized in four typologies, each with a different interface. Figure 57 shows the location of the various types, accompanied by a sketch.

Figure 57 - Various types of flood barriers in the project area.



1. *Floodwall on earthen levee*

This type mainly occurs alongside the outfall canals; during Hurricane Katrina, several sections of this type collapsed. A concrete wall on top of an earthen elevation prevents open water access. Although this type of flood protection does not allow for open water to be used as amenity, it does provide a sense of security to residents living in Orleans Lakeside. Conversations with residents during fieldwork showed that a lowering of the walls would not be preferred, even if conditions would allow it.

2. *Earthen levee*

The primary flood defense with the interface of Lake Pontchartrain takes shape as an earthen levee, which cars and pedestrians can cross. The earthen levees are not spatially integrated to be used as open space, although access on top of the levee is not restricted.

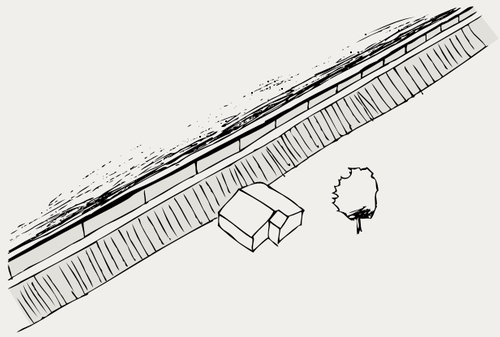
3. *Floodwall*

A solid concrete floodwall is used near the Orleans Marina, where space is limited. Design standards for a storm with a return period of 100 years result in a significant height of the required wall. There are few passageways.

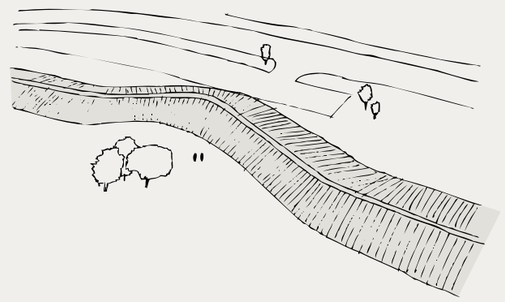
4. *Structure*

There are several structures in place along the interface with Lake Pontchartrain and the Inner Harbor Navigational Channel. Bayou St. John can be closed with a gate and each outfall canal can be closed with a gate at the pumping stations near the lake. The levees and floodwalls have gates that are usually open for traffic but can be closed in case of high water. Gates of floodwalls, such as the ones near the Orleans Marina, are the full height of the flood protection system. In contrast, gates on earthen levees have a limited height.

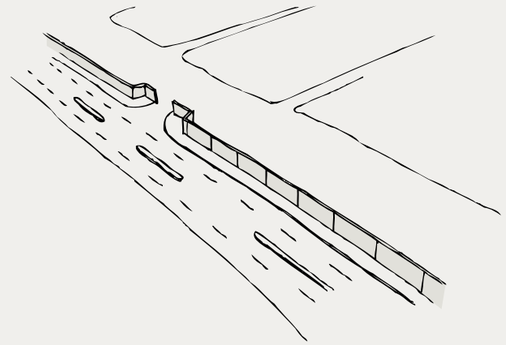
Type 1: floodwall on earthen levee



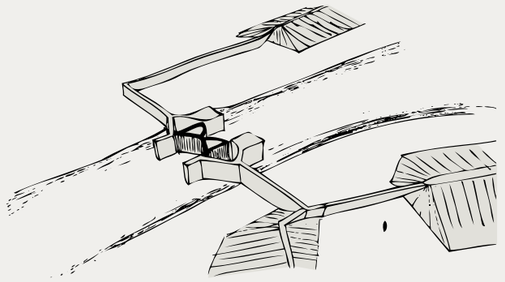
Type 2: earthen levee



Type 3: floodwall



Type 4: structure



3.3.4 Urban Fabric

Although Orleans Lakeside is traversed by the I-610 interstate highway in an east-west direction, primary access points to the project area are through several north-south oriented roads (see Figure 59). An important east-west connection is Lakeshore Drive, which runs parallel to Lake Pontchartrain. As Figure 60 shows, a more fine-grained grid pattern fills the area in between primary access roads.

Orleans Lakeside contains various public parks and open space, although these assets are not evenly distributed across the area. With a size comparable to New York City's Central Park, City Park functions as a dividing element between Lakeview and Gentilly. Other major open spaces are Pontchartrain Park and Lakeshore Park.



Figure 58 - Open space in Orleans Lakeside (source: City of New Orleans (2019), elaborated by author).

Figure 59 - Major access roads.



Figure 60 - Street pattern.



500 m 1 km

500 m 1 km

3.3.5 Block & building typologies

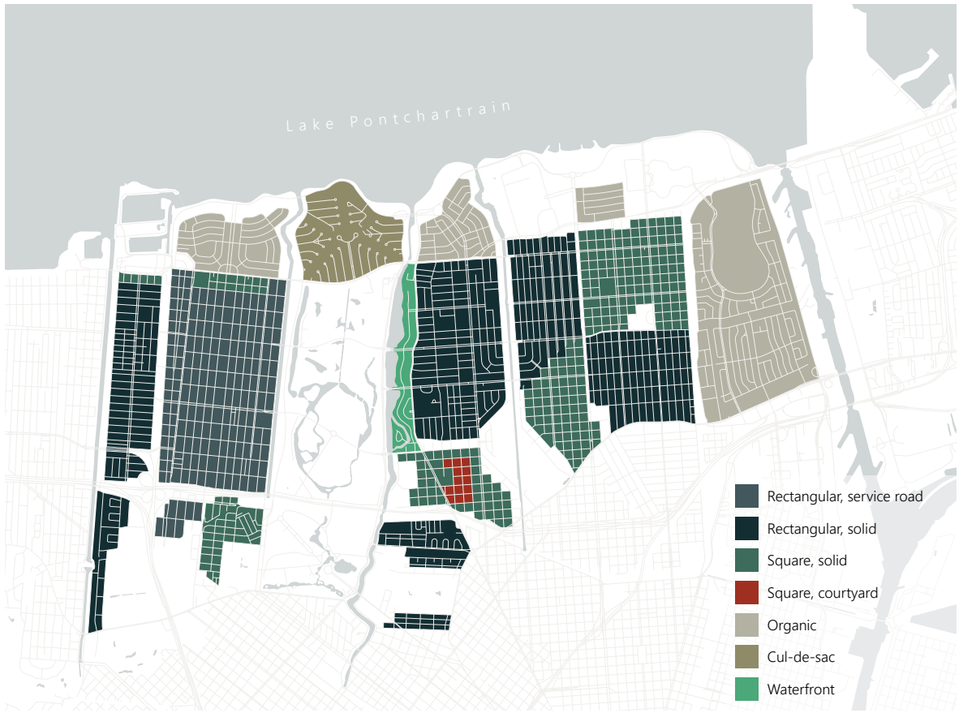


Figure 61 - Distribution of block typologies.

Type A - Rectangular, service road

Building types:
ranch home, 1-story bungalow, 2-story bungalow



Type B - Rectangular, solid

Building types:
2-bay shotgun home, 4-bay shotgun home, ranch home, 1-story bungalow, 2-story bungalow



Figure 62 - Predominant block typologies in Orleans Lakeside with their most common building types.

Type C - Square, solid

Building types:
ranch home, 1-story bungalow, 2-story bungalow



Type D - Square, courtyard

Building types:
garden-style apartments, townhomes



Type E - Organic

Building types:
ranch home, 1-story bungalow, 2-story bungalow



Type F - Cul-de-sac

Building types:
ranch home, 1-story bungalow, 2-story bungalow



Type G - Waterfront

Building types:
ranch home, 1-story bungalow, 2-story bungalow



500 m 1 km

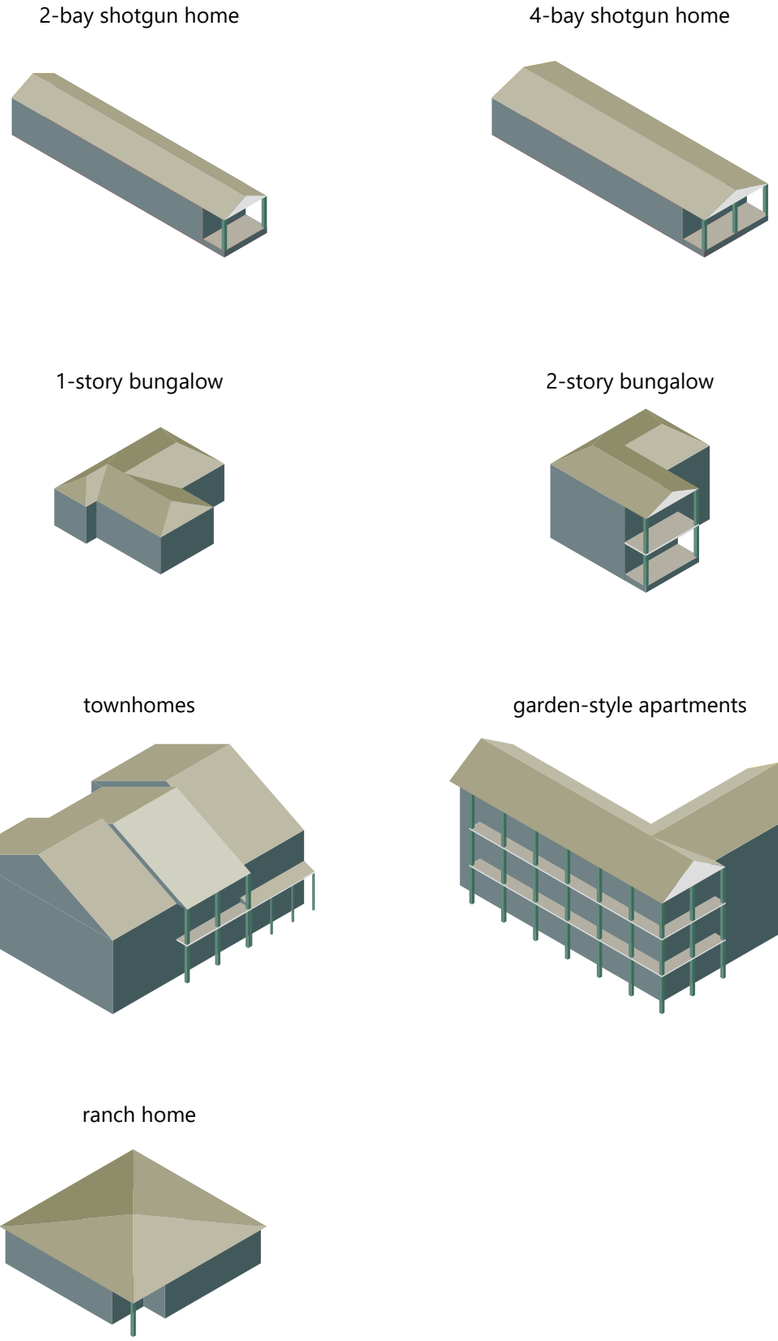


Figure 63 - Predominant building typologies in Orleans Lakeside.

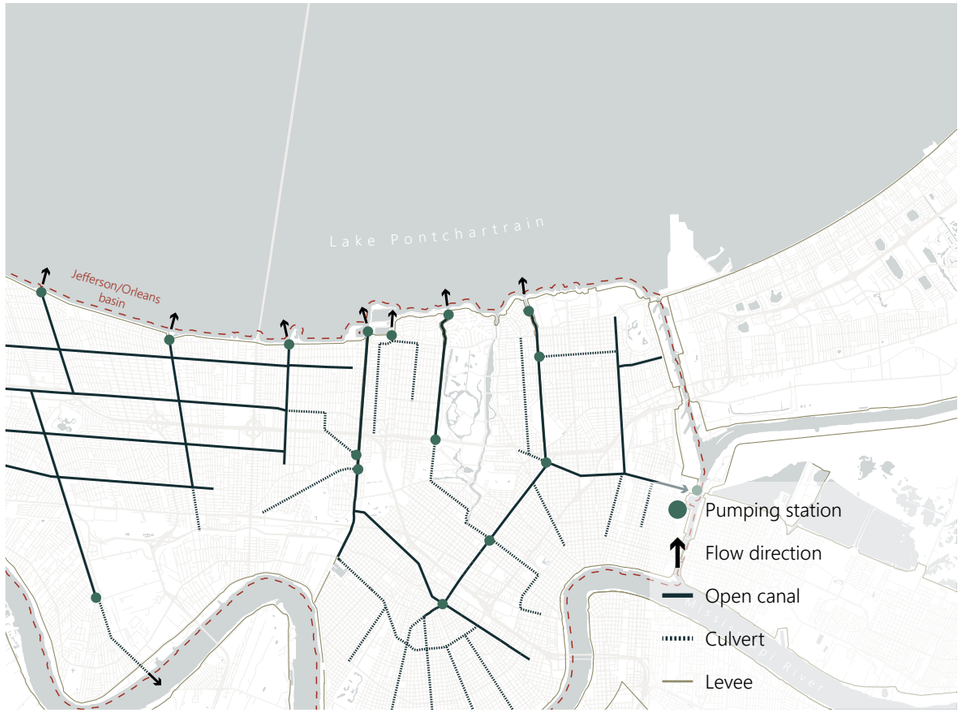
3.4 Drainage Infrastructure

Drainage of stormwater in New Orleans has a strong engineered character; powerful pumping stations discharge stormwater towards Lake Pontchartrain through a network of open and closed concrete canals. This network disregards local topography, meaning that even precipitation falling near the Mississippi River is transported northwards. Figure 64 shows the drainage of the Jefferson/Orleans basin.

Figure 65 shows a more detailed schematization of the drainage infrastructure in the Orleans Lakeside sub basin. Striking is the double configuration of pumping stations near Lake Pontchartrain; new pumping stations are being built to replace the temporary system put in place after Hurricane Katrina. These new pumping stations will reduce the dependence on other pumping stations, turning the outfall canals into boezems (see glossary) and shortening the required length of the primary coastal flood defense system.

Almost every public road in Orleans Lakeside has one or more underground drainage pipes, with a few minor exceptions. A set of sizable box culverts connect conduits to the pumping stations. These box culverts were originally designed as open canals, but are now covered due to fears of a mosquito-borne diseases.

Figure 64 - Drainage infrastructure in New Orleans.



Lake Pontchartrain

Pumping station
Gate
Weir
Major culvert
Conduits

250 m 500 m

Figure 65 - Drainage infrastructure in Orleans Lakeside sub basin. Source: Ardurra Group, 2016.

4 VULNERABILITY ANALYSIS

4.1 Threshold Domain Analysis
4.2 Coping & Recovery Domain Analysis
4.3 Adaptive Domain Analysis
4.4 Analysis conclusions

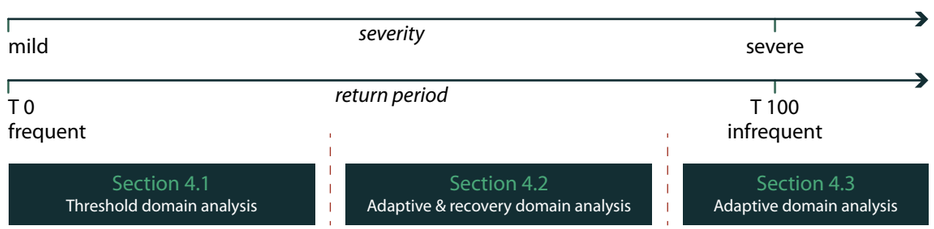


Figure 66 - Schematic narrative for vulnerability analysis.

This chapter connects to one of the primary knowledge gaps identified earlier in Chapter 2. The lack of consideration of extreme events, by focusing merely on moderate weather events, leaves out the pressing matter of how the urban water system would perform during extreme weather events.

The analysis presented in this chapter relate to the previous, more general synthesis of existing analyses.

This chapter's narrative for analysis is based on the vulnerability framework by de Graaf et al. (2009), which was elaborated in Section 2.5.2. This theory defines three main domains related to time: threshold domain (frequent, mild events), coping & recovery domain (relatively infrequent, limited severity events) and the adaptive domain (infrequent, severe events). A schematic representation of this chapter's narrative is given in Figure 66, which shows the interdependence of return period and severity of the storm. Similarly to the previous chapter, each section is internally sorted by scale (macro-meso-micro-nano).

Figure 67 shows the structure of the chapter, including the integration of theories.

The vulnerability analysis is undertaken from a socio-spatial standpoint. This implies that the focus is on issues that can be solved in the spatial domain, and that governance and legislation issues are not addressed in detail.

Casting forward, the goal of this vulnerability analysis chapter is to provide insight in the current vulnerability of Orleans Lakeside to ultimately provide leads for the design phase.

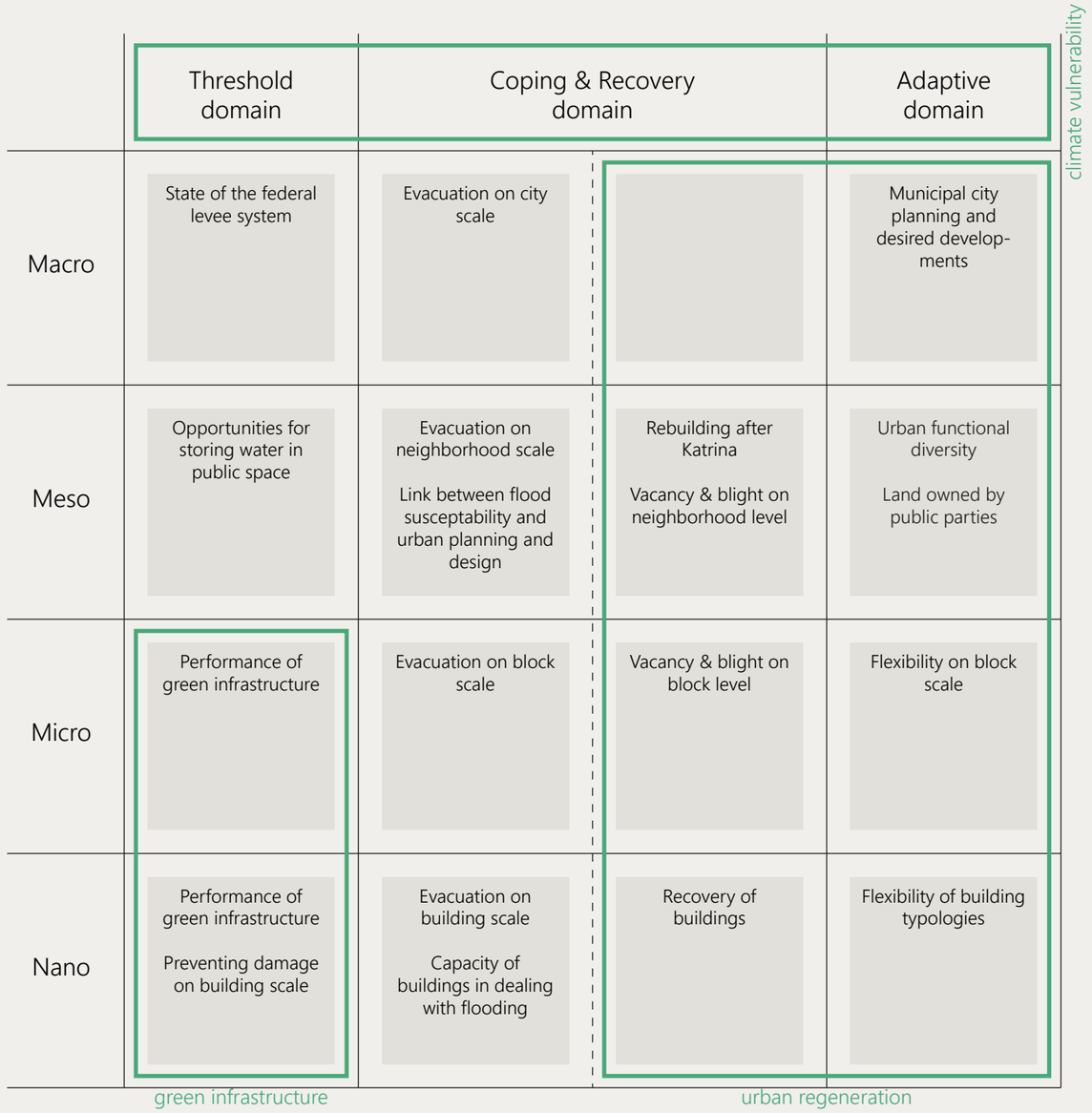


Figure 67 - Structure of the vulnerability analysis.

4.1 Threshold Domain Analysis

The threshold domain comprises measures that prevent damage to the built environment (de Graaf et al., 2009). Focusing on flood and drought resilience, relevant topics to analyze are the state of federal levees, the capacity of the current drainage system and measures that could improve the drainage system. Furthermore, building-scale design choices that help preventing damage due to moderate flooding is a relevant topic.

MACRO | MESO | MICRO | NANO

4.1.1 Federal levee

As discussed earlier, the federal levee system surrounding New Orleans is designed for a storm with a return period of 100 years (US Army Corps of Engineers, 2012).

However, there are serious concerns whether the current system is able to adequately protect the city from future hurricanes. In recent years, several newspapers reported on doubts amongst experts of the current system's capacities.

New Orleans Levees Rebuilt After Katrina May Not Withstand 100-Year Storm, Corps of Engineers Says

By Jan Wesner Childs · April 15 2019 03:43 PM EDT · weather.com

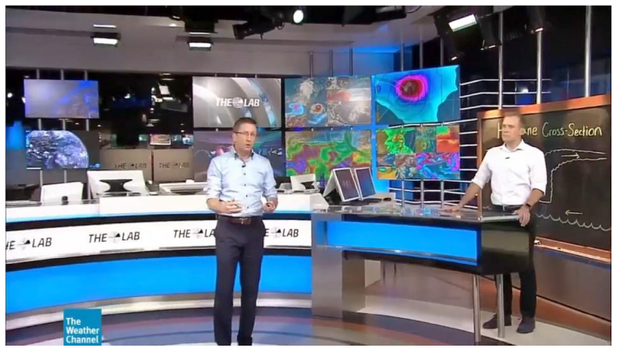


Figure 68 - Childs (2019).

Figure 69 - Schwartz and Schleifstein (2018).

FORTIFIED BUT STILL IN PERIL, NEW ORLEANS BRACES FOR ITS FUTURE

In the years after Hurricane Katrina, over 350 miles of levees, flood walls, gates and pumps came to encircle greater New Orleans. Experts say that is not enough.

By JOHN SCHWARTZ and MARK SCHLEIFSTEIN FEB. 24, 2018

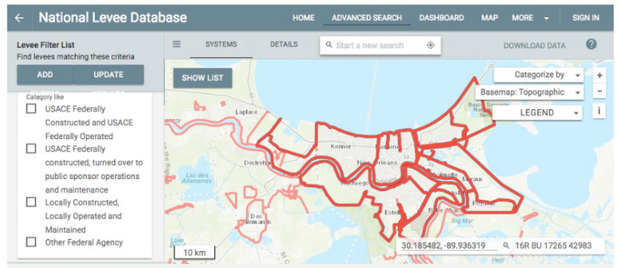
"Climate change is turning that 100-year flood, that 1 percent flood, into a 5 percent flood or a 20-year flood," said Rick Luettich, a storm surge expert and vice chairman of one of the New Orleans area's two regional levee authorities. By that inexorable logic, the 500-year flood becomes a 100-year flood, and so on.

The corps itself has repeatedly acknowledged that the new system will not prevent future floods. "There's still going to be a lot of people that will be inundated," the corps's former commander, the retired Lt. Gen. Robert L. Van Antwerp, warned as far back as 2009. In storms at 200- to 500-year levels, the corps has said, New Orleans could still suffer breaches like those experienced during Katrina.

Figure 70 - Schleifstein (2019).

Public meetings planned to discuss raising New Orleans area hurricane levees

Updated Apr 26, 2019; Posted Apr 26, 2019



New Orleans area levees as seen on the U.S. Army Corps of Engineers National Levee Database. The corps is doing studies to determine how to keep hurricane levees in New Orleans elevated to 100-year risk reduction levels.

Figure 71 - Levee breach during Hurricane Katrina (source: Laforet, 2005).



4.1.2 Storing water in public space

This section is meant to introduce the modelling approach and provide a qualitative and quantitative flooding analysis of Orleans Lakeside.

Model introduction

The Storm Water Management Model (SWMM) software package, developed by the United States Environmental Protection Agency (EPA), is used for modelling in this thesis. SWMM is a dynamic rainfall-runoff simulation model used for modelling both quantity and quality of runoff. The model transforms precipitation into runoff by means of subcatchments that contain specific information regarding initial losses, perviousness, infiltration, evaporation and other processes. The generated runoff enters a system of open of closed conduits, which in the case of New Orleans, leads to a pumping station.

The base model (current situation) is provided by Ardurra Group and has extensive information on pipe locations, diameters and invert levels. In the model, streets are entered as trapezoidal open conduits. Orleans Lakeside is split into two different files: one containing Gentilly (east of City Park), and another containing Lakeview and City Park. Figure 72 gives an overview of both models.

The base version of the model is not configured to show flooding. Rather, it is designed to keep all water in the system to get insight in the total water to be pumped out. This does not provide an accurate quantification of flooding issues, nor does it provide insight in the spatial variability of flooding. The following characteristics of the model are found to be unrealistic:

- Nodes have a maximum depth of 6 meters (20 ft), which would indicate a deep invert level. This is not true as most nodes and pipes are located roughly 2 meters (6.5 ft) beneath street level.
- The streets modelled in SWMM have a maximum depth of 0.6 meters (2 ft), which suggests that only a water level above 2 ft. would result in damage. A maximum depth of 10 cm (0.35 ft.) is a more realistic value, as this amount of water could be contained between street curbs.
- The model assumes a perfect functioning of the drainage system, with good connections and no sediments in the pipes. New Orleans's drainage system is in a notoriously bad state, which makes this assumption invalid.
- The model is calibrated for a synthetic Chicago Type-III storm and does not contain other sets of design storms. A discussion on a representative design storm follows below.
- The model is not verified with street observations during representative storms. Rather, the model is calibrated on the input using radar rainfall data.

It is important to clearly define urban flooding, as a different interpretation of model results would lead to different conclusions. For this thesis, significant urban flooding is defined as having more than 15 cm (6 inches) of water on the streets. Anything below this level is considered to be insignificant, as the water level would not rise above street curbs.



Figure 72 - An overview of both models (model supplied by Ardurra Group, 2016).

Design storm

The synthetic Chicago Type-III design storm is common practice for urban drainage professionals in New Orleans. This design storm is symmetrical and has a high peak in the middle of the storm.

The consultants that produced the Urban Water Plan (2013) acknowledged the shortcomings of using the Type-III storm for modelling pluvial flooding and developed a representative T10 rain storm based on an historical event. This design storm has multiple smaller peaks before a final major peak near the end. This allows reservoirs to fill up before exposing the system to the highest peak.

Interestingly, for modelling the focus is often on normative input, while in reality the output is more relevant. The goal of modeling is to mimic system behavior and to come to reality as close as possible. While using an actual rain storm is likely to produce more accurate results than a Type-III storm, a brief comparison of past significant precipitation events serves to boost confidence in using the selected T10 precipitation event.

Figure 73 displays four significant 24h rain events, and while the total precipitation differs per storm, the pattern of a late peak seems recurrent. This thesis is therefore confident in using the selected design storm as shown in Figure 48.

Qualitative model results

The first use of the model is to provide a qualitative indication of flooding in Orleans Lakeside. As expected, using the T10 actual rain storm results in extensive flooding in New Orleans. Figure 74 shows the degree of flooding at various instances during the storm. A street marked in red indicates that the water level exceeds the 10 cm (0.35 ft.) threshold.

The first stages of the storm seem to cause little flooding, as at T=18:00 there are few roads at maximum capacity. This is likely due to storage in the system which fills during the first stretch of the precipitation event.
At T=20:30, in the middle of the final peak, first serious flooding starts to occur. Lakeview (west of City Park) has no more storage available, which results in flooding across the area. Gentilly (east of City Park) suffers from flooding as well, albeit less severe at this time.
At T=21:45 maximum flooding occurs in Orleans Lakeside. Most streets are at maximum capacity, even on high ground.
Immediately after the rain event, at T=23:30, flooding retreats to generally lower areas. At this point, high ground no longer suffers from flooding.
At T=26:00, two hours after the rainstorm, several concentrated spots in Gentilly stay submerged. Lakeview, on the other hand, still suffers from extensive flooding at this point.

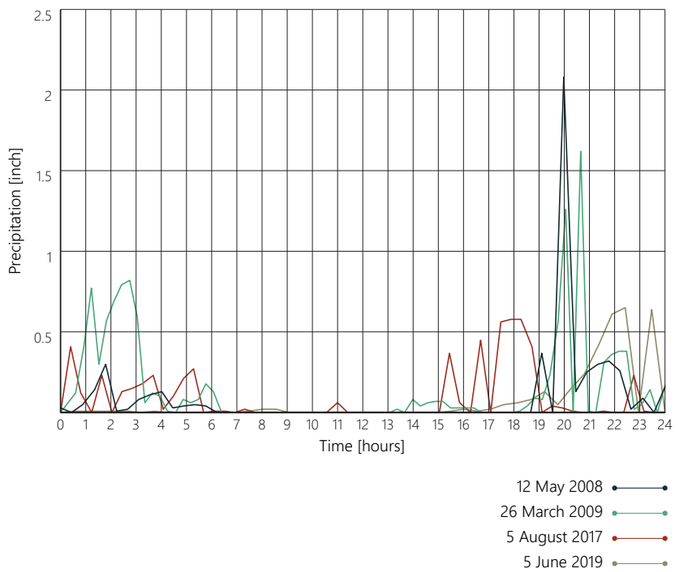
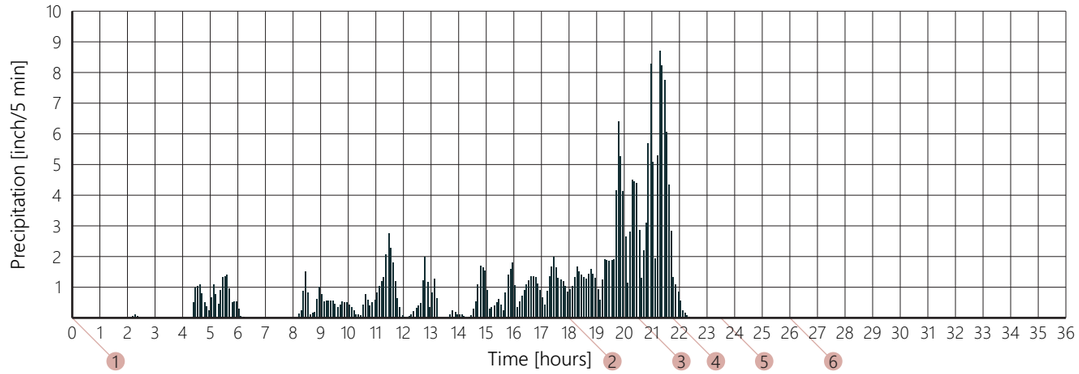


Figure 73 - Comparison of multiple 24-hour rain storms in New Orleans.

Figure 74 - (right) Schematic representation of flooding during the design storm.







Quantitative model results

A quantification for required water storage capacity is done by constructing cumulative discharge and pump flow curves. The maximum difference between the depth of water that entered the drainage system and the pumped depth at the same time during the event returns the required storage capacity. This amount is given in depth, so an average over the entire drainage basin.

For evaluation purposes, quantitative SWMM results are compared to the required storage volumes as outlined in the Urban Water Plan (see Figure 49). This comparison points out the difference in model: SWMM is a hydro-dynamic, deterministic model, whereas the values in the UWP were obtained with a conceptual water balance model. However, as the figures from the Urban Water Plan were produced with relatively little data, a new urban water balance model (UWM) provided by Deltares is used to produce new SDF curves based on longer time series of data. The new SDF curves for each catchment are given in Appendix A. The required storage capacity for existing pumping capacities, determined by the urban water balance model, are summarized in Table 4.

Due to limitations of SWMM, it is not feasible to determine required storage capacity for catchment 3 North, 6 North and 7 North. Pumps for these catchments also receive water from areas outside of Orleans Lakeside, which makes it difficult to compare runoff volumes to the total amount of drained water.

	SWMM		UWM		GNO-UWP	
	Acre-foot	**m^3**	**Acre-foot**	**m^3**	**Acre-foot**	**m^3**
PS 3 north	-	-	122	150,000	99	122,000
PS 4	428	528,000	466	575,000	370	456,000
PS 6 north	-	-	126	155,000	53	65,000
PS 7 north	-	-	170	210,000	190	234,000
PS 12	706	871,000	495	610,000	334	412,000

Table 4 - Comparison of required water storage in m^3 as determined by SWMM, the new conceptual water balance model and as stated in the Urban Water Plan in 2013.

4.1.3 Measuring performance of green infrastructure

Introduction

In recent years, several green infrastructure projects have been finished across New Orleans. These installations come from different designers and their diversity is reflected in the detailing of the designs. The finished rain gardens are scattered across the city and do not adhere to a central scheme or strategy. Their performance and efficiency is unknown and a more detailed analysis is required to understand their contribution to mitigating stormwater runoff.

Research goal

The following questions will be researched in this subsection:

- What are the costs of 1 m^3 (cf) of rain water storage?
- What is the actual % of rain water storage (per urban catchment)? At what amount does this become significant?

Methodology

Assessing the performance of green infrastructure involves constructing an inventory of completed green infrastructure projects in New Orleans. This inventory draws from municipal documents, community initiative groups and landscape architecture firm portfolios. Green infrastructure projects gardens are mapped in a GIS environment. Furthermore, design, construction and maintenance costs of diverse projects is collected to provide insight in the cost effectivity of green infrastructure. This assessment only considers rain gardens and bioswales; other types of green infrastructure are omitted.

The following methods are used in this part of the research:

- Collecting major green infrastructure locations and general data;
- Collecting and estimating costs;
- Visiting sites;
- Meeting stakeholders.

The general procedure is displayed in Figure 75. Relevant information regarding the methods is given below.

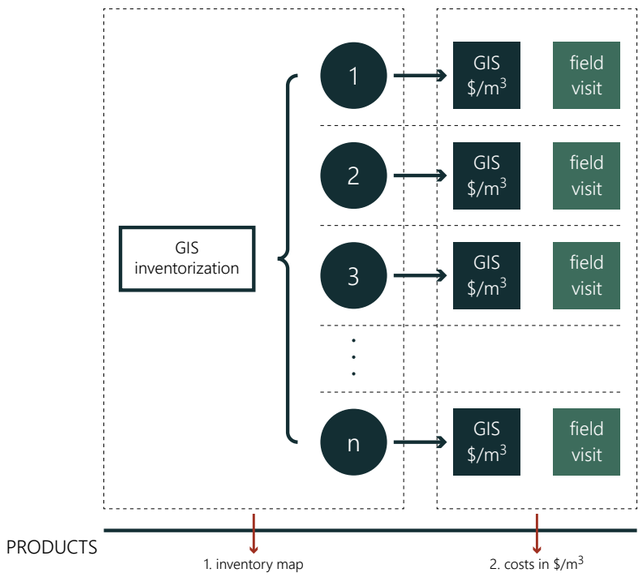


Figure 75 - Chronological flowchart for assessing green infrastructure.

Collecting green infrastructure locations and general data

Data on green infrastructure locations and capacities is provided by the municipality, Dana Brown & Associates and stormwater permits via OneStopApp.

Estimating costs

The costs of storage is calculated for each green infrastructure project evaluated in this assessment. This calculation considers initial costs (design & construction) and returning costs (annual maintenance). The goal of this part is to obtain insight in which types of green infrastructure with a certain set of features has the lowest cost (expressed in $/$m^3$ of storage).

Fieldwork / meeting stakeholders

Individual stakeholders in green infrastructure projects are approached through several meetings. In addition, a community workshop serves to engage the public and provide external insight into the operation of finished projects. Independent input can provide a unique insight in challenges and opportunities for the improvement of green infrastructure.

Results

A wide range of actor groups were consulted for providing valuable insight into the design, maintenance and performance of green infrastructure projects. This subsection presents a synopsis of all consulted actor groups; a complete overview of all stakeholders that have been contacted during visits to New Orleans is given in Table 2.

Stakeholders

<u>Design</u>
Landscape architecture firms, architecture firms, private landowners.

<u>Maintenance</u>
Contractors, community groups, private landowners.

<u>Government</u>
Sewage & Water board, City of New Orleans, universities.

Description of green infrastructure

<u>Bioswale</u>
Bioswales are depressed planted areas with overflow structures that collect, detain, infiltrate, and filter runoff. In addition, bioswales are also conveyance facilities (linear systems) that are greater in length than width. Due to their efficacy in filtering and removing pollutants from stormwater runoff, these features are commonly located adjacent to impervious areas that receive substantial amounts of automotive use such as parking lots or roadways. Depending on site constraints the construction of a bioswale can take several forms.

<u>Rain garden</u>
Rain gardens are stormwater detention features that collect, detain, infiltrate, and filter stormwater runoff prior to releasing it to a storm sewer system via an overflow or discharge mechanism. These facilities typically feature both surface level (freeboard) and subsurface stormwater detention. The cross section of a rain garden moving from the surface level down is most commonly as follows: planting (trees & native shrubs), mulch layer, rain garden soil, aggregate bridging course, aggregate subbase, pipe underdrain, undisturbed native soil.

Inventorization of green infrastructure

An overview of all major green infrastructure projects in New Orleans is shown in Figure 76. The master file containing all green infrastructure projects is included in Appendix B.

Lake Pontchartrain

Mississippi River

Bioswale
Rain garden
Permeable pavement
Underground storage

500 m 1 km

Figure 76 - Green infrastructure in New Orleans.

Cost-benefit analysis

Table 5 gives the results of the cost-benefit analysis of green infrastructure projects in New Orleans.

The analysis highlights a difference in cost effectiveness between rain gardens and bioswales. Rain gardens generally have a higher capacity and lower construction costs than bioswales and tend to be cheaper regarding annual maintenance. As a result, rain gardens are more effective at storing large amounts of runoff than bioswales, although there is no astronomical difference. In addition, while rain gardens are useful interventions for capturing runoff in concentrated spots, bioswales serve an additional function as transport facility.

Generally, the current capacity of green infrastructure projects to store stormwater is almost insignificant. For pumping station catchment 4, for instance, the total capacity of finished green infrastructure projects does not exceed 1,000 m^3. This is merely 0.17% of the water assignment for this area (575,000 m^3).

Monitoring results

The subsurface plays a key role in the performance of green infrastructure. Therefore, monitoring the reaction of groundwater during precipitation events provides useful data on the potential storage. Hourly groundwater levels were recorded for a rain garden in the Lower Ninth Ward over a period of three years. This site was fitted with two divers: one in a standpipe on the center of the facility, and a diver in a standpipe adjacent to the sidewalk.

To convert diver pressure data to groundwater and surface water levels, atmospheric pressure from Lakeview Airport was used. Figure 77 shows the procedure to calculate groundwater levels from pressure data.

Monitoring results are shown in Figure 78, while Figure 79 highlights the 5 August 2017 heavy precipitation event on a smaller time scale.

Figure 78 shows that while groundwater peaks rise above street level during heavy precipitation, they quickly return to the neutral state (elevation of drainage pipes). This indicates that there is ample room for storage in the subsoil at this particular rain garden. Also, the groundwater level drops more quickly inside of the facility compared to the reference measurement. This can be attributed to more porous soil in the rain garden due to the presence of plants. Macropores caused by vegetation activity allow for rapid infiltration of water.

	Green infrastructure facility	
	Rain garden	Bioswale
Average capcity [m^3]	473	88
Average construction cost [$]	82,419	139,675
Average maintenance costs [$/year]	17,861	9,246
Costs per m3 storage $/$m^3$]	904	1,322
Maintenance costs per m^3 of storage [$/$m^3$/year]	92	149

Table 5 - Cost-benefit analysis of green infrastructure in New Orleans.

Figure 77 - Calculating groundwater level from diver pressure data. p(baro) = barometric pressure, p(diver) = pressure at diver, TOC = distance between the top of the standpipe and the reference level, CL = diver cable length, WC = water column, WL = water level.

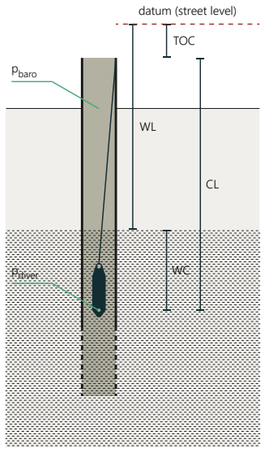


Figure 78 - Groundwater levels at the rain garden in the Lower Ninth Ward.

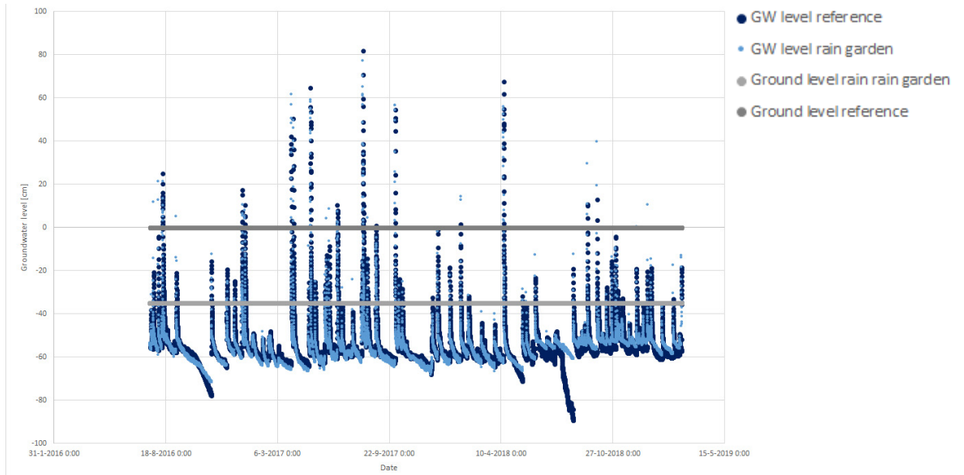
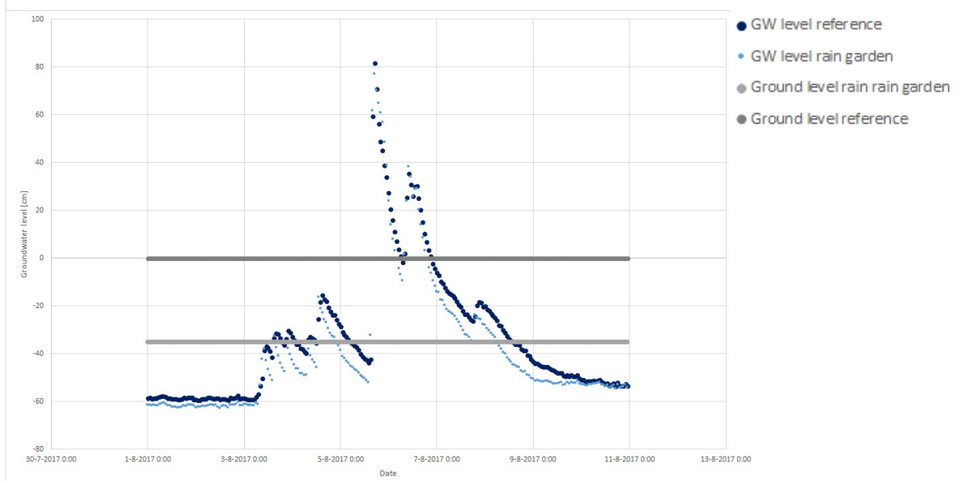


Figure 79 - 5 August 2017 precipitation event.



MACRO | MESO | MICRO | NANO

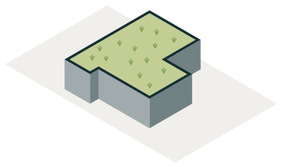
4.1.4 Preventing damage on building scale

This subsection distinguishes several measures on building scale that help prevent flooding. The measures considered are:

- Rain barrel, or other type of on-property water storage tank;
- Green roof (intensive and extensive);
- Blue roof.

A survey by the author showed that none of these measures are widely used in Orleans Lakeside.

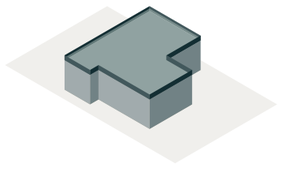
Green roof



Distinction between extensive and intensive green roofs. Extensive green roofs consist of sedum vegetation and store water in the soil layer. Intensive green roofs are accessible as garden and can be used for urban agriculture.

\+ Moderate contribution to water assignment
\+ Aesthetic value
\+ Cooling effect
\- Costly
\- Requires major roof retrofit.

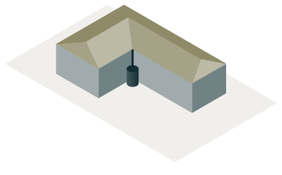
Blue roof



Blue roofs are designed to store significant quantities of water before any runoff occurs. While the contribution to the water assignment is significant, this measure requires a large structural capacity of the building.

\+ Significant contribution to water assignment.
\+ Cooling effect.
\- Costly.
\- Requires major roof retrofit.

On-property water storage tank



An on-property storage facility captures runoff from the roof and allows the owner to use the water in dry periods. The least far-reaching measure is a rain barrel next to the house; an underground storage facility is more radical but provides a more significant storage capacity.

\+ Affordable measure.
\- Small contribution to water assignment.

4.2 Coping & Recovery Domain Analysis

The analysis of the Coping & Recovery domain revolves around characteristics and features of the urban environment that are relevant for less frequent and more intense weather events, during which damage mitigation is the primary goal.

MACRO | MESO | MICRO | NANO

4.2.1 Flood Susceptibility & Urban Planning

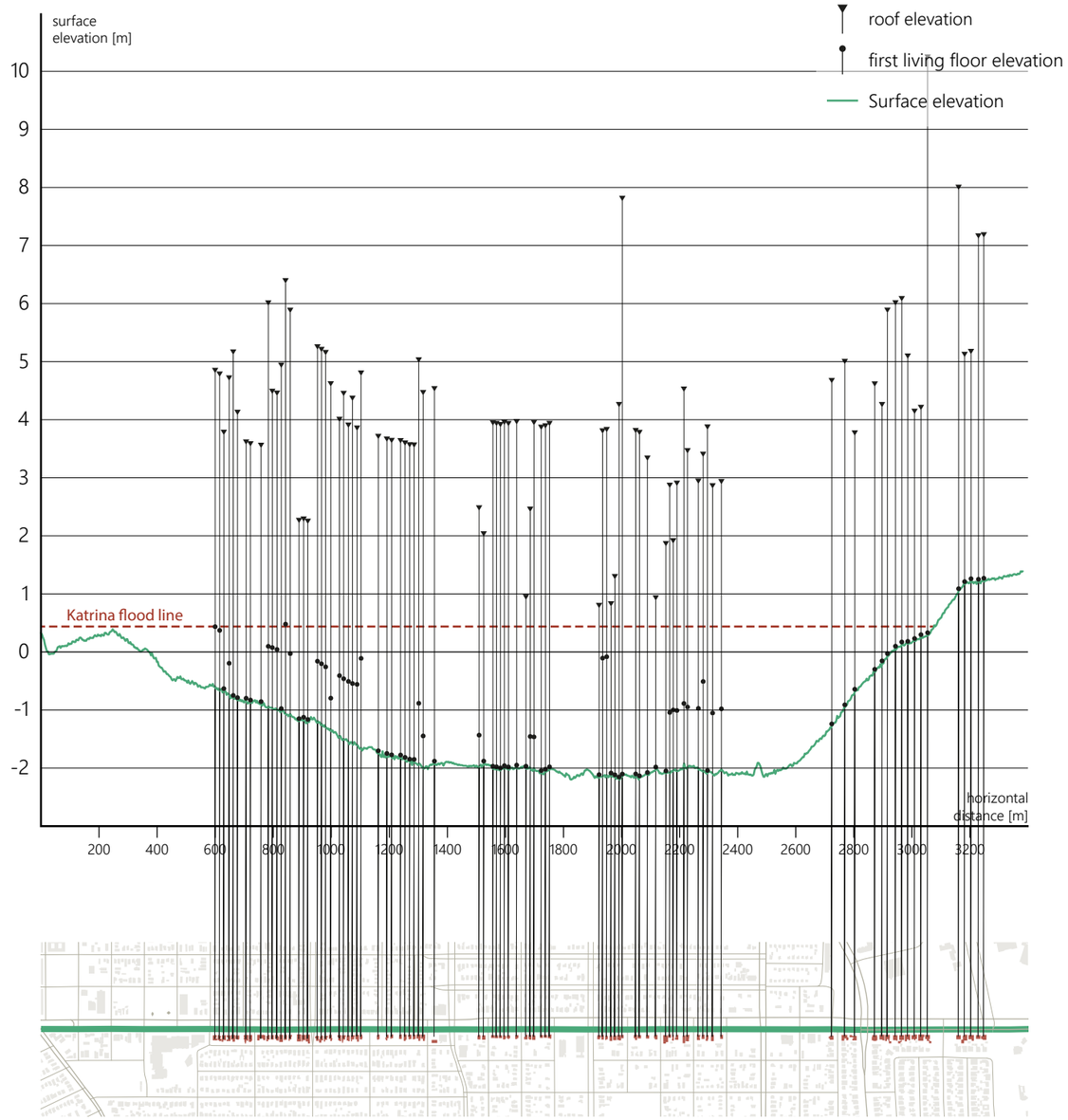
The Orleans Lakeside project area is bordered by the Gentilly Ridge, artificially raised land and open water. There is a large variation in elevation throughout the project area, which directly influences the flood and drought vulnerability of the built environment. In effect, New Orleans' suburbs can be seen as a bowl. It is relevant to research whether the urban environment is designed with the flood susceptibility in mind.

Two profiles of representative streets on both sides of City Park provide insight in the relation between the building typologies and elevation. Figure 81 shows the longitudinal profile of Canal Boulevard in the Lakeview neighborhood, while Figure 80 shows the longitudinal profile of Elysian Fields Avenue in Gentilly.

Figure 80 - Relation between topography and building typology on longitudinal profile of Elysian Fields Avenue. Building levels by own survey, land elevation by National Oceanic and Atmospheric Administration (2017), Katrina flood line by U.S. Department of Housing and Urban Development (2005).

Elysian Fields Avenue

The Elysian Fields Avenue profile shows that dwellings on higher ground often have the first living floor on ground level. Surprisingly, not all dwellings in lower lying areas have an elevated first floor. Of all dwellings alongside Elysian Fields Boulevard, only a handful have the first living floor above the Katrina flood line. Regarding evacuation, most buildings in lower areas have multiple floors, resulting in a roof that is above the Katrina flood line. Still, ranch-style homes or similar typologies would be completely submerged.



Canal Boulevard

Most buildings on higher ground alongside Canal Boulevard have the first living floor on ground level; most dwellings in lower areas have an elevated first floor. The profile shows that buildings rarely have a first floor above the Katrina flood line, meaning that a future severe flood will cause significant damage. Roof elevations are generally higher than those alongside Elysian Fields Boulevard, which provides opportunities for evacuation.

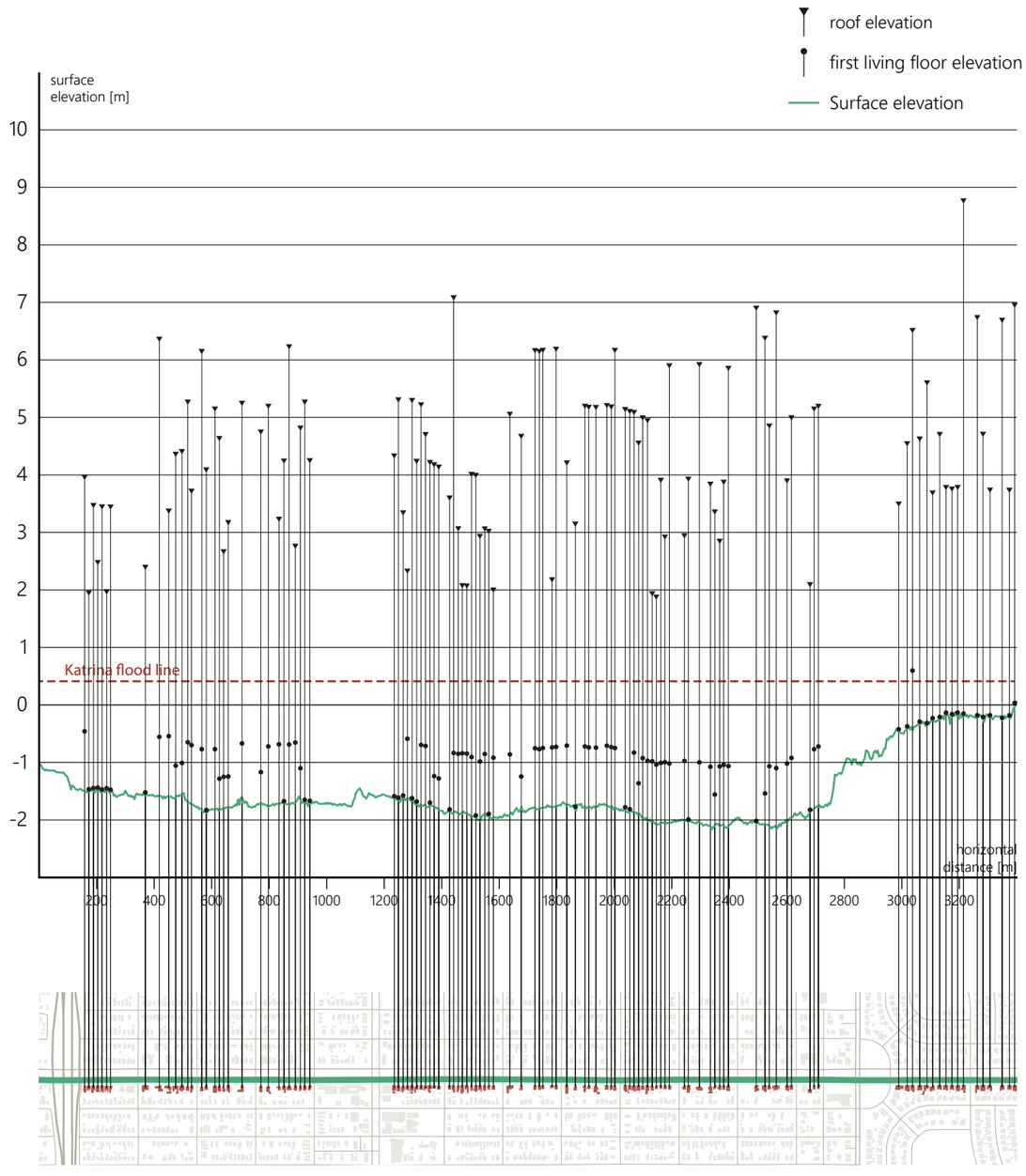


Figure 81 - Relation between topography and building typology on longitudinal profile of Canal Boulevard. Building levels by own survey, land elevation by National Oceanic and Atmospheric Administration (2017), Katrina flood line by U.S. Department of Housing and Urban Development (2005).

4.2.2 Evacuation

Evacuation is a major part of natural hazard mitigation planning in the United States. There is an elaborate network of government-selected roads that together form an evacuation system. For those without private transportation there are central pick-up points from where the government evacuates residents.

Figure 82 shows the evacuation network in New Orleans. There are two major routes via which local residents can leave the city: either west- or eastwards via the I10, or northwards via the Lake Pontchartrain Causeway. Data from the U.S. Department of Housing and Urban Development (2005) shows that several key links in the evacuation system flooded during Hurricane Katrina, making it difficult for residents to leave once the event started. Although local pick-up points in the central city remained largely dry, pick-up points in the lower neighborhoods of New Orleans flooded severely.

The Committee on Homeland Security and Governmental Affairs (2006) indicates a problematic pre-storm evacuation of New Orleans, citing few evacuation routes and long waiting times for more northern parishes to wait for southern perishes to complete their evacuation. An estimated 100,000 people stayed behind, part of whom were unable to evacuate.

Post-landfall evacuation in 2005 was heavily criticized due to a lack of effort by multiple levels of government. According to the Committee on Homeland Security and Governmental Affairs (2006), some 10,000 to 15,000 residents sheltered at the Superdome, which was designated as a "refuge of last resort". A lack of buses prevented a large part of the population to leave; it took several days for the city to designate buses and drivers for post-landfall evacuations (Committee on Homeland Security and Governmental Affairs, 2006).

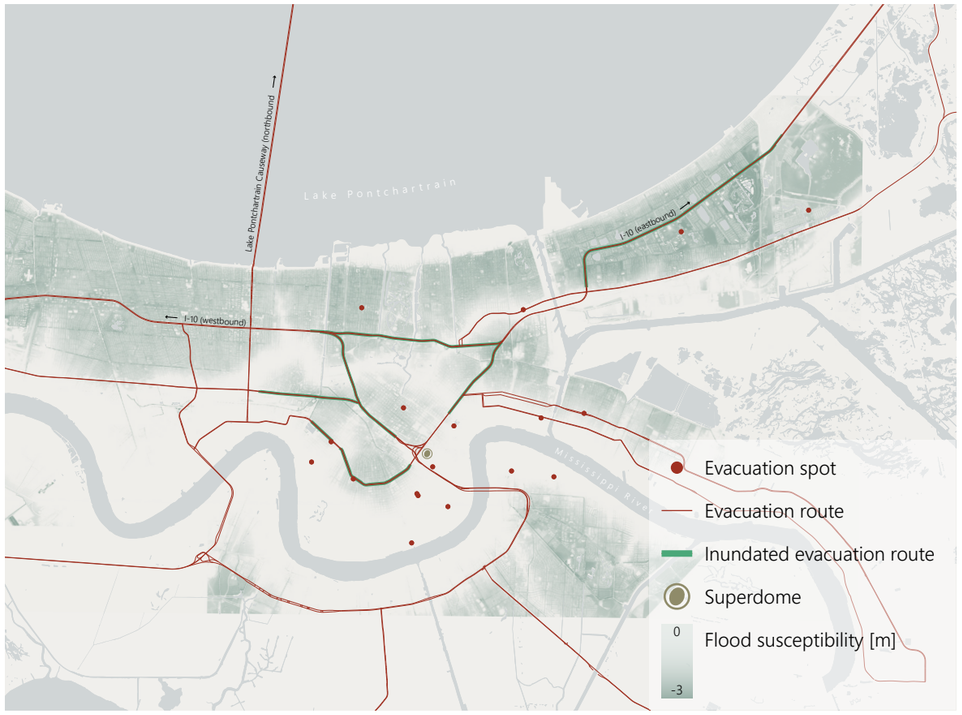


Figure 82 - Evacuation spots and primary evacuation routes. Parts of the evacuation road system was severely inundated during Hurricane Katrina (source: U.S. Department of Housing and Urban Development (2005), City of New Orleans (2018a), elaborated by author).

Evacuation on building scale

The Hurricane Katrina disaster showed shortcomings in the capacity of local and higher governments to safely evacuate New Orleanians before and short after a storm. This makes it relevant to study evacuation possibilities on building scale. Certain housing typologies might offer the opportunity to shelter in place, reducing the necessity of mass evacuation.

With the earlier given overview of prevailing typologies in Orleans Lakeside, it becomes obvious that only few buildings in Orleans Lakeside provide the opportunity for sheltering. As Figure 80 and Figure 81 show, the elevation of certain roofs are suitable for emergency evacuation. However, a quick survey of roofs in the project area reveals that no roofs are accessible from the inside through a hatch or by other means. Still, Figure 84 shows that Orleans Lakeside has a couple of high rise buildings that currently provide opportunities for vertical evacuation. In this study a building is designated as high rise if it has 5 or more stories. All suitable buildings are located on higher ground, which makes it difficult for those living in low areas to have access to vertical evacuation.



Figure 83 - Evacuation shortly after Hurricane Katrina made landfall (source: The Times-Picayun Publishing Co., 2005).



Figure 84 - High rise buildings suitable for vertical evacuation.



Figure 85 - Properties sold by NORA (source: New Orleans Redevelopment Authority (NORA), 2019).

MACRO | MESO | MICRO | NANO

4.2.3 Rebuilding after Katrina

This section discusses the recovery of New Orleans after Hurricane Katrina, distinguishing between residential and commercial districts.

Housing recovery

The days directly after Hurricane Katrina, the Federal Emergency Management Agency (FEMA) was responsible for emergency procedures in the city. Key responsibilities include search and rescue, as well as providing trailers as temporary housing for residents.

After the immediate emergency phase, the New Orleans Redevelopment Authority (NORA) was assigned with the task of structural rebuilding of the city. The agency was given control over the portfolio of vacant lots. As of 2019, most of the vacant lots in NORA's possession have been sold to new owners or to neighbors via the "lot next door" program. Figure 85 shows the properties sold by NORA, and those still up for sale.

Business recovery

There is little data available on business recovery in New Orleans after Katrina (R. Campanella, 2008). A survey done by R. Campanella (2008) shows remarkable business recovery in commercial strips on high ground (Magazine Street), while business recovery in lower lying areas was much less. Figure 86 shows business recovery in the first 66 weeks after Hurricane Katrina.

LeSage, Pace, Lam, Campanella, and Liu (2011) found that the decision by business owners to reopen after Hurricane Katrina largely depended on surrounding businesses, although this effect only became significant after a couple of months. Sole proprietorships were the quickest to reopen, while after 6 months the spillover effect of neighboring business became significant. After 12 months, when disaster aid and other factors brought the economic climate back to pre-disaster conditions, the effect of neighboring businesses became less significant.

Recent policy documents attribute a greater importance to business recovery after a disaster. Initiatives such as the Main Street Resilience Plan are designed to provide business owners resources to quickly reopen after a calamity.

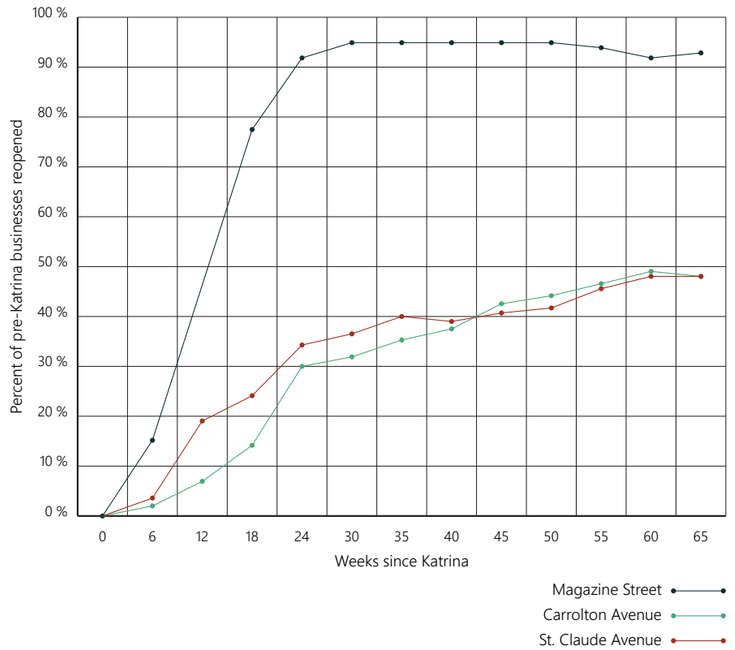


Figure 86 - Business recovery after Hurricane Katrina (source: R. Campanella, 2008).

500 m 1 km

4.2.4 Recovery & Vacancy

The most recent survey concluded an estimated 40,901 vacant parcels across New Orleans (City of New Orleans, 2018c). Orleans Lakeside is estimated to have 2,600 vacant parcels, most of which are located east of City Park. This subsection investigates whether there is a relation between the flood susceptibility and vacancy in order to provide an image on how the physical location influences recovery.

Figure 87 shows that there seems to be a relation between the elevation and amount of vacancy in Orleans Lakeside. Higher parts of the area generally suffer less from flooding and are therefore not quickly destroyed and abandoned. However, while Gentilly shows a clear relation between elevation and vacancy, this relation is not as clear in the wealthier Lakeview neighborhood. Lakeview experienced similar flooding as Gentilly during Hurricane Katrina, but its quicker reconstruction can be attributed to more financial means and often better flood insurance of building owners.

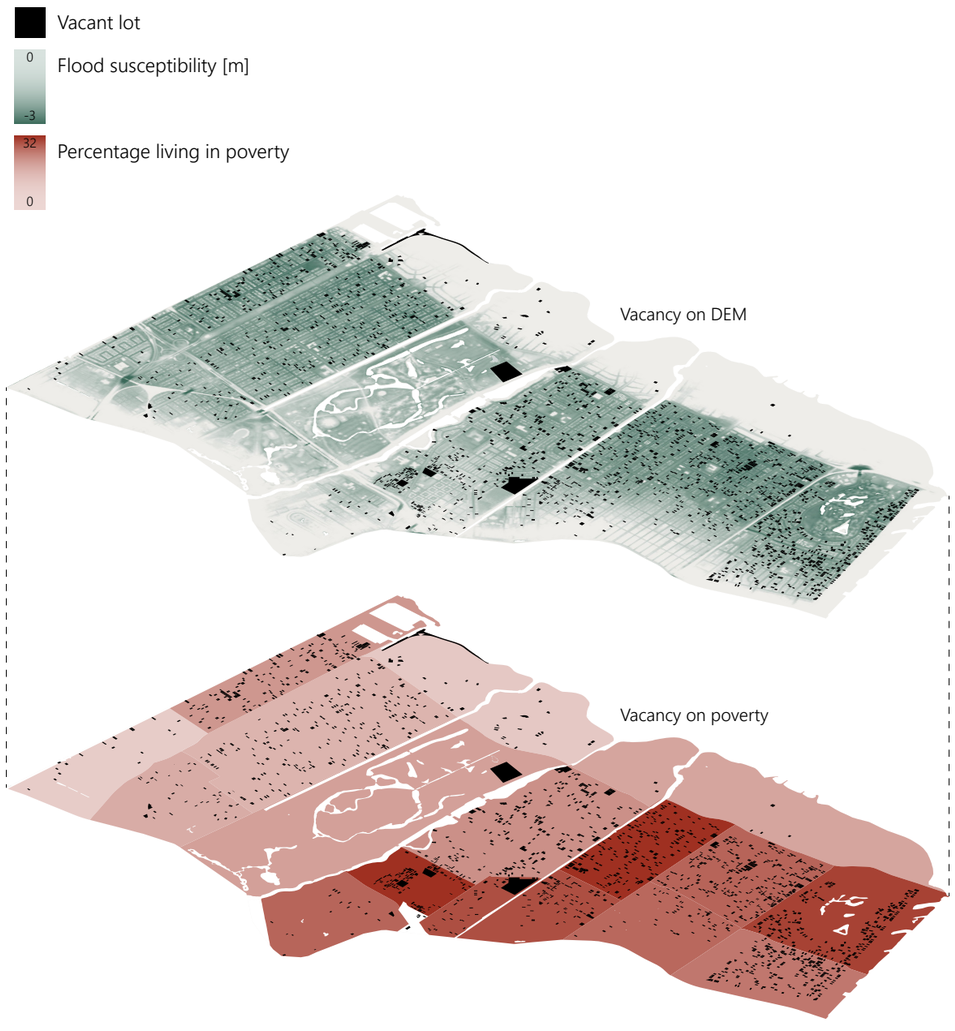


Figure 87 - Vacancy in relation to elevation and poverty level. This map highlights the relation between flood susceptibility and vacancy, especially prominent in less affluent neighborhoods. Elevation data by National Oceanic and Atmospheric Administration (2017), vacant lot data by City of New Orleans (2019), poverty rate data by The Data Center (2017).

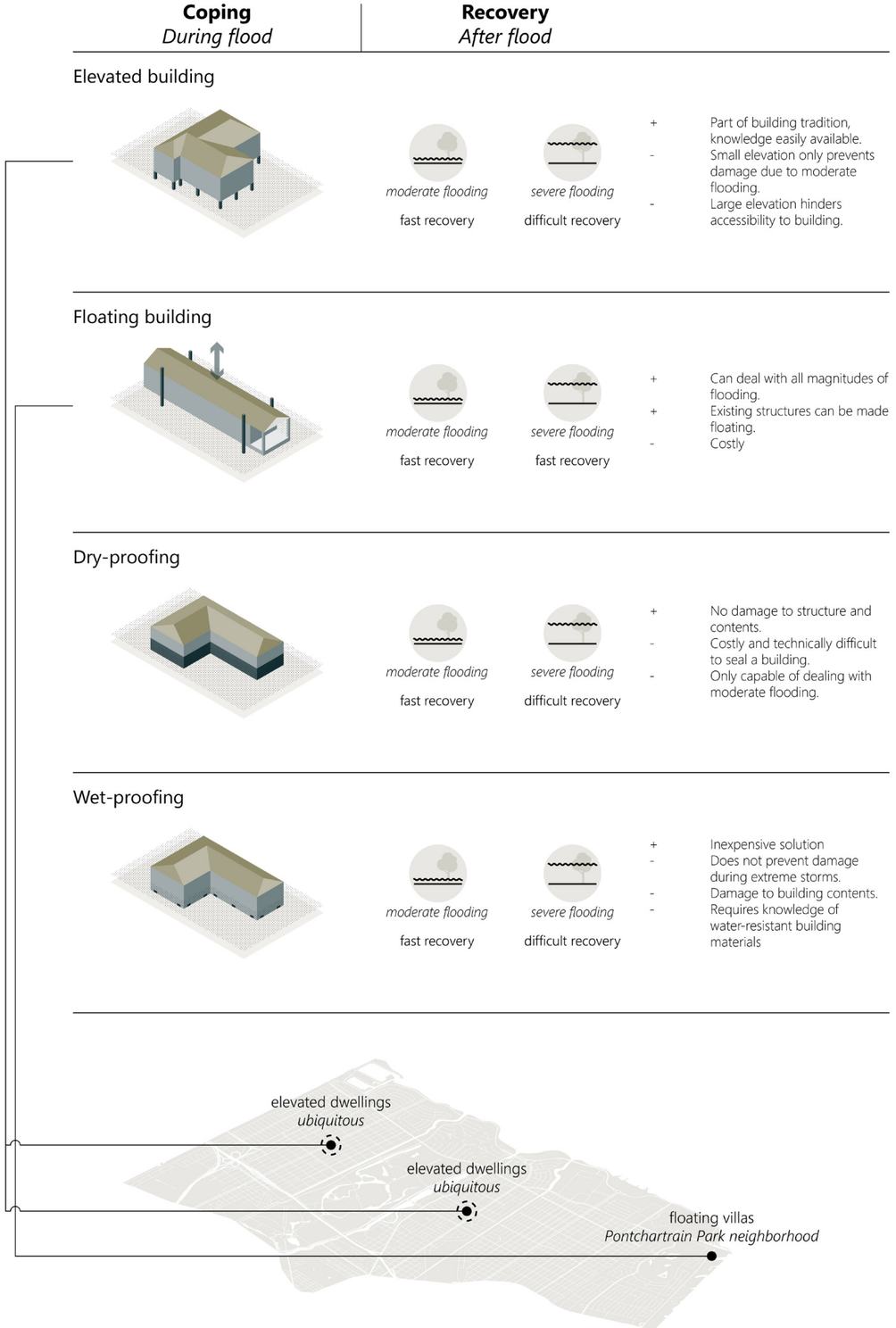
4.2.5 Dealing with flooding on building scale

Building-scale design decisions play a significant role in flood vulnerability. This section provides an overview of measures that improve the coping and recovery capacity of individual buildings.

In a conventional flooding scenario, as water rises it enters the structure through cracks and openings. In general, the water level in the building is similar to that outside, albeit with a slight delay. When floodwaters recede, the water level inside the building slowly drops. In this case, flooding causes damage to the building structure, finishing and its contents. In the case of rapid flooding with floating debris, damage is more extensive. To some extent damage to the building can be repaired, otherwise it needs to be replaced.

Four types of measures that increase the coping and recovery capacity are considered here. An overview of the properties and performance of different measures is given in Figure 88. If available, example locations in Orleans Lakeside are given.

Figure 88 - Coping and recovery capacity of buildings in Orleans Lakeside.



4.3 Adaptive Domain Analysis

The adaptive domain analysis appraises the capacity of the existing built environment to change and adapt to future developments. A major determinant of adaptive capacity is flexibility of the urban environment, which takes shape on multiple levels of scale. On the largest scale, this section analyzes municipal city planning and desired future developments that might influence the adaptive capacity. On a smaller scale, features such as functional diversity are major determinants of adaptive capacity. Flexibility of individual buildings provides insight in adaptive capacity on the smallest scale.

MACRO | MESO | MICRO | NANO

4.3.1 Municipal vision & strategy

The Plan for the 21st Century, or Master Plan in short, provides a desired course of action for New Orleans, which could greatly influence the adaptive capacity. This subsection discusses the major goals and vision of the municipality.

The Master Plan has no strategic component, nor does it translate its goals into spatial requirements. It mainly consists of a set of guidelines on topics such as housing, transport and environmental sustainability. The primary spatial output of the plan solidifies in the land use plan, which is a legally binding document that stipulates the allowed building functions on all parcels across the city.

In the Master Plan, the vision emphasizes two key terms that together form the basis of all plans: equity and resilience. Figure 89 summarizes the main supporting thougths.

EQUITY

An equitable city government acts with purpose to achieve just and fair inclusion, ensuring that all residents participate, prosper, and reach their full potential. It leverages its power and resources to dismantle institutional racism and discrimination wherever they exist. It implements bold strategies to eliminate income and neighborhood inequities.

RESILIENCE

As a resilient City, New Orleans will:

- Adapt to thrive: By adapting our city to our natural environment and the risks of climate change, we can create opportunities for all New Orleanians to thrive.
- Connect to opportunity: By investing in equity – the driving force behind our economy's growth and innovation, our communities' safety and stability and our families' health and prosperity – we are investing in resilience.
- Transform city systems: We are building a New Orleans for the Future – on that embraces change, prepares for risks of the future and honors our traditions.

Figure 89 - Equity and resilience as key aspects of the municipal vision.

With equity and resilience as cornerstones in plans for New Orleans, the following action points can be distilled from the Master Plan:

- Introducing walkable, mixed-use neighborhood hubs. Providing a mix of commercial activity to attract both local and regional clients.
- Developing empty parcels with the aim of reducing vacancy.
- Diversifying job opportunities, moving away from tourism as driver of the economy.
- Providing affordable housing to all.
- Placing the natural system central in all plans.

Evaluation of the Master Plan

The following conclusions are drawn from the Master Plan.

The two key terms, equity and resilience, target the most pressing issues facing New Orleans. Despite its noble ambitions, the Master Plan offers little concrete plans to tackle these issues in the spatial domain. For instance, the aim of introducing walkable, mixed-use neighborhoods is not reflected in the zoning ordinance at all. Commercial activity remains isolated, with some residents having to travel more than a kilometer to the nearest commercial center. The zoning ordinance indicates merely a name change rather than actually trying to induce walkability.

The aim of reducing vacancy would suit well the adaptive capacity. However, parcels sold to neighbors are officially no longer vacant, while in reality the density stays equally low.

Another remark concerns the natural system. The Master Plan indicates a central role for the natural system in designs. However, no concrete spatial measures are offered to re-introduce the natural system in the urban environment. Mechanical drainage persists and there is no sign of acknowledging the geographical location of building in wetlands.

Although the Master Plan isolates the most pressing future challenges for New Orleans, it provides little tangible elements to increase the adaptive capacity of the city.

4.3.2 Functional Diversity

Functional homogeneity and a lack of diversity is often associated with a low resilience to disturbances (Tyler & Moench, 2012). An analysis of the spatial diversity of functions provides insight in the adaptive capacity of the urban environment. Figure 90 shows an axonometry of functional zoning in Orleans Lakeside. It highlights problematic homogeneous zoning and strong spatial segregation of functions. Pure residential zoning is ubiquitous in Orleans Lakeside; commercial activity is limited to concentrated spots of either car-oriented or pedestrian-oriented retail. Mixed use zoning is rare. Availability of open space is unevenly distributed across the project area. City Park and Pontchartrain Park provide massive open spaces, although the amount of high quality public space within residential districts is minimal.

Figure 90 - Zoning analysis of Orleans Lakeside (source: City of New Orleans, 2019).



MACRO | MESO | MICRO | NANO

4.3.3 Land owned by public parties

Interventions are more easily achieved in public space, as there are no issues with private landowners that are not willing to cooperate. It is therefore relevant to assess the publicly owned land in Orleans Lakeside. Figure 91 shows land that is currently owned by public parties.



Figure 91 - Publicly owned parcels in Orleans Lakeside (source: City of New Orleans, 2019).

MACRO | MESO | MICRO | NANO

4.3.4 Flexibility on block and building scale

The flexibility of the built environment is assessed is two scales: blocks-scale for a representative suburban block and building-scale for the most prevalent construction methods used in Orleans Lakeside.

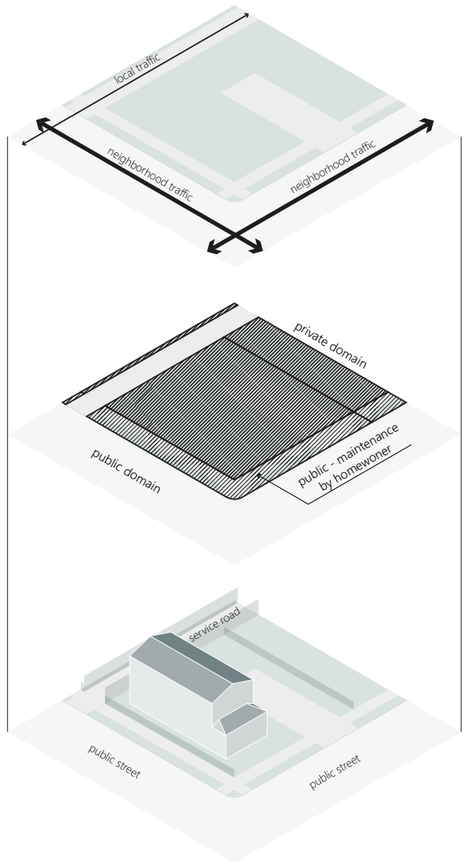
Block flexibility

Figure 92 shows a diagrammatic representation of a typical suburban block. Generally, private properties border each other on two sides and extend from the sidewalk to a service road on the backside, or a third property on the backside if no service road is present. Both the main street and the service road are publicly accessible, although the latter is almost exclusively used by traffic that has a destination there.

Interestingly, although the sidewalk, green strip and curb is not private property, responsibilities for maintenance and permits still lie with the adjacent homeowner. This reduces maintenance costs for the municipality, but results in differing qualities of sidewalk along a street.

Street profiles are generally wide, leaving ample opportunities for interventions in the public domain. The green buffer between sidewalk and road generally has no function other than spatial separation of traffic flows, allowing room for easy interventions. However, with sizeable private parcels, it would be undesirable to only depend on the public domain for interventions.

Figure 92 - Standard block typology.



Building flexibility

Buildings can be flexible in multiple ways. This section discusses the functional flexibility and structural flexibility of buildings in Orleans Lakeside. Functional flexibility allows the building to host a variety of functions. This requires the building to have a high ceiling clearance, moveable partition walls and possibly a modular design. Structural flexibility implies that the integrity of the load bearing structure building is not dependent on a fixed, difficult to change form. Rather, disassembly has to be easy. Alternatively, being able to move the structure is a strong point as well.

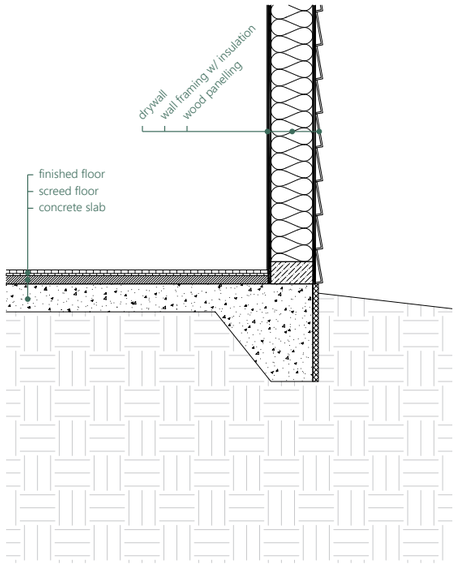
With the abundance of single-family dwellings, it can be stated that functional diversity is minimal. Current buildings in Orleans Lakeside have little capacity to host other functions (with the exception of small businesses at home).

An analysis of the structural flexibility, with special attention to raising or making the structure floating, reveals a dichotomy in construction methods. Figure 93 shows the two most prevalent construction methods in New Orleans: slab on grade foundation and stem wall foundation. Slab on grade dwellings have a concrete floor that is cast in place on compacted soil, without structural support. Stem wall dwellings have foundation, on which rests a concrete slab. As slab on grade dwellings are built on a single slab, they can be moved more easily than houses that rely on deeper foundation.

Possibilities for disassembly are present, albeit limited, for both construction types, as wooden wall frames are used for load bearing capacity. Most wooden elements are bolted together, which allows some degree of flexibility.

Slab on grade foundation

can be raised or moved

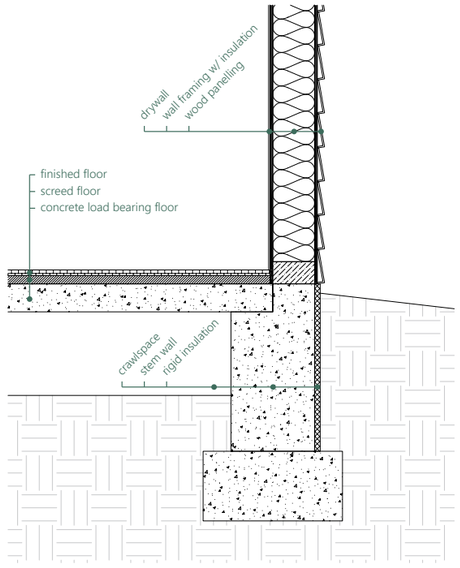


used for:

2-bay shotgun home
4-bay shotgun home
1-story bungalow
2-story bungalow

Stem wall foundation

difficult to raise or move



used for:

1-story bungalow
2-story bungalow
ranch home
townhome
garden-style apartments

Figure 93 - Prevalent construction methods in New Orleans.

4.4 Analysis conclusions

Threshold capacity

1 federal levee
The current levee system is not sufficient for protecting against large future weather events. Urban developments in the short term cannot rely on a fully functioning hurricane protection system.

2 flood vulnerability
Although most streets suffer from flooding, concentrated spots in the lower part of Orleans Lakeside are exposed to the most severe inundation. There areas are in the most need of buffering capacity.

3 green infrastructure
Finished green infrastructure projects in the city do not significantly contribute to the water assignment. Per catchment the contribution does not exceed 1% of the total required volume.

4 flood prevention on building scale
The current built environment has little building-scale measures to prevent flooding. Even affordable, easily accessible measures such as rain barrels are not common.

Coping & recovery capacity

5 flood susceptibility and urban planning
There is a positive relation between flood susceptibility, vacancy and poverty rates, with the notable exception of wealthy Lakeside.

6 evacuation on city scale
Evacuation on city scale is problematic, with major evacuation routes completely inundated during Hurricane Katrina.

7 evacuation on building scale
Regarding evacuation on building scale, there are few tall buildings suitable for vertical evacuation, and no such facility is available in the most vulnerable part of the project area.

8 vacancy and recovery
After Hurricane Katrina, programs such as the 'lot next door' aim to reduce vacancy rates. Business recovery was slow in Orleans Lakeside, especially compared to city districts on higher ground, such as Market St.

9 coping and recovery of buildings
The application of different forms of architecture that are inherently better capable of dealing with flooding is highly limited, with only a few examples present in Orleans Lakeside.

Adaptive capacity

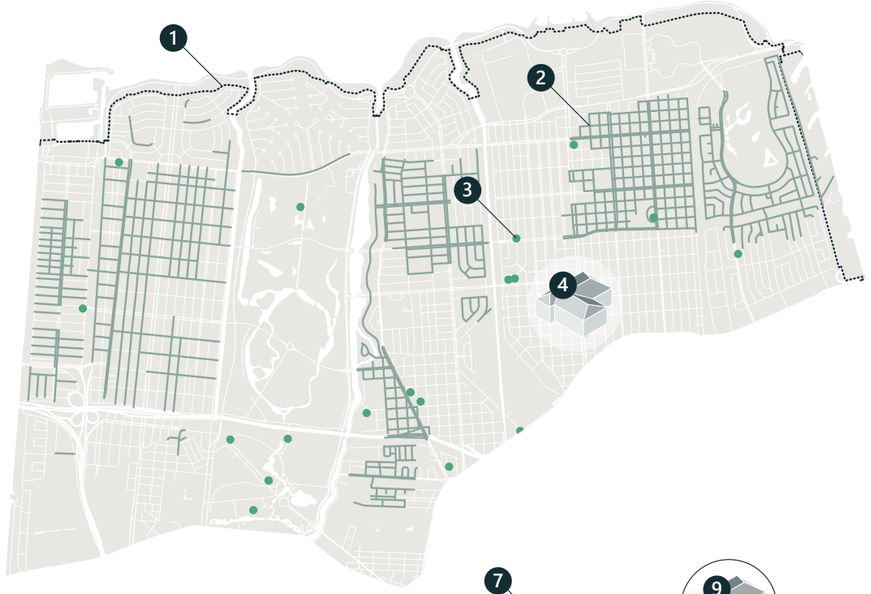
10 city's master plan
The city's Master Plan has no strategic component, nor does it translate its goals into spatial requirements. Overall, the Master Plan does not advocate flexibility in either functional nor spatial terms.

11 functional homogeneity
Functional homogeneity is an obstacle to adaptive capacity. Most of Orleans Lakeside is dominated by suburban residential zoning, with scattered, car-oriented commercial districts.

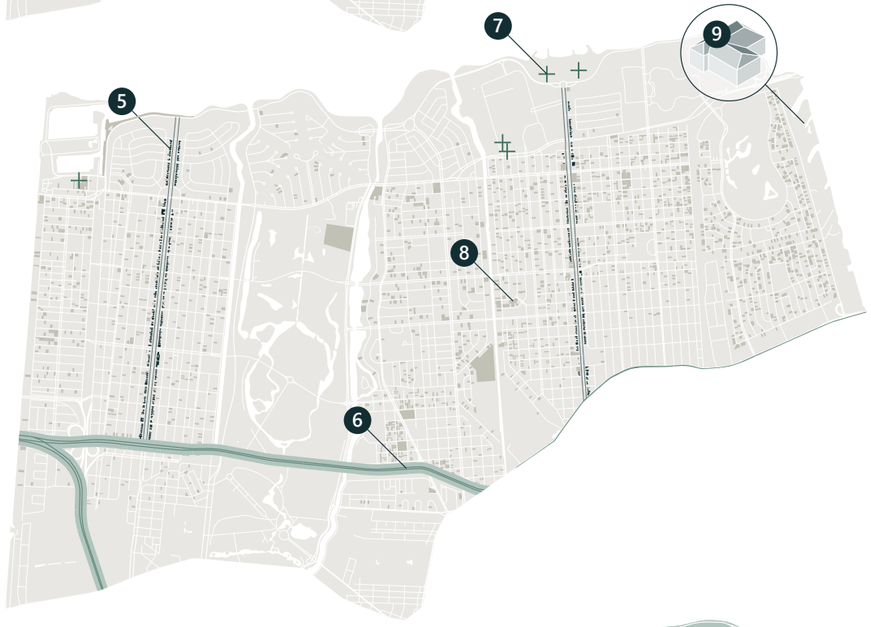
12 public space
Scattered public parks across Orleans Lakeside, in addition to wide boulevards in Gentilly and Lakeview, present opportunities for easy interventions. City Park and Pontchartrain Park demonstrate capacity for large scale interventions without the need to compensate private landowners.

13 flexibility
The typical suburban block shows flexibility mainly in wide street profiles and green buffer zones between private property and the street curb. On building scale, slab on grade foundation shows the highest degree of flexibility concerning raising and relocation of the structure.

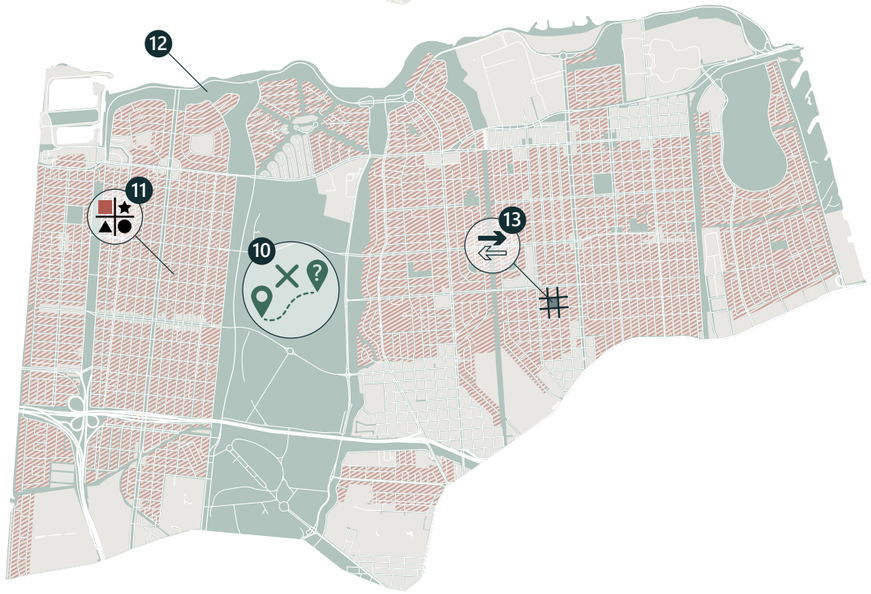
THRESHOLD CAPACITY



COPING & RECOVERY CAPACITY



ADAPTIVE CAPACITY



5 Scenario & Vision

5.1 Scenario
5.2 Vision

This chapter provides a projection for the future as a basis for designs, as well as a vision for Orleans Lakeside, to which design projects in this thesis contribute.

Instead of providing an elaborate scenario analysis with a myriad of variables and outcomes, this chapter constructs a simple scenario through projecting a "neutral situation". This projection considers current and planned developments, as well as uncertain factors that could influence the development of Orleans Lakeside. This "neutral situation" sketch is not inherently negative; it might contain positive developments that contribute towards a better flood and drought resilience. However, given the extensive problem field, this autonomous situation will be far from ideal.

The reduced scenario considers two key variables: demographics and climate change. By plotting these variables against each other, pretext for interventions is given. The scenario offers a time horizon as well.

Deviations from the autonomous situation, the "improved situation", solidifies as a vision for Orleans Lakeside. The vision provides a course of action for the ideal situation for the project area. It describes the outcome if the design framework and design interventions are implemented in the best possible way.

Deviation from the neutral situation towards the improved situation by means of design interventions is schematically shown in Figure 94.

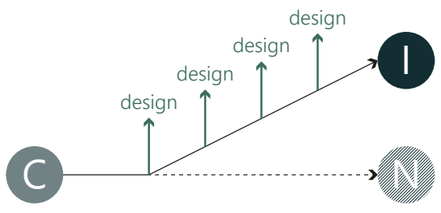


Figure 94 - Neutral vs. improved situation (C=current situation, N=neutral situation, I=improved situation).

5.1 Scenario

As a fundamental basis for future projections, this project considers two key variables that give pretext to societal and environmental shifts. The chosen variables are 'population' and 'climate change'. These variables are plotted against each other, resulting in a graph with four quadrants. This model is based on climate scenarios developed by the Dutch weather institute KNMI. The two variables substantiating the scenario are briefly explained below.

Climate

As outlined in Section 1.2.3, climate change effects include an increase in precipitation intensity, longer dry spells, rising sea levels and more frequent Atlantic hurricanes. In short, weather events will become more intense.

Population

GCR & Associates (2018) produced a population projection for 2030 based on US Census data and housing developments (Figure 95). The high scenario projects a return to pre-Katrina population to due net migration; the low scenario projects a population decline due to a decreasing household size. The moderate scenario is a combination of the above-mentioned factors and will serve as the basis for this project's scenario.

Leading scenario

With a projected stagnation of inhabitants and high climate change, the relevant scenario for this project is given in Figure 96.

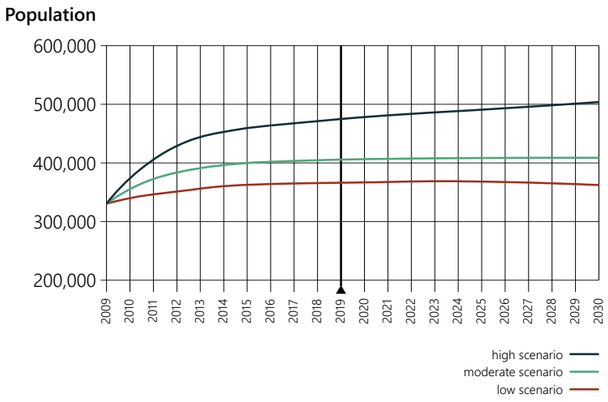


Figure 95 - Projected population development (source: GCR & Associates, 2018).

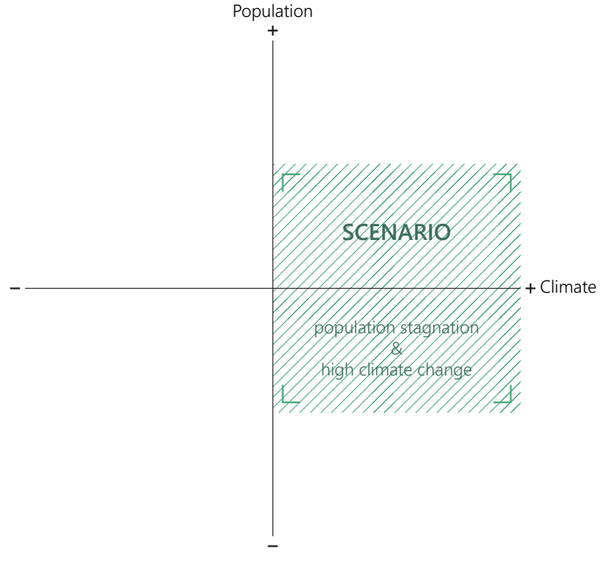


Figure 96 - Project scenario.

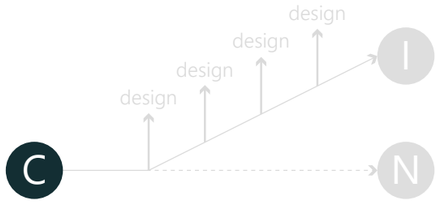


Figure 97 - (left) Current situation.

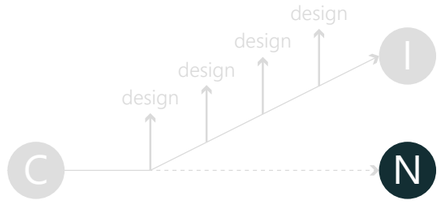


Figure 98 - (right) Current situation.

Current situation

The current state of Orleans Lakeside, with all its pressing issues, can be distilled from the earlier analyses. The current state is characterized by a poor flood and drought resilience and little capacity for flexibility in the urban environment. Orleans Lakeside completely depends on mechanical drainage and the existing building typologies are not suited for dealing with inundation.

Neutral situation

Drawing from this project's scenario, New Orleans will likely have a stagnating population hovering around 400,000 inhabitants. As household sizes are projected to decrease, vacancy rate is expected to drop over time. However, this represents a false indication of development, as the effective population count and density remains low.

Steps towards more flood and drought resilience will be small and in line with the currently prevailing conservative approach. This is defined by van Veelen (2016) as 'incremental resilience': measures that are taken do contribute positively, but fall within existing paradigms and are unlikely to be capable of combatting the effects of climate change. Measures currently being taken will only minimally contribute to an increased flood and drought resilience in New Orleans. In the neutral situation, the occasional pump will be replaced, drainage pipe upgraded or bioswale constructed.

In line with municipal policy, private landowners' contribution to the water assignment will slowly increase. Public perception that the municipality has a leading role in tackling flooding issues, however persists.

In the neutral situation, Orleans Lakeside will incrementally recover from Hurricane Katrina and improve its drainage system. A next major weather event, however, will again bring destruction to the built environment.

5.2 Vision

Improved situation

The narrative for an improved situation is constructed through a standpoint, core vision principles, vision statement and vision map.
Standpoint
R. Campanella (2008) describes three inherently different standpoints of urban planners and decision makers after Hurricane Katrina: an abandonist view, a concessionist view and a conservatist view. The abandonist standpoint advocated for restricting the built environment to high ground, or relocate the entire city to the north of Lake Pontchartrain. This standpoint was shared by planners and professionals not directly tied to the city, with little to lose in the case the city would disappear (R. Campanella, 2008).
The conservatist standpoint, popular with local residents, advocated for a complete preservation of the city's footprint and rebuild all damaged neighborhoods to their pre-disaster state.
The concessionists fall between the conservatists and abandonists. This standpoint acknowledges that it is impossible to either complete rebuild the city, or to abandon it at all. R. Campanella (2008) argues this view is widely shared amongst professionals and residents living on higher ground, but generally loathed by residents in vulnerable areas with claims of being racist or elitist.

In the end, the politically correct conservatist stance prevailed. The complete footprint of the city has been conserved and new development takes place within the existing urban grid and fabric.

This project positions itself in the concessionist camp. It recognizes that it is undesirable to forsake the rich history of the city, but states that only bold and far-reaching interventions have the capacity to make Orleans Lakeside significantly more flood and drought resilient. This is echoed by Garret Graves, a Louisiana congressman and former chairman of the Coastal Protection and Restoration Authority. Mr. Graves underlines that repeatedly repairing hurricane damage is far more expensive than investing in adequate and far-reaching protection (Schwartz & Schleifstein, 2018).

Figure 99 - Improved situation.

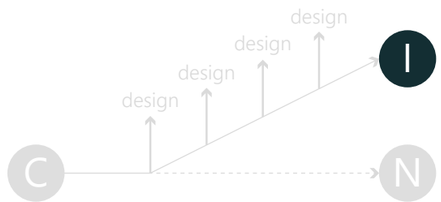
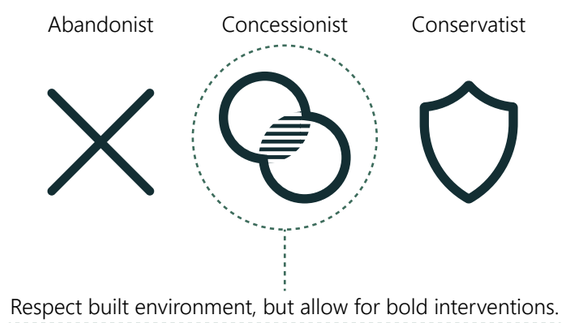


Figure 100 - Three main positions of planners after Hurricane Katrina and the chosen position for this project.



Core vision principles

The following core principles lie at the core of the vision:

ENGINEERING
- The water assignment for a T10 rain storm is completely covered.
- Orleans Lakeside is better able in dealing with severe storms, considering all vulnerability capacities.

DESIGN
- The quality of the public space is greatly enhanced by introducing water as amenity in the urban space. Water system improvements are used as accelerator for spatial development.
- Orleans Lakeside is internally better spatially integrated.
- New local and regional destinations enrich the current program.
- Orleans Lakeside is less dependent on the city center for employment. Decentralized jobs are added.
- Orleans Lakeside is better suited and organized to deal with uncertainties regarding the context of stagnation.

Vision Statement

Orleans Lakeside is to become more flood and drought resilient.

Orleans Lakeside will be capable of successfully handling severe rain storms with a return period of ten years through an improved water system which acts as an accelerator for spatial development. Green-blue infrastructure projects introduce water as an amenity and reintroduce the city's geographical location of wetlands and bayous. In addition, these green-blue elements deliver a better spatial integration within Orleans Lakeside. Bold interventions and structural changes to the urban fabric make Orleans Lakeside better capable of dealing with uncertainties in the context of stagnation. Orleans Lakeside will be resilient to severe storms and hurricanes through means of spatial flexibility, as well as vertical evacuation for those unable or unwilling to leave. Strategic densification creates viable development potential with decentralized job opportunities and destinations for local and regional traffic.

Figure 101 - Vision map.



6 Design Framework

6.1 Strategic component
6.2 Layers of the design framework

This chapter introduces the design framework, which provides guiding principles and boundary conditions for the integrated hydrological and urban design. A design for the complex environment of New Orleans should not be arbitrary. Rather, it should rest upon a logical set of arguments based on earlier research and observations. This chapter translates the earlier advocated concessionist stance into spatial terms.

Enriching the current spatial hierarchy by using the water assignment as accelerator for development.

As underscored in the vision for Orleans Lakeside, the water assignment is used as accelerator for development. Following this line of argumentation, the hydrological design framework is the leading design layer for this project. Other facets of the design framework relate back to the water system and to each other to a lesser extent.

Drawing from the vision, other important aspects to the project that deserve an elaboration in the design framework are connectivity (Subsection 6.2.2), spatial quality (Subsection 6.2.3) distribution of functions (Subsection 6.2.4) and evacuation (Subsection 6.2.5).

Relating to factors of uncertainty in development, the design framework contains a concise strategic component that touches upon flexibility in phasing and a strategy for relocating existing residents.

6.1 Strategic component

6.1.1 Flexibility in phasing

In light of the uncertain development portrayed in Chapter 5, it is essential to divide the design into smaller projects that can be built incrementally. Should, for any reason, development stall in the middle of the process, the system would still function.

Naturally, in an ideal situation all components of the proposed design are actually built. To increase the financial feasibility of the plan, potentially profitable projects, such as building new housing, should be grouped together with interventions that require large investments. This way, the financial burden does not entirely rest upon the municipality, but is shared by developers.

Section 7.6 provides an elaboration on the phasing of the proposed design.

6.1.2 Property rights and relocation

One of the primary obstacles for interventions is property rights. Autonomy and the right of owning private property is deeply entrenched in American culture, and expropriation through eminent domain is highly unpopular. With this in mind, any proposed plan has to incorporate strategies for compensation of homeowners or providing alternative spaces to live. Figure 102 shows the leading strategy for dealing with displacement and compensation for affected homeowners. The process is briefly elaborated below.

In the case development takes place on vacant or municipality owned land, this strategy does not apply; no further action is required. However, if desired development concerns private property, land owners are presented two options: accepting a market-rate buyout or agreeing to alternative housing. As it is not desirable to forcefully relocate residents, this strategy relies on providing attractive alternatives.

Residents that agree to alternative housing are presented with a similar typology as close to their current location as possible. It is a possibility that the desires of displaced residents do not fit in the program of the proposed development. The desired housing typology might not be available, or a quantitative limit prevents more houses of the typology in question. In the case the desires of displaced residents do not fit in the proposed program of the new development, suitable alternatives have to be found in the Orleans Lakeside project area.

While a certain share of the residents would agree to living in a different housing typology, it is to be expected that most residents demand a similar typology housing as compensation. This implies that when proposing new development, it is important to closely examine which housing typologies are replaced at that particular location.

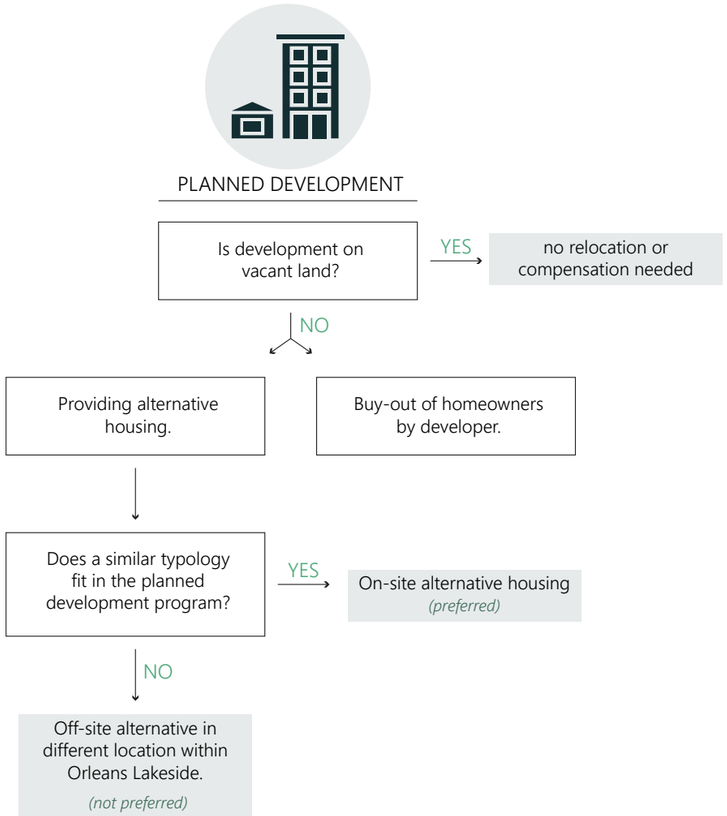


Figure 102 - Main strategy for relocation of residents.

Requirements for an attractive living environment

When proposing alternative housing options, it is important to understand what would motivate current residents to agree with the proposed plans. As the American definition of a desirable neighborhood is different to that of a Dutch point of view, or other cultures for that matter, this thesis relies on literature to provide guidance. Literature review provided a collection of key desired qualities of the living environment. The qualities are divided into two categories: one concerning intangible requirements and one considering spatial requirements. In addition to qualities found in literature, New Orleans local Jessica Link provided a shortlist of desired neighborhood qualities.

Intangible requirements

Safety (Frey, 1979), (Alofsin, 2018)
A sense of safety scores high on home buyers' list of demands.

Affordability (Frey, 1979)
Affordability is a key factor in decision making on the location.

Financial security and independence (Pyati, 2016), *(Alofsin, 2018)*
Homeownership is perceived to be a safe investment.

Fitting the stage of life (Pyati, 2016), (Forbes, 2014)
In contrast to popular belief, suburbs have evolved to support residents' preferences across target groups. A successful living environment should have a variety of dwellings, reflecting the range of income and age.

Idea of belonging (Alofsin, 2018)
Belonging to a community ranks high in consumer demands. This does not necessarily have to take shape in physical proximity to each other. Rather, an extensive network of jogging and cycling trails can fulfill this role, as well as shared facilities.

Spatial requirements

Responsiveness to home buyers' desires (Alofsin, 2018)
Tailoring the building design to consumers' needs is highly desired. This opens ways for collective private commissioning.

Proximity to shopping and restaurants (Forbes, 2014)
Having amenities within a short walk or drive is considered to be a desired quality.

Public transport accessibility (Forbes, 2014)
Rather than completely substituting private automobiles with public transportation, the availability of multiple modes of transport is a desired addition to a neighborhood.

Walkability (Forbes, 2014)
Being able to leave the car at home when using amenities such as supermarkets and parks is a desired quality.

Neighborhood qualities shortlist provided by Jessica Link

- A convenience store and/or pharmacy within walking distance from the living address is expected.
- A grocery store within walking distance is desired, but not critical.
- High-quality, accessible water such as Bayou St. John is cherished amongst residents, but poorly maintained water conjures images of damaging flooding and mosquito nuisance.
- Flooding is perceived to be less disturbing if the flooded area looks natural.
- Gathering place in the form of a school, church or other building is critical to social fabric.
- High-quality green space within walking distance is desired.
- Perspective on privacy differs between suburbs, but generally an open front yard and fenced-off backyard is expected amongst New Orleans residents.
- Safety is highly valued, and takes precedence over other neighborhood qualities.
- Open water access would be appreciated, albeit only for light recreation.

6.2 Layers of the design framework

This section presents all layers of the design framework (hydrology, connectivity, spatial quality, programming and evacuation) individually, as well as their domain-specific goals.

Note: Synergies between layers may not immediately be clear due to the nature of the circular design process. As the water system is leading for spatial interventions, choices and design rules in any of the design layers all relate to the final hydrological design. To understand how the other design layers exactly relate to the water system, it is advised to see the proposed hydrological design in Chapter 7.1.

1. Hydrological design

As outlined in the vision for Orleans Lakeside, the water assignment will be used as an accelerator for development. Hence, articulating a hydrological design framework is an essential step in developing a design for Orleans Lakeside. The hydrological design framework consists of three components: general hydrological principles, a toolbox of interventions and a section on water quality.

The final proposed hydrological design, on which the other layers of this design framework are based, is given in Chapter 7.1.

A New Polder

To a certain extent, Orleans Lakeside's water system can be described as a polder, which is 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). Although Orleans Lakeside is currently below sea level, there is little to no regulation of the surface water level and groundwater level. 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. Figure 103 shows the current system in Orleans Lakeside, which is focused on grey drainage infrastructure. This connects to New Orleans' diluted identity: it is built as any American city with underground drainage, but does not connect to its geographical location.

GOALS

- Reimagining the polder; create integrated water system.
- Ability to handle a T10 rainstorm.

In short, the characteristics of the current Orleans Lakeside polder system are:
- Focus on fast drainage;
- Reliance on underground, out-of-sight drainage;
- Equilibrium of groundwater table by drainage through broken pipes, causes subsidence.

The starting point for the hydrological design is that Orleans Lakeside will be reimagined as polder. The aim is to reconnect to the geographical location of wetlands, therefore reducing the reliance on underground drainage and shifting the focus to surface water. As biggest benefit, open water offers significantly more storage than underground drainage infrastructure. This principle is explained in Figure 105, which shows a significantly higher storage capacity for open water bodies compared to underground drainage infrastructure. Figure 104 shows an improved version of Orleans Lakeside's polder, which is much more focused on surface water and mitigates subsidence caused by oxidation of organic material.

Figure 103 - Current polder system in Orleans Lakeside.

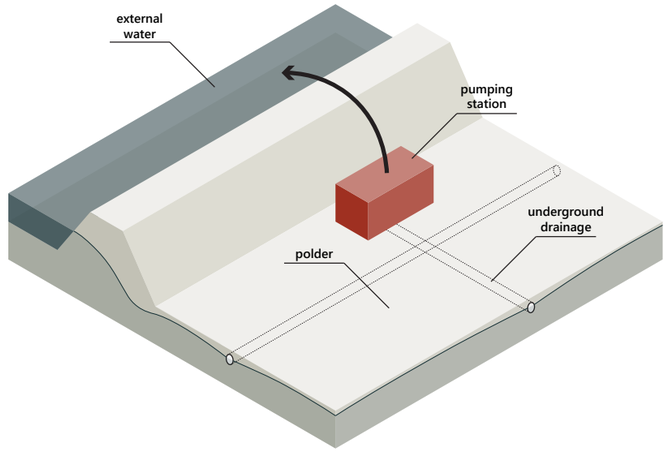
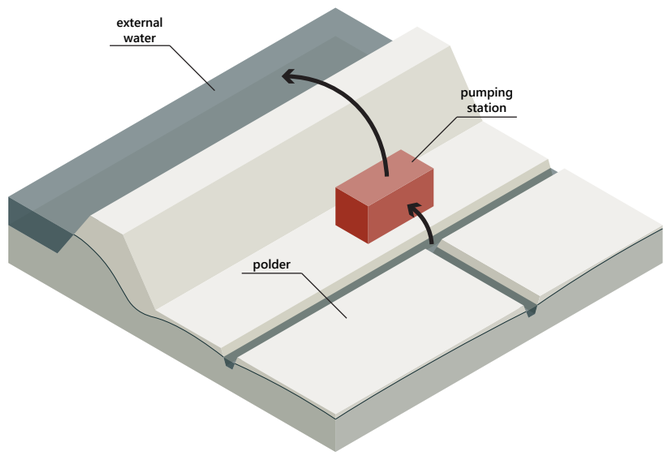


Figure 104 - Proposed polder system for Orleans Lakeside.



In short, the characteristics of the proposed polder for Orleans Lakeside are:
- Focus on retention;
- System of canals providing significant water storage;
- High groundwater tables mitigate subsidence in times of drought.

To achieve a reimagined polder, two leading principles underpin the hydrological design framework: moving the main pumping stations towards Lake Pontchartrain (Figure 106) and lowering the water level in the outfall canals (Figure 107). These two principles open up ways for a myriad of opportunities for an improved and better east-west integrated water system.

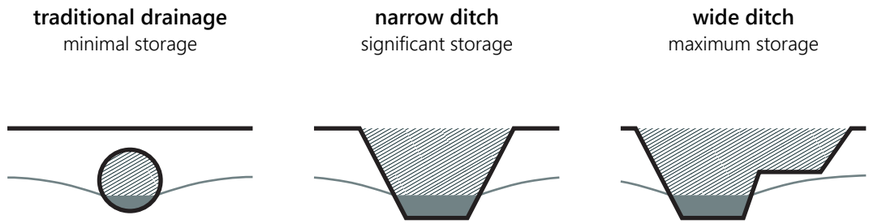


Figure 105 - Additional storage capacity of traditional underground drainage versus open canals.

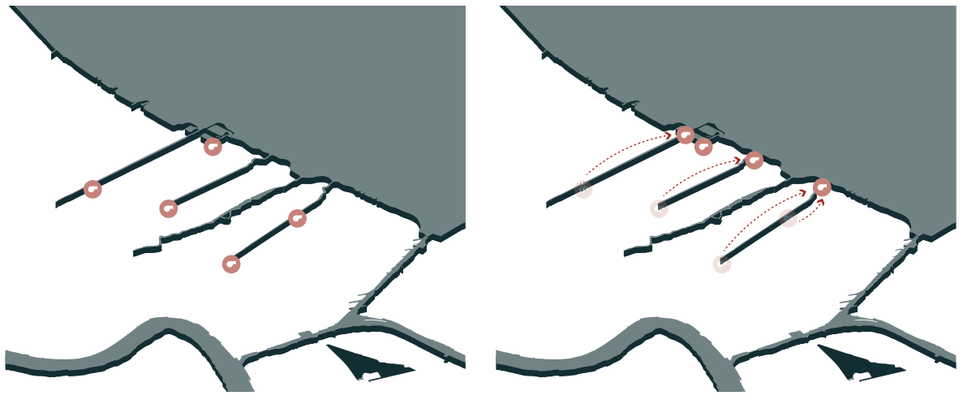


Figure 106 - Moving pumping stations to Lake Pontchartrain.

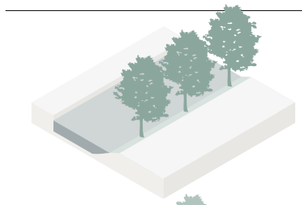
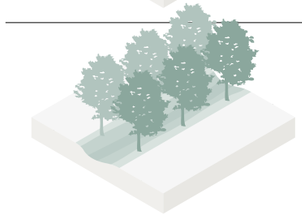
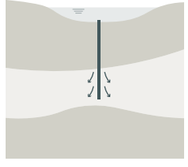
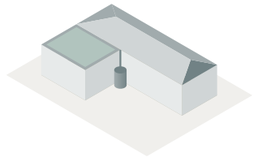


Figure 107 - Proposed system of two hydrological basin, separated by Bayou St. John.

Toolbox of interventions

The hydrological design framework uses six categories of key interventions that together form a toolbox. These six general categories are displayed in Figure 108, along with basic information regarding applicability. An elaborated overview of available interventions is given below. Naturally, interventions outlined in the toolbox are merely generic designs, and site-specific adaptations are made where necessary.

Figure 108 - Categories of design interventions.

	Category		Elevation	Soil	Pair with element	Public / private
1		Open water	low	any	2 5	public
2		Blue corridor	low	any	1 3	public
3		Green corridor	high	permeable layer	2 4	public
4		Green infrastructure facility	any	permeable layer	3 6	public / private
5		Infiltration facility	any	permeable layer (Pine barrier)	1	public / private
6		Building-scale interventions	any	any	4	public / private

Based on the six categories displayed in Figure 108, an expansion into sixteen actual design interventions serves to create a more detailed design. Definitions of the interventions are adapted from the AST New Orleans (Deltares, 2016). Note that some types of interventions have earlier been defined in Section 4.1.3.

1. Open water

a. Retention basin
Retention basins, or wet ponds, are permanent bodies of water. As stormwater is collected and detained, the water level rises above the static elevation. This area above the static water line is known as freeboard. The edges of retention ponds are often planted in order to provide additional water quality and aesthetic benefits. See Figure 109.



Figure 109 - Retention basin (source: Deltares, 2016).

b. Constructed wetlands
A constructed wetland is a system consisting of a sediment forebay and one or more permanent stormwater collection zones with emergent aquatic vegetation covering a significant portion of the basin. These facilities collect and treat substantial amounts of runoff and tend to be a minimum of 5,000 square feet in area and has an outflow connection. See Figure 110.



Figure 110 - Constructed wetlands (source: Deltares, 2016).

2. Blue corridor

a. Open canal
An open canal is a permanent linear water body that serves multiple purposes. Its main function is to convey water across an area, but recreation and aesthetic value are relevant properties as well. See Figure 111.



Figure 111 - Open canal (source: Unsplash, 2019).

3. Green corridor

a. Bioswale
Bioswales are depressed planted areas with overflow structures that collect, detain, infiltrate, and filter runoff. In addition, bioswales are also conveyance facilities (linear systems) that are greater in length than width. Due to their efficacy in filtering and removing pollutants from stormwater runoff, these features are commonly located adjacent to impervious areas that receive substantial amounts of automotive use such as parking lots or roadways. Depending on site constraints the construction of a bioswale can take several forms. See Figure 112.

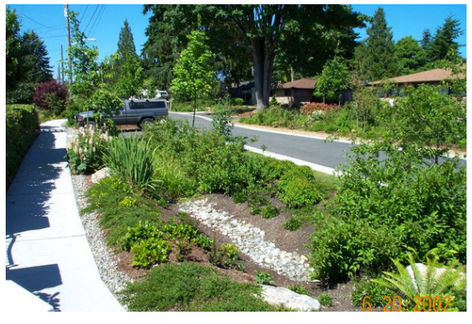


Figure 112 - Bioswale (source: The Nature Conservancy, N.D.).

Figure 113 - Grassed swale (source: Keltic Engineering, N.D.).



b. Grassed swale
A grassed swale is shallow depressed conveyance channel with gently sloped sides designed to temporarily store and slow down runoff in order to remove solid matter and pollutants from the runoff. Unlike a bioswale, these facilities are typically seeded with turf grasses. Swales contain an overflow or outfall connection. See Figure 113.

4. Green infrastructure facility

Figure 114 - Dry detention pond (source: McPhillips, 2019).



a. Dry detention pond
Dry detention ponds are excavated areas that are designed to detain a prescribed amount of stormwater runoff before reaching an overflow elevation that allows for excess runoff to be discharged to an outfall. In absence of rain these facilities are dry and can be fully planted with native plant species or simply turf grasses. See Figure 114.

Figure 115 - Rain garden (source: NORA Green, N.D.).



b. Rain garden
Rain gardens are stormwater detention features that collect, detain, infiltrate, and filter stormwater runoff prior to releasing it to a storm sewer system via an overflow or discharge mechanism. These facilities typically feature both surface level (freeboard) and subsurface stormwater detention. The cross section of a rain garden moving from the surface level down is most commonly as follows: planting (trees & native shrubs), mulch layer, rain garden soil, aggregate bridging course, aggregate subbase, pipe underdrain, undisturbed native soil. See Figure 115.

Figure 116 - Water square (source: Deltares, 2016).



c. Water square
Water squares are public plazas that manage stormwater during rain events. Water squares can integrate interpretive elements into the design that illustrate its function of managing water. Depending on weather conditions at any time, a water square can be either entirely full or not contain any water at all. See Figure 116.

5. Infiltration facility

a. Infiltration well
By perforating a poorly drained top soil with vertically placed tubes, water can infiltrate to deeper, better drained soils. However, the hydrological implications for groundwater flow have to be understood before such an intervention is made. See Figure 117.

b. Pervious pavement
Pervious pavement in its many variations contain void space on the surface that allows water to pass through the pavement layer into the subbase below. In addition to reducing stormwater runoff and providing detention with its subbase, pervious pavement filters pollutants such as suspended solids and heavy metals. See Figure 118.

c. Infiltration boxes
These modular underground structures are used to detain, retain, and infiltrate stormwater on site. A major benefit of these facilities is the ability to maximize usable land for functions, such as a parking lot, while managing stormwater within the subgrade below. See Figure 119.

d. Infiltration trench
An infiltration trench, also known as a French drain, is a linear feature used to reduce stormwater runoff and improve water quality. These shallow excavated trenches are filled with aggregate or crushed stone that is designed to allow for stormwater to infiltrate the ground plane and ultimately percolate though permeable soils into the groundwater. See Figure 120.

6. Building-scale measures

a. Green roof
A green roof is a multi-layered roof system that is partially or entirely covered with vegetation. Extensive green roofs have a maximum depth of six (6) inches and is a layered system containing growing media, waterproofing membrane, drainage, and often irrigation components. Intensive green roofs have a larger minimum depth than their counterpart extensive green roofs. Extensive green roofs can support groundcovers and shallow root plant material, and therefore require less structural support and reduced maintenance when compared to intensive green roofs. See Figure 121.

b. Blue roof
A blue roof is a roof designed to store water, and depending on the design can provide a number of benefits. Blue roofs can be designed for surface storage, storage within or beneath a pervious media or modular surface, or below a raised decking surface or cover. Blue roofs that are used for temporary rooftop storage can be classified as active or passive depending on the types of control devices used to regulate drainage of water from the roof. See Figure 122.

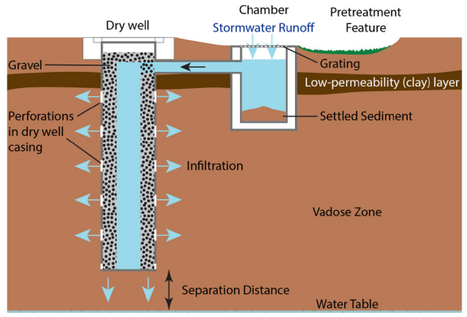


Figure 117 - Infiltration well (source: Edwards and Mandler, N.D.).



Figure 118 - Pervious pavement (source: Pate, 2019).



Figure 119 - Infiltration boxes (source: Deltares, 2016).



Figure 120 - Infiltration trench (source: Deltares, 2016).



Figure 121 - Green roof (source: Deltares, 2016).



Figure 122 - Blue roof (source: Deltares, 2016).



Figure 123 - Rainwater harvesting (source: Board of Water Supply, 2019).



Figure 124 - Cistern (source: Deltares, 2016).

c. Rainwater harvesting
Rainwater harvesting is the collection and storage of stormwater for reuse on site. This is most commonly be achieved by capturing runoff from the roof of a building. The collection structures can take on multiple forms and be installed either above ground or in the subsurface. Depending on its source and treatment, the harvested water can be reused on site. See Figure 123.

d. Cistern
Cisterns are essentially large rain barrels with capacities that typically range from 100 to 10,000 gallons, although much larger systems are no exception. These stormwater facilities, which can be sited either above ground or buried subsurface, collect and temporarily store runoff from rooftops and adjacent impervious surfaces. The collected runoff is often reused as irrigation. If not reused, the collected runoff is either allowed to infiltrate into the ground or it is discharged through an outfall connection. See Figure 124.

As a first step in translating generic design principles into spatial terms, Figure 126 shows the applicability of categorized measures within the project area. This map is based on the 'slow, store & drain' (vasthouden, bergen & afvoeren) principles developed by the Commissie Waterbeheer 21e eeuw (2000), which represents a threefold approach to managing stormwater. Figure 125 shows a diagrammatic overview of the slowing, storing and drain principles.

The first component, slowing stormwater, focuses on detaining as much runoff on high ground as possible. This alleviates downstream areas and reduces dependence on external water in times of drought. For this, green infrastructure projects, building scale interventions and green corridors offer the highest potential.

Stormwater that cannot be locally held, must be stored in retention basins. As it is difficult to retain permanent water on higher ground, storage is concentrated in lower areas. In the case of New Orleans, permanent retention ponds and open canals offer opportunities for significant storage on lower ground.

The third step, discharging runoff, becomes relevant when runoff cannot be locally detained or stored in retention basins. As Orleans Lakeside lies below sea level, eventually most runoff has to be discharged to Lake Pontchartrain. However, as the SDF curves in Appendix A show, installing bigger pumps at some point does not yield better results.

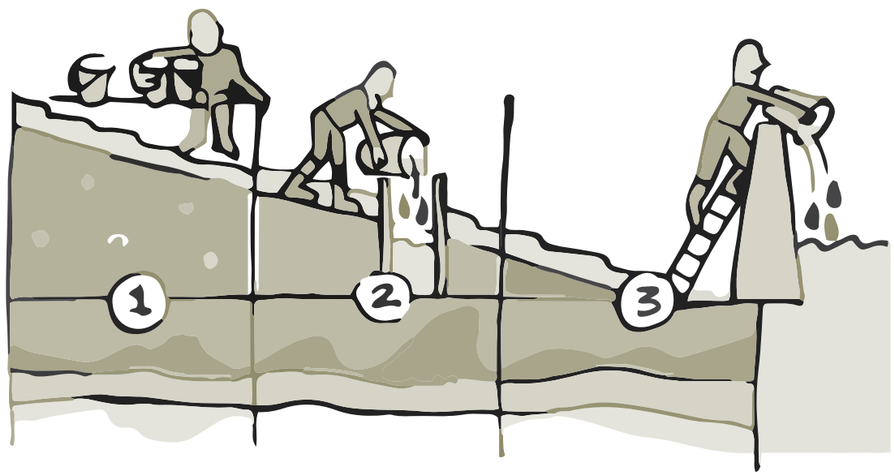


Figure 125 - Slow, store & drain principles (source: Commissie Waterbeheer 21e eeuw, 2000).

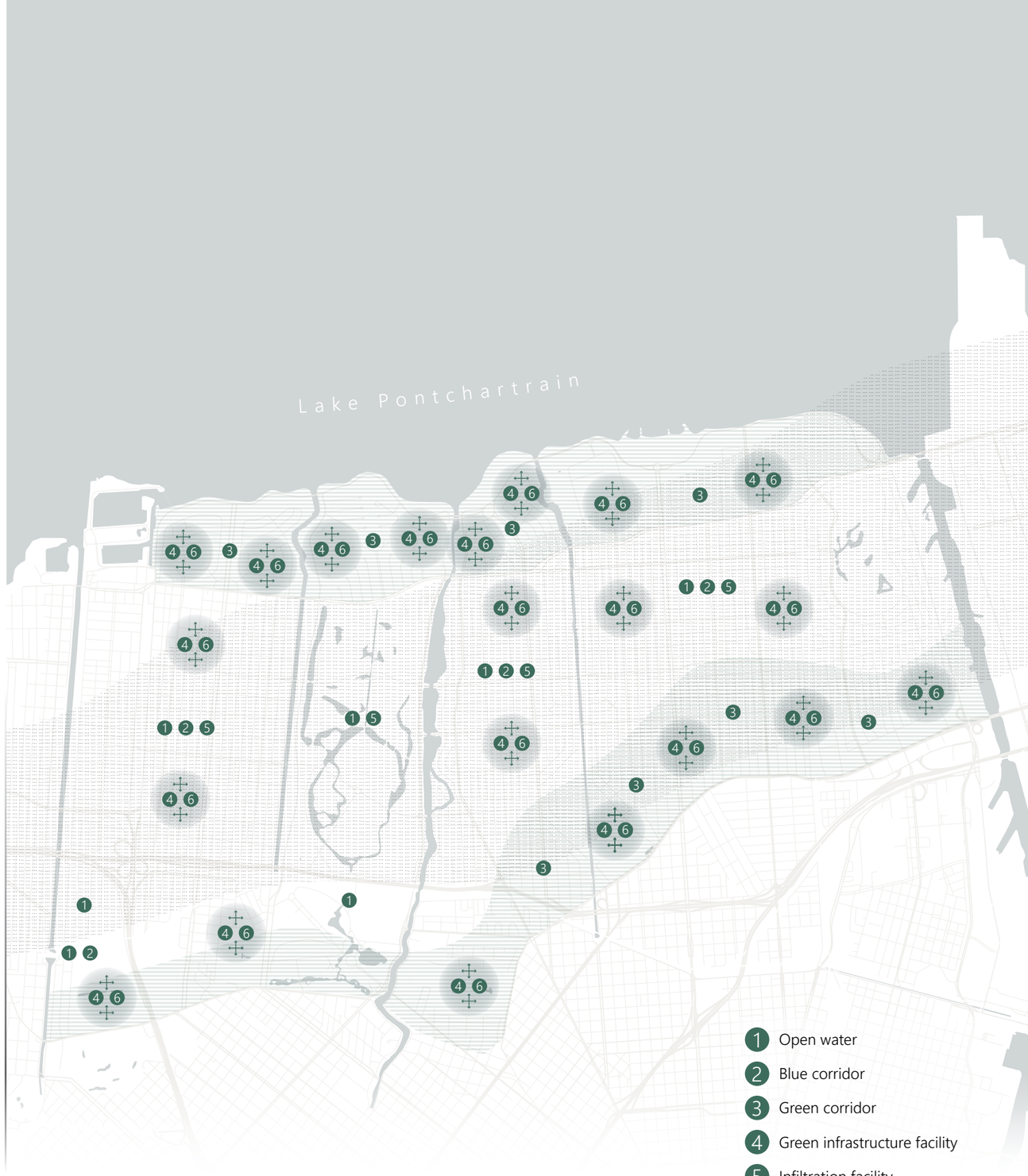


Figure 126 - Suitable locations for interventions.

Water Quality

Good water quality results in a healthy water system which is safe for humans and animals to enjoy. Furthermore, it is a major determinant for public acceptation of adaptation measures. This project considers three major aspects of water quality:

- Salinity
- Eutrophication
- Spawning conditions for mosquitos

Salinity is caused by seepage from Lake Pontchartrain; an excessive salinity makes it difficult for plants to grow. Eutrophication is caused by nutrient-rich runoff that ends up in open water without treatment. This could lead to anaerobic conditions in surface water, which is disastrous for the ecology. Finally, spawning conditions for mosquitos should be minimized in the designed hydrological system. This can be achieved by good circulation, brackish water and introducing natural predators. Note: the specifics of deploying natural predators will not be further elaborated; it is assumed that creating a nature-friendly water system, including native vegetation, will support this type of biodiversity.

The three major concerns regarding water quality imply a series of design principles to safeguard water quality:

1. System design has to include proper circulation; dead ends with stagnant water should be avoided. In the case dead-end measures are implemented, circulation must be ensured by inlets.
2. In addition to circulation, other measures might have to be taken regarding mosquito control, such as introducing natural predators.
3. Where possible, natural filters alongside nature-friendly embankments are deployed to reduce biological oxygen demand (BOD) and prevent eutrophication of the surface water.
4. Source control by filtering pollutants in runoff from major roads by bioswales reduces the overall pollution of surface water.

Figure 127 shows the water quality design principles.

Figure 127 - Water quality principles.

Drought effect mitigation

A reimagined polder system has the opportunity to mitigate the effects of drought on the built environment. In Orleans Lakeside, compaction and oxidation of organic soil is the primary cause of subsidence (van Asselen et al., 2019). Preventing further oxidation of organic matter by retaining high groundwater levels is an effective measure to mitigate subsidence and associated damages. This advocates for the implementation of open water bodies, as these hydrological elements stabilize groundwater levels in times of drought. Figure 128 shows a diagrammatic representation of the potential of open water in retaining high groundwater levels.

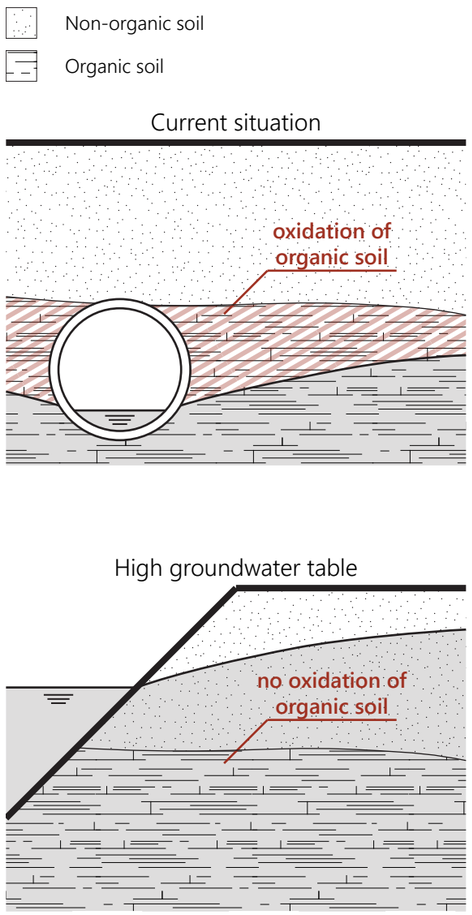
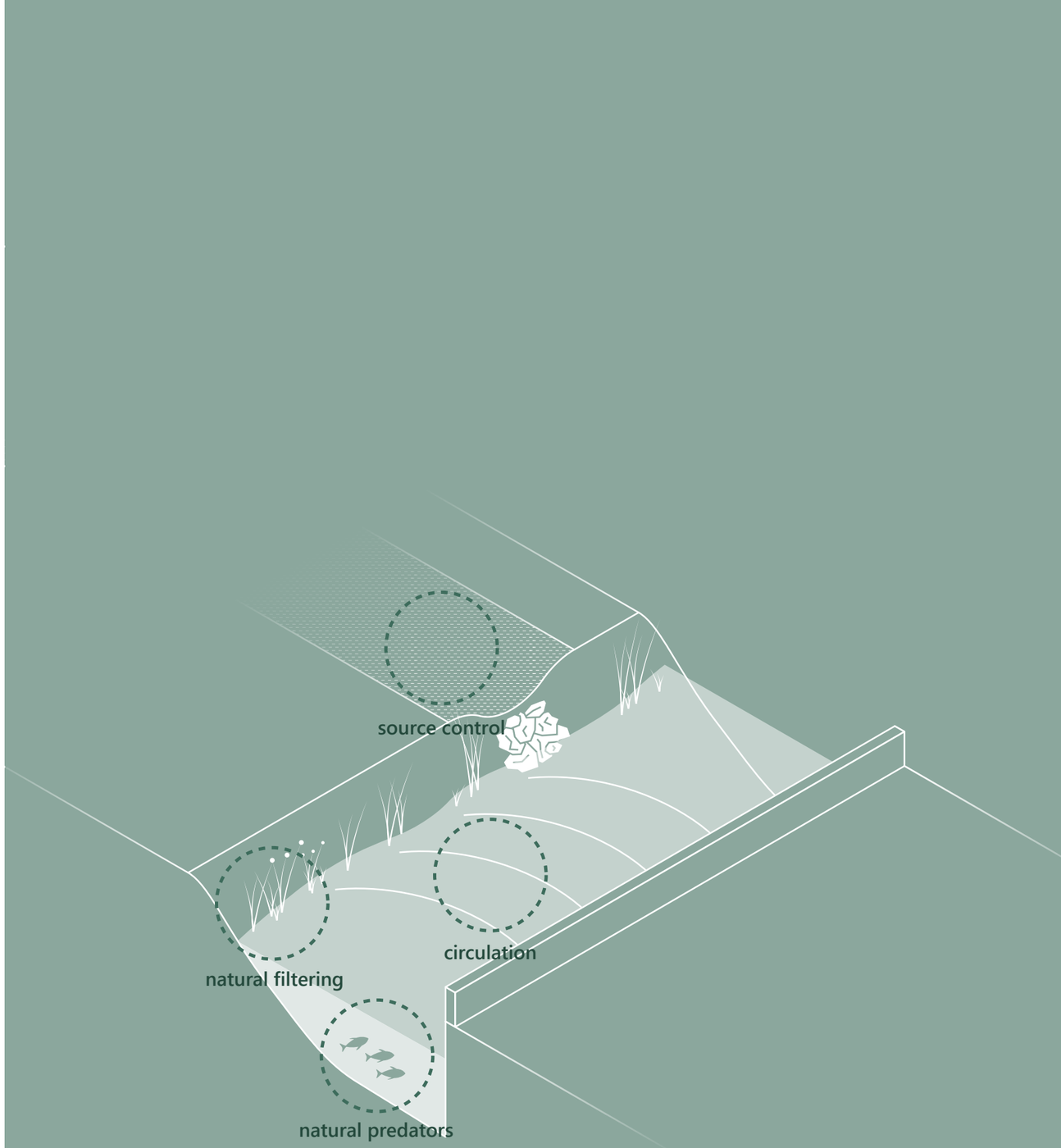


Figure 128 - Mitigation of subsidence through high groundwater table as a result of open water bodies.



2. Connectivity

Based on the ambition to improve both external and internal connectivity of Orleans Lakeside, the connectivity design framework proposes some key new connections between neighborhoods of Orleans Lakeside. As the vision map in Figure 101 illustrates, there is a particular lack of east-east connections. With the outfall canals functioning as obstructions, neighborhoods in between are hardly accessible to each other by means other than the car.

Figure 129 illustrates the new connections that are proposed for Orleans Lakeside. Most new connections relate to the reimagined water system, which revolves around introducing more surface water in the area. The polder system principles as explained in Figure 107 allow for east-west connections.

GOALS

- Achieve better spatial integration, focusing on east-west connections.
- Associate new connections with reimagined water system.



Figure 129 - Connectivity design framework.

3. Spatial Quality

The reimagined water system plays a major role in upgrading deteriorated public space. Tying to the water system is a recreational network of pedestrian and bike routes that connect major parts of the hydrological system and new commercial functions.

This recreation route system adds a new layer to the spatial hierarchy in Orleans Lakeside. Currently, the built environment consists of major throughways with small residential streets directly attached to these arteries (see Figure 59 & Figure 60 in Chapter 3.3). Figure 130 illustrates how the added layer functions within the existing hierarchy. As the recreational routes are located in between major roads, they allow for a network of spaces that are pleasant to reside in.

Regarding the perception of public space, the goal is to reintroduce the wetland identity of Orleans Lakeside; to move towards a more natural system in which the urban space becomes legible as settlement in marshland. This results in an interesting offset between organic shapes found in nearby wetlands and the orthogonal urban grid. Given the rigid grid pattern of the entire urbanized area of Orleans Lakeside, the approach is not to object against a geometrical layout as a whole, but rather to enrich the grid with interesting exceptions.

Figure 131 illustrates a map of patterns that introduce more interesting spaces within the grid. Generally, the plan aims to create an interplay between open and closed spaces, using green and blue infrastructure as its components. Wide boulevards belonging to major throughways are left open to signify their importance. In contrast, on the mid-level hierarchy, streetscapes containing the recreational route system have a closed character that all lead towards an open water body. Hence, by travelling through the new recreational network, one experiences alternating closed and open spaces.

GOALS

- Reintroduce wetland identity to Orleans Lakeside
- Enrich the grid with new destinations

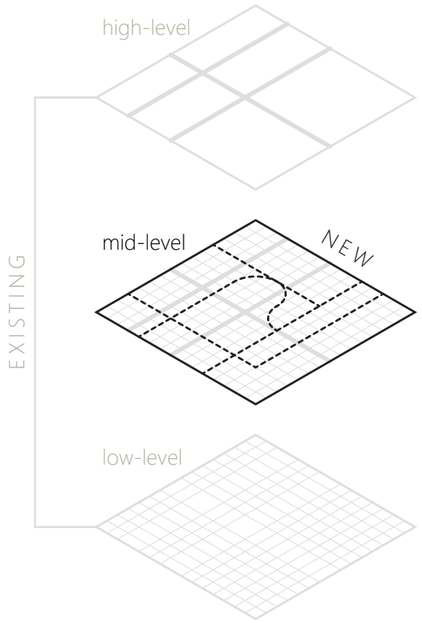


Figure 130 - Enrichment of grid with mid-level hierarchy.



Figure 131 - Recreational routes design framework.

4. Distribution of functions

GOALS

- Add employment through new local and regional functions.
- Connect new programming to the reimagined water system

One of the primary analysis conclusions, reflected in a core vision principle, is that a higher functional diversity would increase resilience and, when tied to the water system, could add value to residents. Hence, the goal of the functional design framework is to enrich the programming of New Orleans with both regional and local functions that are related to the reimagined water system.

Residential functions

Regarding residential functions, the focus of the design framework is on introducing new living environments. In light of stagnation, neither a significant increase or decrease in offered housing is projected. However, a more diverse offer of housing will increase resilience and introduce different target groups to the area. Consequently, this framework advocates for a partial replacement of single-family dwellings to multi-family apartment buildings.

Non-residential functions

The design framework for distributing non-residential functions acknowledges a distinction between two groups: regional functions and local destinations. Regional destinations attract both regional and local customers and are therefore situated alongside major thruways. Following functions, however, only target local customers and are therefore located on the mid-level recreational route as described earlier.

Figure 132 combines the plan for introducing new housing typologies with local and regional functions into the functional design framework. As the map shows, a significant portion of the functions are already existing; they would only have to be reconfigured corresponding to their regional or local character.



Figure 132 - Functional design framework.

5. Evacuation

The goals of the evacuation system are twofold: upgrading the existing evacuation system to enhance road accessibility during evacuation and providing local means for vertical evacuation.

Major roads should be accessible during moderate flooding to increase their benefit once the severe weather event has started. Although most evacuation will take place prior to the event, raised roads will make it easier for emergency services to access key locations in the city.

Perhaps more importantly, this evacuation design framework introduces local shelters for vertical evacuation, in both areas of low and high elevation. On high ground, sheltering opportunities are sought at educational campuses, since these facilities are capable of handling a large crowd. Furthermore, the northern strip of raised land is suitable for local sheltering. On low ground, soil that is excavated to create open water bodies is locally used to create mounds. Vertical evacuation is particularly feasible in these locations. Also, intersections of major streets provide suitable, accessible locations for vertical sheltering. Figure 133 shows the evacuation framework.

GOALS

- Upgrade existing evacuation system.
- Provide opportunities for vertical evacuation.

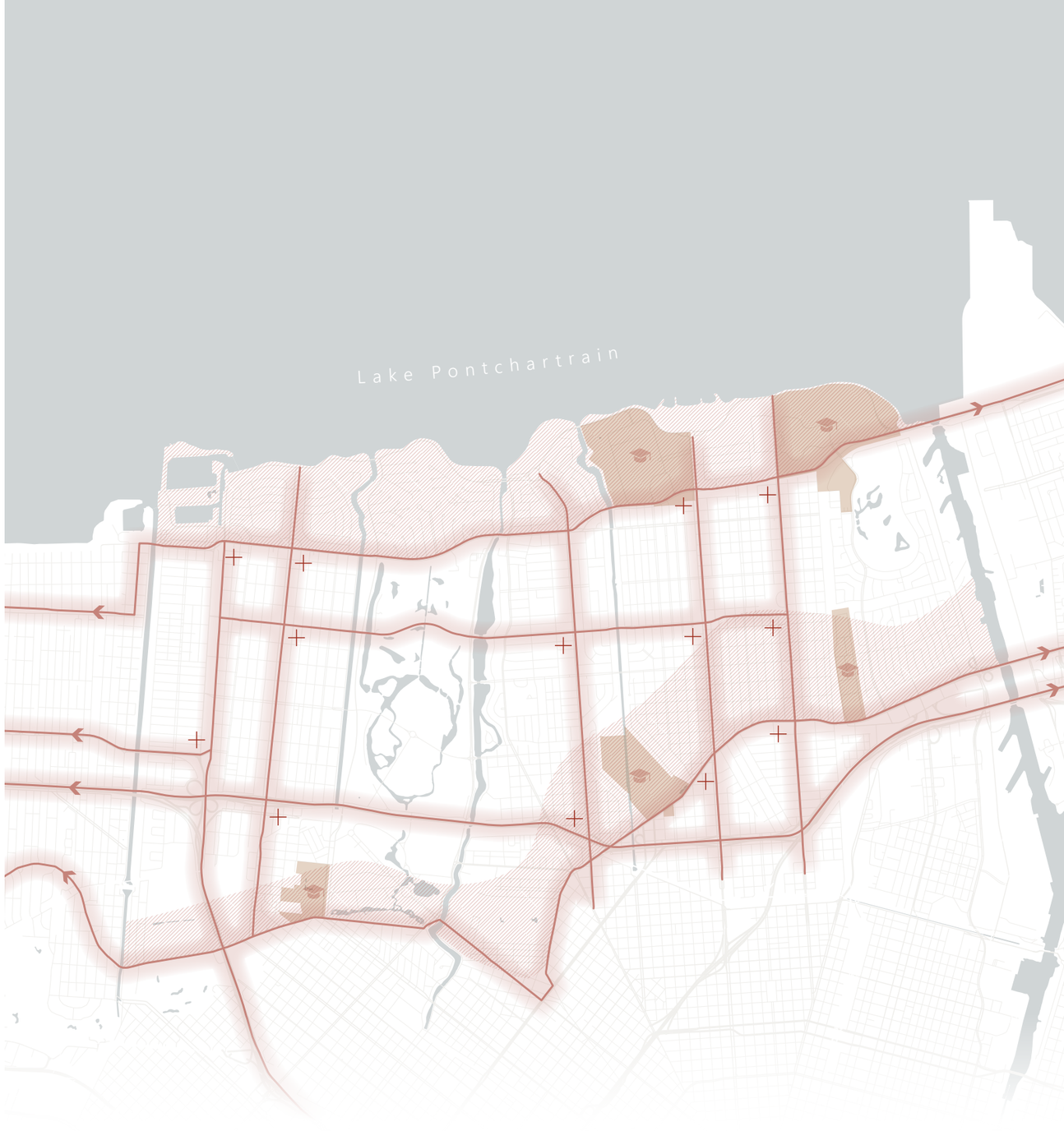


Figure 133 - Evacuation framework.

7 Design

7.1 Hydrological design
7.2 Macro-scale design
7.3 Micro-scale design
7.4 Demonstration project
7.5 Design evaluation
7.6 Implementation

This chapter elaborates on the combined hydrological and urban design for Orleans Lakeside on multiple scales. It is the consolidation of the composed design framework of the previous chapter into actual designs. On the macro scale, this chapter presents an elaborate hydrological design for Orleans Lakeside, as well as an urban design in which the merger of interest comes forward.

On smaller scales, this chapter shows typological designs of newly introduced living environments that are much more centered around water. A demonstration project, in which a set of interventions come together, serves to show how the large-scale design unfolds on a smaller scale.

Finally, this chapter concludes with a section on implementation and phasing. This segment elaborates on the proposed order of interventions, and which projects could easily kickstart development.

Evaluation framework

Evaluation criteria are introduced to assess whether the proposed designs are successful in improving on key issues for Orleans Lakeside. It is critical to answering the main research question, as the capacity to merge different interests into one design is one of the primary goals of this research. Evaluation of the design consists of two parts. The first component of the evaluation is based on the fundamental principles for the vision earlier outlined in Chapter 5, which are reduced to the evaluation framework given in Figure 134. The second component relates to the feedback given by different groups of stakeholders during visits to New Orleans.

Figure 134 - Evaluation framework based on the vision.

Engineering	
Threshold capacity	Does the design cover a T10 rainstorm?
Coping & Recovery capacity	Does the design mitigate damage during flooding and does it improve recovery capacities?
Adaptive capacity	Does the design promote flexibility?
Design	
Improved spatial integration	Does the design make Orleans Lakeside more spatially connected, both internally and externally?
Enhanced quality of public space	Does the design increase the quality of public space by offering a high-quality urban environments?
Added local and regional destinations	Does the design add local and regional destinations as to provide a more diverse programming?

7.1 Hydrological design

Using the hydrological design framework layer presented in Section 6.2.1, this section elaborates on the specifics of the hydrological design. It contains an approach to solving the water assignment for Orleans Lakeside, as well as the final hydrological design including consideration for water quality and subsoil. The section concludes with representative street section typologies to show how certain interventions can be solved in the available space.

7.1.1 Solving the water assignment

In this section, the tools from the hydrological design toolbox in Section 6.2.1 are consolidated into a design for solving the water assignment. While Figure 134 provides a first step in the translation to the spatial domain, this subsection presents a detailed plan for each catchment in which the distribution of measures is configured optimally. The modelling exercise in Section 4.1.2 gave an indication of the most vulnerable parts of the system, as well as the required storage capacity for each catchment. Figure 135 reiterates the main conclusions from the vulnerability analysis.

The hydrological design presented in this section is valid for a T10 rainstorm. While more intense rainstorms are not rare in New Orleans, there will not be made elaborate designs for these storms. However, a brief paragraph in the reflection serves to give an indication of the design approach for larger rainstorms.

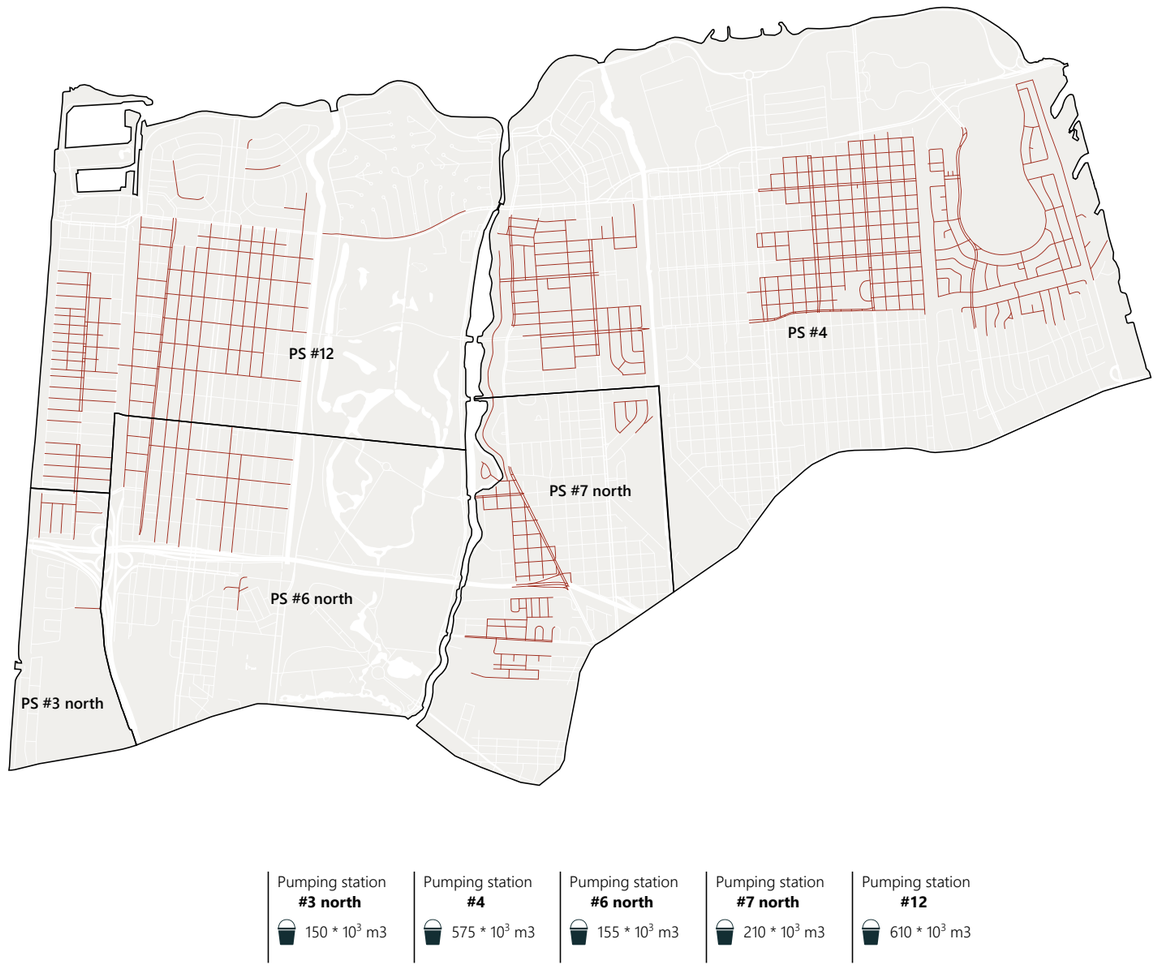
Procedure

As Orleans Lakeside consists of five pumping station catchments, the same procedure for solving the water assignment is repeated a total of five times. The following steps are taken to come to produce a hydrological design:

1. Key catchment characteristics. An overview of key catchment characteristics provides the first steps towards a design.
2. Flooding analysis. The qualitative and quantitative flooding analysis of Figure 135 provides information on the amount of required storage, as well as the most vulnerable spots.
3. Maximization method. Using GIS data, the maximum potential storage of each measure in the toolbox is determined. This provides insight in the maximum possible contribution towards the water assignment, and whether the focus should be on private or public land. This maximization method yields the absolute maximum potential and is therefore not realistic. For instance, the maximization for infiltration boxes calculates the available storage in case 100% of all paved area (including parking lots) are fitted with infiltration boxes. This step is merely useful to give direction to the design by showing which measures should be emphasized.
4. Configuration of measures. Using an iterative approach, and considering the goals of other layers in design (merger of interest), a final hydrological design is made for each catchment using a configuration diagram. This scheme shows to what extent measures can be coupled and if they have estimated benefits in terms of water quality and drought mitigation.

In order to simplify the process, the maximization method uses the assumptions outlined in Table 6.

Figure 135 - Most vulnerable parts of Orleans Lakeside to pluvial flooding.



Measure	Assumption for maximization	
1.1	Available public area	Public parks and existing open water.
	Available private area	Vacant lots.
	dH(max)	1 meter. Balance between water storage capacity and subsidence mitigation. This amount retains groundwater level at a high level.
1.2	Storage	Is calculated as part of open water, so no additional storage is attributed to this intervention.
2.1	Available public area	Neutral grounds of major boulevards.
	Available private area	-
	dH(max)	1 meter. Balance between water storage capacity and subsidence mitigation. This amount retains groundwater level at a high level.
3.1	Available public area	Total length of streets multiplied with a variable width depending on the street profile.
	Available private area	-
	Available depth	Slightly less available depth than grassed swale due to dense vegetation. Fixed depth of 0.2 meter (0.67 foot).
3.2	Available public area	Total length of streets multiplied with a variable width depending on the street profile.
	Available private area	-
	Available depth	Fixed depth of 0.3 meter (1 foot) due to safety concerns.
4.1	Available public area	Neutral grounds of major boulevards, surface area of public parks and educational campus terrain.
	Available private area	Vacant lots.
	Available depth	Maximum of 0.5 meter due to safety concerns.
4.2	Number of available entities	Number of parks and vacant lots.
	Storage per unit	Storage for large, public facility is estimated to be 300 m^3, those for private gardens is estimated to be 2 m^3.
4.3	Available public area	Surface area of public parks.
	Available private area	-
	dH(max)	dH(max) of 1 meter is assumed for all water squares.
5.1	Available public area	Same surface area as intervention 1.1 (open water).
	Available private area	-
	Available depth	Total storage for an average weather event is 0.6 inches, based on the Adaptation Support Tool (AST).
5.2	Available public area	Surface area of streets, in addition to 10% of other paved surface area.
	Available private area	Estimated to be 90% of other paved area, excluding surface area of streets.
	Available depth	Total storage for an average weather event is 0.6 inches, based on the Adaptation Support Tool (AST).
5.3	Available public area	Surface area of streets, in addition to 10% of other paved surface area.
	Available private area	Estimated to be 90% of other paved area, excluding surface area of streets.
	Available depth	Storage for with one layer of crates is 0.65 meter, based on the Adaptation Support Tool (AST). Multiple layered crates are not considered.
5.4	Available public area	Total length of streets multiplied with a total width of 1.5 meter.
	Available private area	-
	Available depth	Total storage for an average weather event is 0.6 inches, based on the Adaptation Support Tool (AST).
6.1	Available public area	Estimated as 10% of total building surface area in Orleans Lakeside.
	Available private area	Estimated as 90% of total building surface area in Orleans Lakeside.
	Available depth	1 millimeter.
6.2	Available public area	Estimated as 10% of total building surface area.
	Available private area	Estimated as 90% of total building surface area.
	Available depth	Estimated as 0.03175 meter (1.25 inch).
6.3	Number of available entities	Total building count.
	Storage per unit	Average, commercially available rain barrel has a capacity of 200 liters (0.2 m^3, 7 cf). Assumed maximum of one cistern per household.
6.4	Number of available entities	Total building count.
	Storage per unit	An average, commercially available cistern has a capacity of 5000 liters (5 m^3, 177 cf). Assumed maximum of one cistern per household. Deviations may occur during design.

Table 6 - Assumptions used for the maximization of hydrological interventions.

Pumping station catchment 3 north

Key characteristics:
Surface area: 4,299,785 m^2 (815 acres)
Water assignment: 150,000 m^3 (121.6 acre-foot)

Design principles:
- No retention or canals, no open water;
- Focus on underground storage: infiltration crates at locations of severe flooding;
- Deploy schools and fairground get responsibility for retaining stormwater;
- Use (bio)swales to slow runoff.

SWMM determined severe flooding near Bayou St. John.

The maximization of measures (Figure 137) shows a large potential for open water, dry detention ponds and rain gardens due to abundant vacant land. In addition, considerable street surface area holds a large potential for infiltration crates.

In the configuration for pumping station catchment 3 north (Figure 138), emphasis lies on the use of infiltration boxes and rain gardens. Sloping ground inhibits the use of open water.

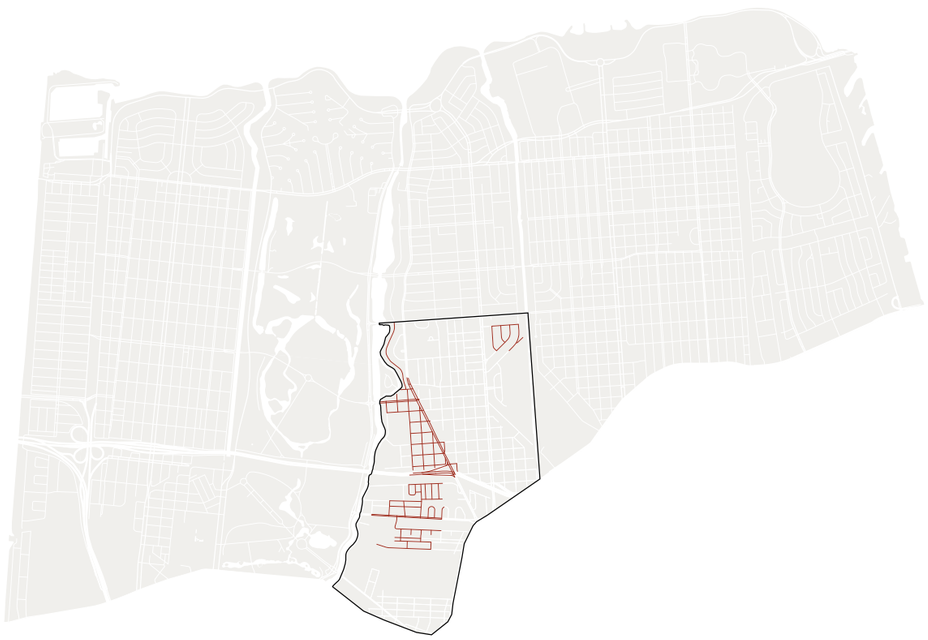


Figure 136 - Qualitative flooding based on SWMM analysis.

Figure 137 - Quantification of maximum storage per measure. For the assumptions and reasoning behind these calculations, see Section 7.1.1.

Cat.	Intervention	Available public area [m^2]	Available private area [m^2]	Available depth or freeboard [m]	Number of available entities [-]	Storage per unit [m^3]	Max. storage capacity (public)	Max. storage capacity (private)	Max capacity as % of water assignment
1.1	Retention basin	93,030	118,954	1	-	-	93,030	118,954	141.3
1.2	Constructed wetlands	93,030	0	-	-	-	0	0	0
2.1	Open canal	33,040	0	1	-	-	33,040	0	22
3.1	Bioswale	49,307	0	0.2	-	-	9,861	0	6.6
3.2	Grassed swale	49,307	0	0.3	-	-	14,792	0	9.9
4.1	Dry detention pond	33,397	118,954	0.5	-	-	24,767	59,477	56.2
4.2	Rain garden	-	-	-	201	300	60,300	4,804	43.4
4.3	Water square	357	0	1	-	-	357	0	0.2
5.1	Infiltration well	93,030	0	0.01524	-	-	1,418	0	0.9
5.2	Pervious pavement	1,115,556	1,775,922	0.01524	-	-	17,001	27,065	29.4
5.3	Infiltration boxes	1,115,556	1,775,922	0.65	-	-	725,112	1,154,350	1,253
5.4	Infiltration trench	49,307	0	0.01524	-	-	751	0	0.5
6.1	Green roof	65,238	587,145	0.001	-	-	66	591	0.4
6.2	Blue roof	65,238	587,145	0.03175	-	-	2,071	18,642	13.8
6.3	Rainwater harvesting	-	-	-	2,983	0.2	0	597	0.4
6.4	Cistern	-	-	-	2,983	5	0	14,915	9.9

500 m 1 km

Figure 138 - Maximum capacity of measures and final configuration for pumping station 3.

Cat.	Intervention	Maximum [m³]	Drought mitigation	Water quality	Actual amount
1.1	Retention basin	211,983	+	0	0 m³
1.2	Constructed wetlands	0	+	++	0 m³
2.1	Open canal	33,040	0	0	0 m³
3.1	Bioswale	9,861	+	++	3,760 m³
3.2	Grassed swale	14,792	+	+	4,073 m³
4.1	Dry detention pond	84,243	+	+	26,134 m³
4.2	Rain garden	65,108	++	++	42,000 m³
4.3	Water square	357	0	0	0 m³
5.1	Infiltration well	1,418	++	0	0 m³
5.2	Pervious pavement	44,066	++	+	3,033 m³
5.3	Infiltration boxes	1,879,461	++	0	83,148 m³
5.4	Infiltration trench	751	++	+	0 m³
6.1	Green roof	656	0	+	59 m³
6.2	Blue roof	20,713	0	0	318 m³
6.3	Rainwater harvesting	597	0	0	30 m³
6.4	Cistern	14,915	0	0	0 m³
				TOTAL	**162,555 m³**

Synergy
No Interaction
Competing for space

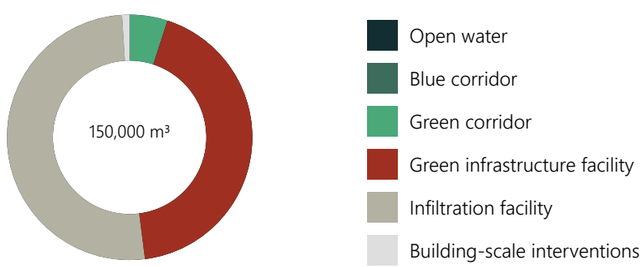


Figure 139 - Configuration of hydrological measures for pumpnig station 3.



Figure 140 - Hydrological design for pumping station catchment 3.

Pumping station catchment 4

Key characteristics:
Surface area: 15,610,749 m^2 (3858 acres)
Water assignment: 575,000 m^3 (466.2 acre-foot)

Design principles:
- Utilize vacant lots and public parks for creating open water;
- Utilize wide boulevards to create canals that connect open water bodies;
- Give leading role to educational campuses: require minimum of 2.5 inch of storage (double of current municipal standard of 1.25 inch);
- Slow runoff from higher ground using north-south bioswales and grassed swales.

SWMM determined severe flooding in the vast majority of pumping station catchment 4; the lowest area is the most vulnerable.

The maximization of measures (Figure 142) shows a high potential for open water due to wide street profile and the presence of public parks. Furthermore, university campuses hold a large potential in the form of dry detention ponds. As a result of the high amount of vacant lots, rain gardens have a high potential as well. Finally, as with all catchments, infiltration boxes have a high potential due to the considerable surface area of streets.

In the final configuration for pumping station catchment 4 (Figure 143), open water (retention basins, canals) represents a large share of the water assignment. Using areas of concentrated vacant lots and public parks, significant water storage is created in the most vulnerable parts. Educational campuses detain large volumes on high ground, while infiltration boxes offer significant storage in areas with little available space.

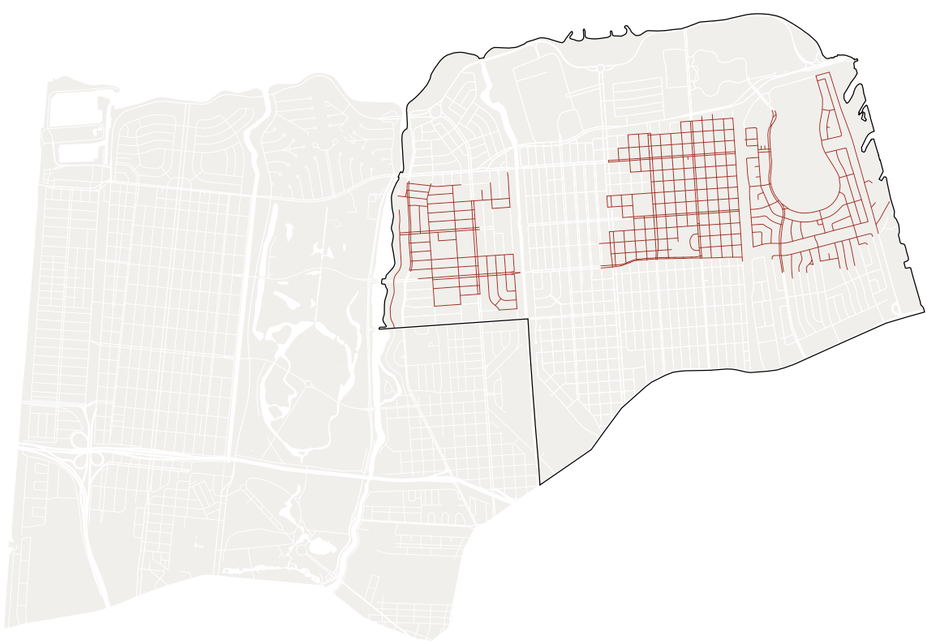


Figure 141 - Qualitative flooding based on SWMM analysis.

Figure 142 - Quantification of maximum storage per measure. For the assumptions and reasoning behind these calculations, see Section 7.1.1.

Cat.	Intervention	Available public area [m^2]	Available private area [m^2]	Available depth or freeboard [m]	Number of available entities [-]	Storage per unit [m^3]	Max. storage capacity (public)	Max. storage capacity (private)	Max capacity as % of water assignment
1.1	Retention basin	316740	0	1	-	-	316,740	0	55.1
1.2	Constructed wetlands	316740	0	-	-	-	0	0	0
2.1	Open canal	176000	0	1	-	-	176,000	0	30.6
3.1	Bioswale	242766	0	0.2	-	-	48,553	0	8.4
3.2	Grassed swale	242766	0	0.3	-	-	72,830	0	12.7
4.1	Dry detention pond	200153	0	0.5	-	-	184,531	0	32.1
4.2	Rain garden	-	-	-	1592	300	512,600	21,654	92.9
4.3	Water square	24153	0	1	-	-	24,153	0	4.2
5.1	Infiltration well	316740	0	0.01524	-	-	4,827	0	0.8
5.2	Pervious pavement	3705261	5834393	0.01524	-	-	56,468	88,916	25.3
5.3	Infiltration boxes	3705261	5834393	0.65	-	-	2,408,420	3,792,356	1078.4
5.4	Infiltration trench	242766	0	0.01524	-	-	3,700	0	0.6
6.1	Green roof	271785	2446065	0.001	-	-	273	2,460	0.5
6.2	Blue roof	271785	2446065	0.03175	-	-	8,629	77,663	15.0
6.3	Rainwater harvesting	-	-	-	13499	0.2	0	2,700	0.5
6.4	Cistern	-	-	-	13499	5	0	67,495	11.7

500 m 1 km

Figure 143 - Maximum capacity of measures and final configuration for pumping station 4.

Cat.	Intervention	Maximum [m³]	Drought mitigation	Water quality	Actual amount
1.1	Retention basin	316,740	+	0	250,000 m³
1.2	Constructed wetlands	0	+	++	62,000 m³
2.1	Open canal	176,000	0	0	96,000 m³
3.1	Bioswale	48,553	+	++	20,000 m³
3.2	Grassed swale	72,830	+	+	18,450 m³
4.1	Dry detention pond	184,531	+	+	79,000 m³
4.2	Rain garden	534,254	++	++	19,000 m³
4.3	Water square	24,153	0	0	7,000 m³
5.1	Infiltration well	4,827	++	0	0 m³
5.2	Pervious pavement	145,384	++	+	1,219 m³
5.3	Infiltration boxes	6,200,776	++	0	83,200 m³
5.4	Infiltration trench	3,700	++	+	366 m³
6.1	Green roof	2,734	0	+	250 m³
6.2	Blue roof	86,292	0	0	1,270 m³
6.3	Rainwater harvesting	2,700	0	0	1,000 m³
6.4	Cistern	67,495	0	0	20,000 m³
				TOTAL	**596,755 m³**

Synergy
No Interaction
Competing for space

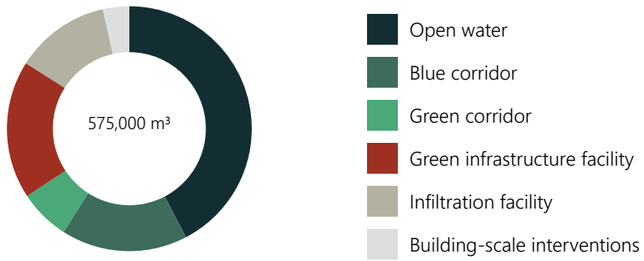


Figure 144 - Configuration of hydrological measures for pumpnig station 4.



Figure 145 - Hydrological design for pumping station catchment 4.

Pumping station catchment 6 north

Key characteristics:
Surface area: 1904046 m² (471 acres)
Water assignment: 155,000 m³ (125.7 acre-foot)

Design principles:
- Focus on infiltration boxes;
- Construct bioswales on cemetery paths to reduce runoff;
- Use cisterns near New Orleans Regional Planning Commission building;
- Widen outfall canal to provide more storage capacity.

SWMM determined flooding to be the most severe in the north of pumping station catchment 6 north.

The maximization of measures (Figure 147) shows a high potential for detention ponds near the highway and infiltration boxes. In addition, widening the 17th Street outfall canal holds potential for water storage. Since there are no wide street profiles available, the potential of canals, bioswales and grassed swales is minimal.

Although the water assignment is small, the little available space results in the focus on underground storage and widening of the 17th Street outfall canal. The final configuration for this catchment is given in Figure 148.



Figure 146 - Qualitative flooding based on SWMM analysis.

Figure 147 - Quantification of maximum storage per measure. For the assumptions and reasoning behind these calculations, see Section 7.1.1.

Cat.	Intervention	Available public area [m²]	Available private area [m²]	Available depth or freeboard [m]	Number of available entities [-]	Storage per unit [m³]	Max. storage capacity (public)	Max. storage capacity (private)	Max capacity as % of water assignment
1.1	Retention basin	41,683	15,440	1	-	-	41,683	118,954	36.9
1.2	Constructed wetlands	41,683	15,440	-	-	-	0	0	0
2.1	Open canal	2,880	0	1	-	-	2,880	0	1.9
3.1	Bioswale	17,442	0	0.2	-	-	3,488	0	2.3
3.2	Grassed swale	17,442	0	0.3	-	-	5,233	0	3.4
4.1	Dry detention pond	110,880	15,440	0.5	-	-	55,440	7,720	40.7
4.2	Rain garden	-	-	-	19	300	113,700	1,330	74.2
4.3	Water square	0	0	1	-	-	0	0	0
5.1	Infiltration well	41,683	0	0.01524	-	-	635	0	0.4
5.2	Pervious pavement	226,834	772,577	0.01524	-	-	3,457	11,774	9.8
5.3	Infiltration boxes	398,518	600,893	0.65	-	-	259,037	390,581	419.1
5.4	Infiltration trench	17,442	0	0.01524	-	-	226	0	0.2
6.1	Green roof	24,147	217,319	0.001	-	-	24	219	0.2
6.2	Blue roof	24,147	217,319	0.03175	-	-	767	6,900	4.9
6.3	Rainwater harvesting	-	-	-	967	0.2	0	193	0.1
6.4	Cistern	-	-	-	967	5	0	4,835	3.1

500 m 1 km

Figure 148 - Maximum capacity of measures and final configuration for pumping station 6 north.

Cat.	Intervention	Maximum [m³]	Drought mitigation	Water quality	Actual amount
1.1	Retention basin	57,123	+	0	50,000 m³
1.2	Constructed wetlands	0	+	++	7,500 m³
2.1	Open canal	2,880	0	0	0 m³
3.1	Bioswale	3,488	+	++	0 m³
3.2	Grassed swale	5,233	+	+	8,640 m³
4.1	Dry detention pond	63,160	+	+	15,500 m³
4.2	Rain garden	115,030	++	++	3,000 m³
4.3	Water square	0	0	0	0 m³
5.1	Infiltration well	635	++	0	0 m³
5.2	Pervious pavement	15,231	++	+	304.8 m³
5.3	Infiltration boxes	649,618	++	0	73,465.6 m³
5.4	Infiltration trench	266	++	+	0 m³
6.1	Green roof	243	0	+	22 m³
6.2	Blue roof	7,667	0	0	50 m³
6.3	Rainwater harvesting	193	0	0	48 m³
6.4	Cistern	4,835	0	0	5000 m³
				TOTAL	**156,030 m³**

Synergy
No Interaction
Competing for space

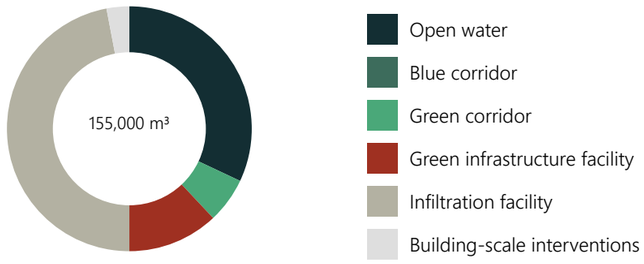


Figure 149 - Configuration of hydrological measures for pumpnig station 6 north.



Figure 150 - Hydrological design for pumping station catchment 6 north.

Pumping station catchment 7 north

Key characteristics:
Surface area: 5,408,624 m² (1337 acres)
Water assignment: 210,000 m³ (170.2 acre-foot)

Design principles:
- Widen City Park lagoons for more storage capacity;
- Construct canals, bio)swales and rain gardens to spread storage capacity evenly across the catchment.

SWMM determined flooding to be the most severe in the northern part of pumping station catchment 7 north.

Due to the abundance of available space for open water in City Park, retention basins hold a large potential. In addition, dry detention ponds, rain gardens and infiltration boxes have a high potential for covering the water assignment.

While City Park offers space for water storage, an even distribution of adaptation measures across the catchment is required. Therefore, storage in City Park is complemented by a canal, swales, rain gardens, dry detention ponds and infiltration crates. The final configuration for this catchment is given in Figure 153.

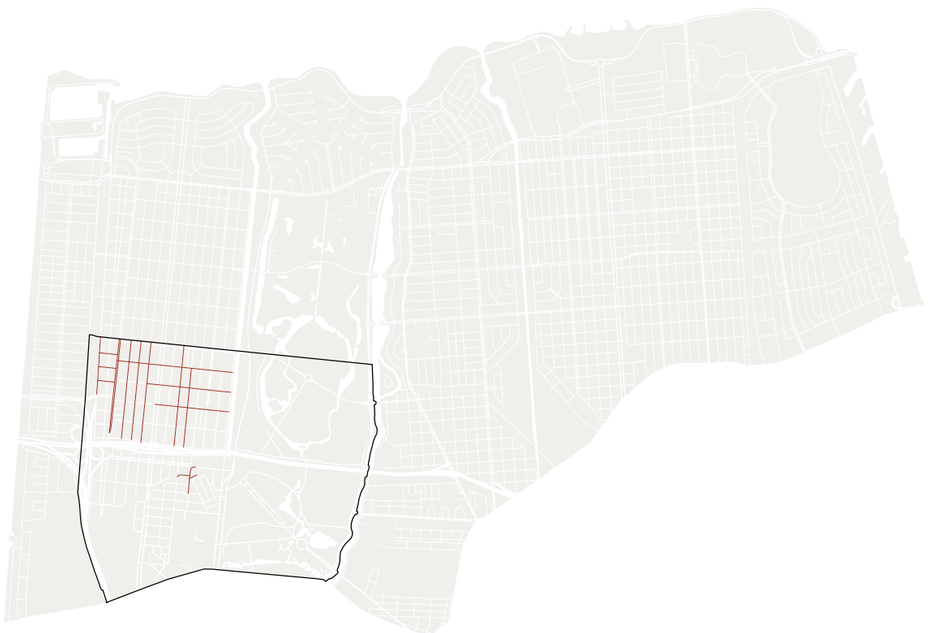


Figure 151 - Qualitative flooding based on SWMM analysis.

Figure 152 - Quantification of maximum storage per measure. For the assumptions and reasoning behind these calculations, see Section 7.1.1.

Cat.	Intervention	Available public area [m²]	Available private area [m²]	Available depth or freeboard [m]	Number of available entities [-]	Storage per unit [m³]	Max. storage capacity (public)	Max. storage capacity (private)	Max capacity as % of water assignment
1.1	Retention basin	2,360,350	72,962	1	-	-	2,360,350	72,962	1,158.7
1.2	Constructed wetlands	2,360,350	72,962	-	-	-	0	0	0
2.1	Open canal	31,600	0	1	-	-	31,600	0	15
3.1	Bioswale	61,707	0	0.2	-	-	12,341	0	5.9
3.2	Grassed swale	61,707	0	0.3	-	-	18,512	0	8.8
4.1	Dry detention pond	2,271,353	72,962	0.5	-	-	1,149,604	36,481	564.8
4.2	Rain garden	-	-	-	133	300	2,263,900	4,801	1,080.3
4.3	Water square	15,753	0	1	-	-	15,753	0	7.5
5.1	Infiltration well	2,360,350	0	0.01524	-	-	35,972	0	17.1
5.2	Pervious pavement	1,337,162	2,601,238	0.01524	-	-	20,378	39,643	28.6
5.3	Infiltration boxes	1,337,162	2,601,238	0.65	-	-	869,155	1,690,805	1.219
5.4	Infiltration trench	61,707	0	0.01524	-	-	940	0	0.4
6.1	Green roof	62,680	564,124	0.001	-	-	63	567	0.3
6.2	Blue roof	62,680	564,124	0.03175	-	-	1,990	17,911	9.5
6.3	Rainwater harvesting	-	-	-	3,547	0.2	0	709	0.3
6.4	Cistern	-	-	-	3,547	5	0	17,735	8.4

500 m 1 km

Figure 153 - Maximum capacity of measures and final configuration for pumping station 7 north.

Synergy
No Interaction
Competing for space

Cat.	Intervention	Maximum [m³]	Drought mitigation	Water quality	Actual amount
1.1	Retention basin	2,433,312	+	0	152,000 m³
1.2	Constructed wetlands	0	+	++	0 m³
2.1	Open canal	31,600	0	0	6,400 m³
3.1	Bioswale	12,341	+	++	13,750 m³
3.2	Grassed swale	18,512	+	+	2,678 m³
4.1	Dry detention pond	1,186,085	+	+	13,927 m³
4.2	Rain garden	2,268,710	++	++	9,000 m³
4.3	Water square	15,753	0	0	0 m³
5.1	Infiltration well	35,972	++	0	0 m³
5.2	Pervious pavement	60,021	++	+	445 m³
5.3	Infiltration boxes	2,559,960	++	0	13,975 m³
5.4	Infiltration trench	940	++	+	23 m³
6.1	Green roof	630	0	+	57 m³
6.2	Blue roof	19,901	0	0	64 m³
6.3	Rainwater harvesting	709	0	0	0 m³
6.4	Cistern	17,735	0	0	0 m³
				TOTAL	**212,318 m³**

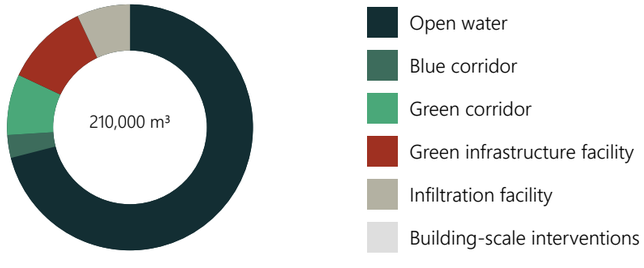


Figure 154 - Configuration of hydrological measures for pumpnig station 7 north.

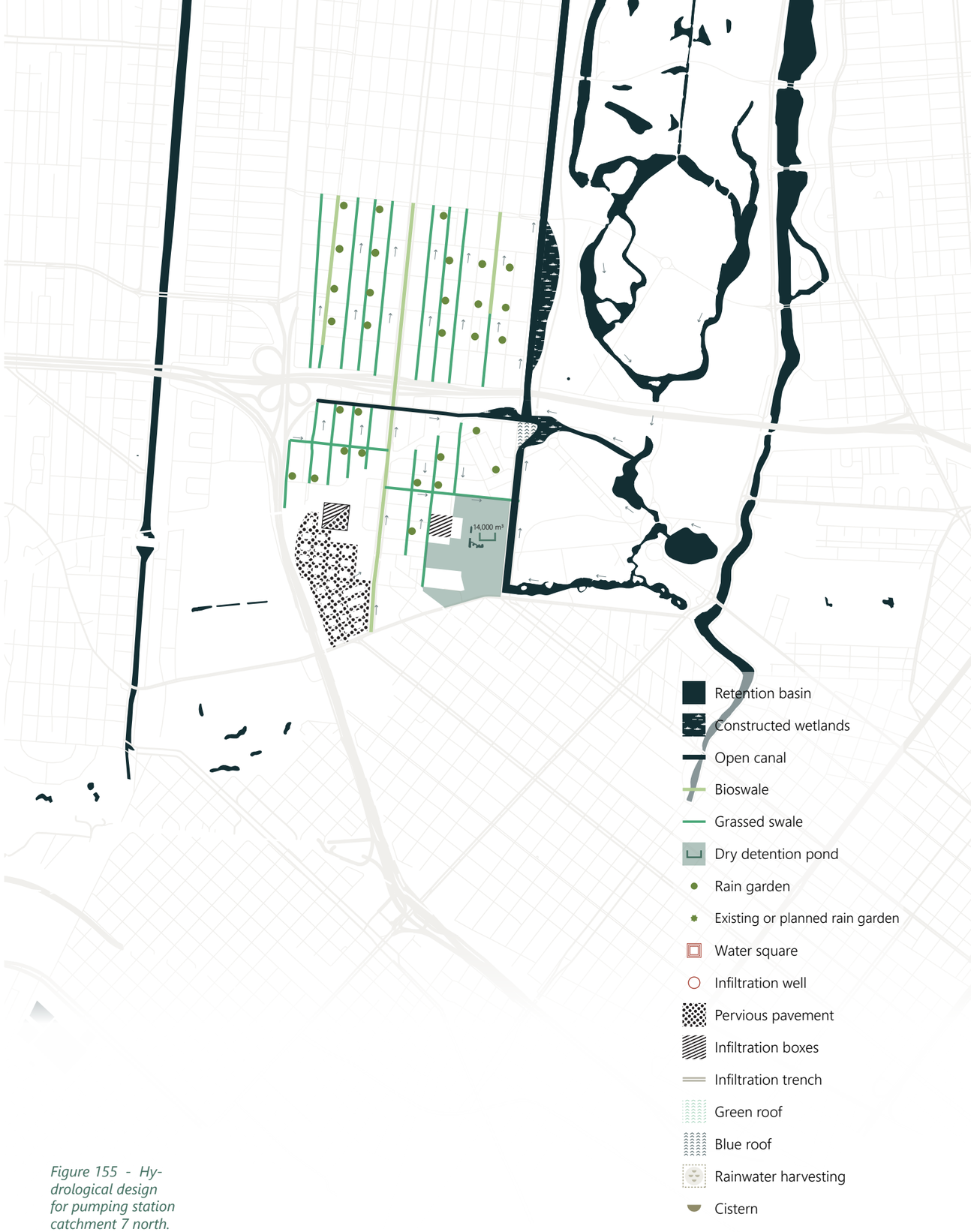


Figure 155 - Hydrological design for pumping station catchment 7 north.

Pumping station catchment 12

Key characteristics:
Surface area: 8,840,763 m² (2185 acres)
Water assignment: 610,000 m³ (494.5 acre-foot)

Design principles:
- Widen City Park lagoons for additional water storage capacity;
- Transform New Basin Canal Park into a permanent water body;
- Connect New Basin Canal Park with 17th Street outfall canal through a system of canals.
- Construct (bio)swales on north-south streets;
- Deploy dry detention ponds to locally store water in Lakeshore – Lake Vista.

SWMM determined heavy flooding in pumping station catchment 12, as most of this basin has a low elevation. Lakeshore - Lake Vista, located in the north of the catchment, stays relatively dry.

In this catchment, the largest potential storage is offered by retention basins, dry detention ponds, rain gardens and infiltration boxes. Water squares and canals offer additional storage potential, albeit to a lesser extent. The potential of measures for this catchment is given in Figure 157.

In the final configuration for this catchment (Figure 158), retention basins and canals represent the vast majority of the required water storage capacity. New Basin Canal Park and wider lagoons in City Park offer a significant contribution to the water assignment, while canals in the west of the catchment connect it to the outfall canal. Infiltration crates, (bio)swales and dry detention ponds have a smaller role in stormwater buffering.

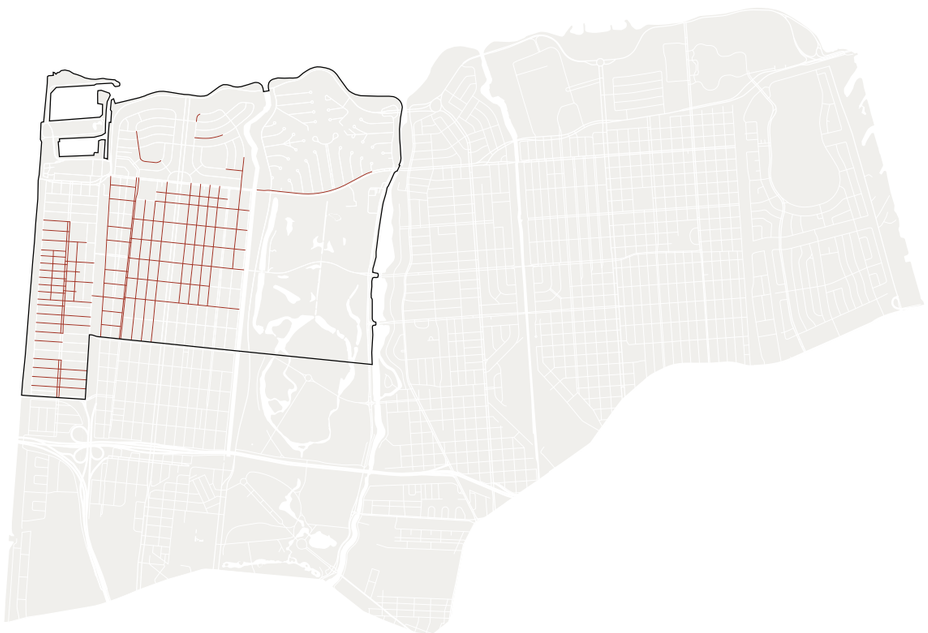


Figure 156 - Qualitative flooding based on SWMM analysis.

Figure 157 - Quantification of maximum storage per measure. For the assumptions and reasoning behind these calculations, see Section 7.1.1.

Cat.	Intervention	Available public area [m²]	Available private area [m²]	Available depth or freeboard [m]	Number of available entities [-]	Storage per unit [m³]	Max. storage capacity (public)	Max. storage capacity (private)	Max capacity as % of water assignment
1.1	Retention basin	2,236,485	364,765	1	-	-	2,236,485	364,765	426.4
1.2	Constructed wetlands	2,236,485	364,765	-	-	-	0	0	0
2.1	Open canal	116,160	0	1	-	-	116,160	0	19
3.1	Bioswale	135,830	0	0.2	-	-	27,166	0	4.5
3.2	Grassed swale	135,830	0	0.3	-	-	40,749	0	6.7
4.1	Dry detention pond	2,040,632	364,765	0.5	-	-	1,020,316	182,383	197.2
4.2	Rain garden	-	-	-	377	300	1,897,100	10,622	312.7
4.3	Water square	140,472	0	1	-	-	140,472	0	23
5.1	Infiltration well	2,236,485	0	0.01524	-	-	34,084	0	5.6
5.2	Pervious pavement	2,036,135	3,836,663	0.01524	-	-	31,031	58,471	14.7
5.3	Infiltration boxes	2,036,135	3,836,663	0.65	-	-	1,323,488	2,493,831	625.8
5.4	Infiltration trench	135,830	0	0.01524	-	-	2,070	0	0.3
6.1	Green roof	137,116	1,234,045	0.001	-	-	183	1,241	0.2
6.2	Blue roof	137,116	1,234,045	0.03175	-	-	4,353	39,181	7.1
6.3	Rainwater harvesting	-	-	-	6,322	0.2	0	1,264	0.2
6.4	Cistern	-	-	-	6,322	5	0	31,610	5.2

500 m 1 km

Figure 158 - Maximum capacity of measures and final configuration for pumping station 12.

Cat.	Intervention	Maximum [m³]	Drought mitigation	Water quality	Actual amount
1.1	Retention basin	2,601,250	+	0	441,000 m³
1.2	Constructed wetlands	0	+	++	85,000 m³
2.1	Open canal	116,160	0	0	27,300 m³
3.1	Bioswale	27,166	+	++	15,860 m³
3.2	Grassed swale	40,749	+	+	37,965 m³
4.1	Dry detention pond	1,202,699	+	+	25,500 m³
4.2	Rain garden	1,907,722	++	++	7000 m³
4.3	Water square	140,472	0	0	3000 m³
5.1	Infiltration well	34,084	++	0	229 m³
5.2	Pervious pavement	89,501	++	+	221 m³
5.3	Infiltration boxes	3,817,319	++	0	55,887 m³
5.4	Infiltration trench	2,070	++	+	160 m³
6.1	Green roof	1,379	0	+	124 m³
6.2	Blue roof	43,534	0	0	250 m³
6.3	Rainwater harvesting	1,264	0	0	126 m³
6.4	Cistern	31,610	0	0	0 m³
				TOTAL	**614,522 m³**

Synergy
No Interaction
Competing for space

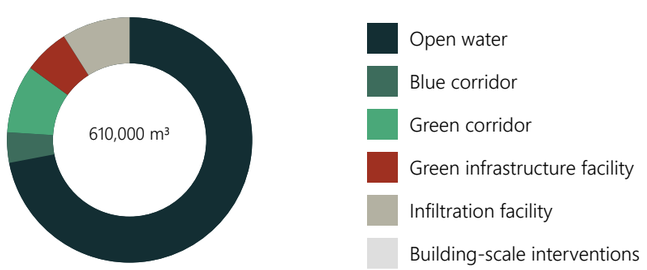


Figure 159 - Configuration of hydrological measures for pumpnig station 12.

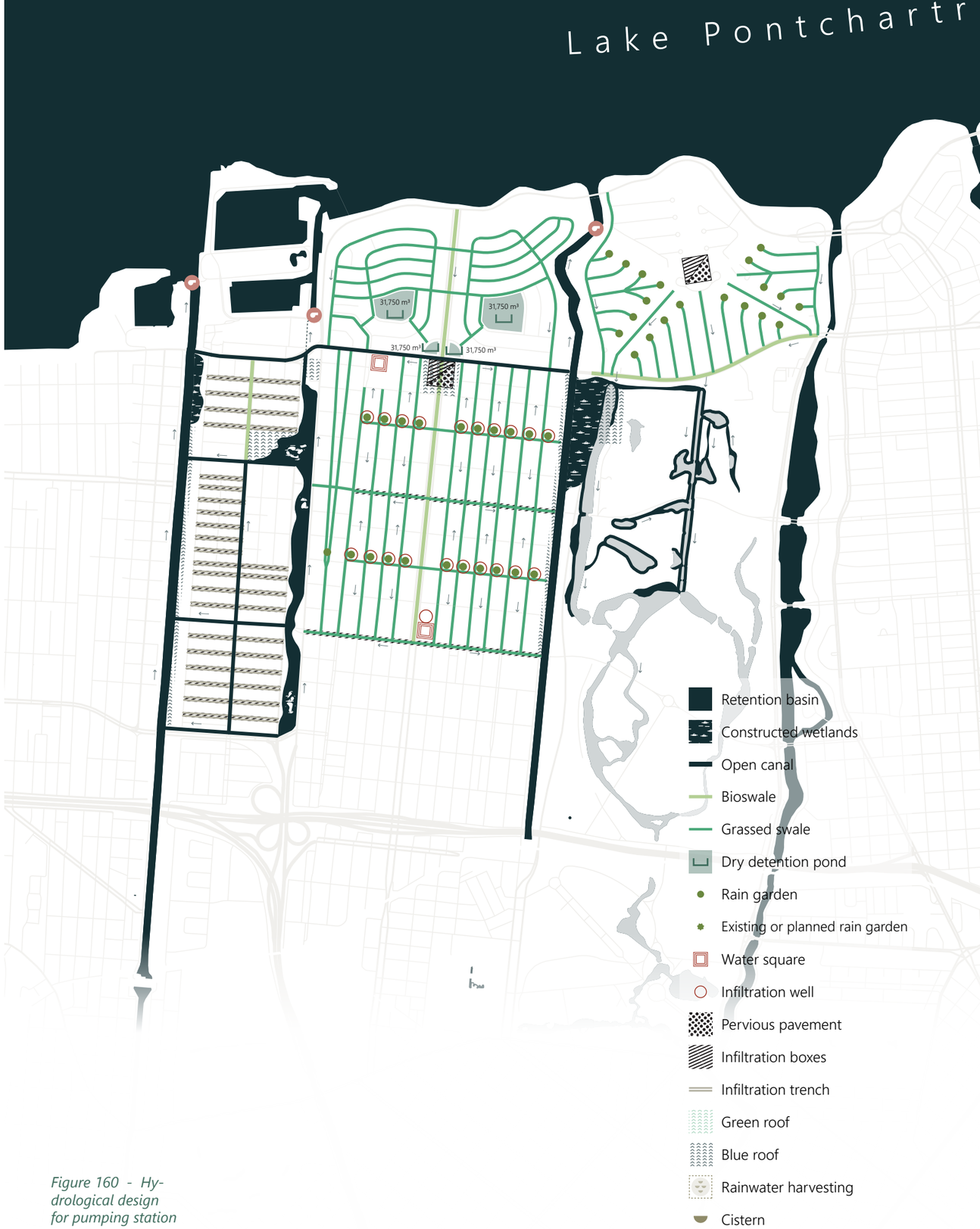


Figure 160 - Hydrological design for pumping station catchment 12.

■ 7.1.2 Comprehensive hydrological design

The design frameworks for each individual catchment combine into the comprehensive hydrological design framework as displayed in Figure 161.



Figure 161 - hydrological design framework.

Water quality design

The proposed water system is designed to provide a good water quality, even in periods of drought. Inlets and hydraulic gradients ensure that all open water bodies have a constant movement of water.

During dry weather conditions, Orleans Lakeside receives water from three external sources: Bayou St. John via Lake Pontchartrain, a small inlet via the Inner Harbor Navigational Channel, and finally water received from the metropolitan area. Figure 162 indicates the direction of flow in this situation.

In wet weather conditions, the sloping streets dispose their water in the canal system, effectively flushing it with runoff that has been filtered by (bio)swales. For this condition, the system functions as indicated in Figure 161.

Interaction with subsoil

Section 3.2.2 provided an overview of geomorphological characteristics in Orleans Lakeside. These conditions return in the hydrological design, as the subsoil plays an important role in the hydrology.

The hydrological design interacts with the subsoil on 3 main topics, which are elaborated after:

- Subsidence mitigation
- Change in seepage
- Salinization

Subsidence mitigation

Figure 163 displays a simplification of subsidence vulnerability in Orleans Lakeside. In the areas marked as most vulnerable, it is key to remain a groundwater level that is above the organic soil layer as to prevent oxidation. Subsidence vulnerability is reflected in the general elevation; low areas tend to be vulnerable, whereas high areas are the least vulnerable for subsidence. The hydrological design proposes open water in low areas, where these elements are deployed as mechanism to mitigate oxidation of organic layers.

The organic layer starts roughly one meter below ground level. Therefore, in these areas a freeboard of one meter compared to the current ground level would ensure minimal subsidence. Naturally, a fill on top of the existing ground level would allow for a higher freeboard.

Change in seepage

Figure 164 shows the depth of well drained Pine Barrier sand underneath poorly drained soil. Poorly drained soil acts as a seal, through which seepage is difficult. It is important to address the fact that any hydrological intervention might cut through this seal, exposing Orleans Lakeside to more seepage. Currently, some box culverts are constructed completely above the permeable Pine Barrier sand layer, while other culverts do intersect with that layer. Open canals proposed in the hydrological design do not necessarily extend deeper into the soil than existing box culverts, but an unsealed bottom of natural waterways could exacerbate seepage into the neighborhood.

Sea level rise will result in a larger pressure difference between Lake Pontchartrain and groundwater levels in Orleans Lakeside. Hence, seepage is expected to increase. Should seepage become unbearable, the bottom of canals could be made impermeable to reduce seepage. An extreme measure would be to construct a sheet piling wall extending from the ground level to the start of the impermeable Pleistocene layer (located at roughly 25 meters depth) alongside Robert E. Lee Boulevard. This measure would stop groundwater from seeping into Orleans Lakeside, although groundwater levels in the area north of Robert E. Lee Boulevard would definitely rise.

Salinization

To mitigate salinization of the entire Orleans Lakeside area, an east-west canal at Robert. E. Lee Boulevard serves to capture most of the saline groundwater and redirecting this towards the pumping stations in the shortest route possible. Figure 165 illustrates this process.

Figure 162 - Dry weather circulation of open water bodies.



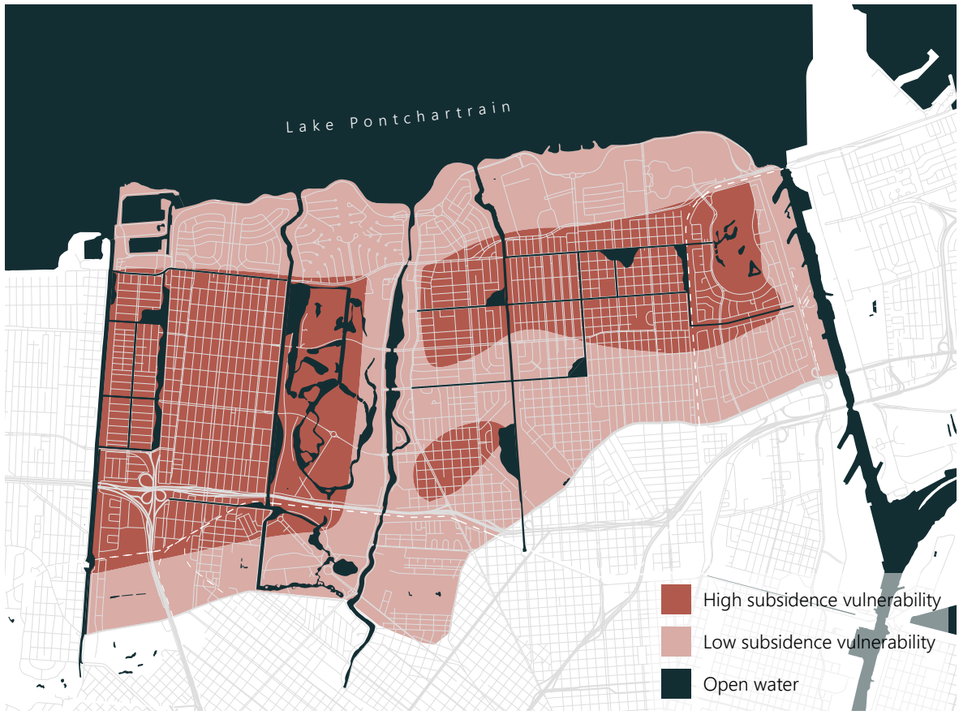


Figure 163 - Subsidence vulnerability (source: adapted from van Asselen et al., 2019).

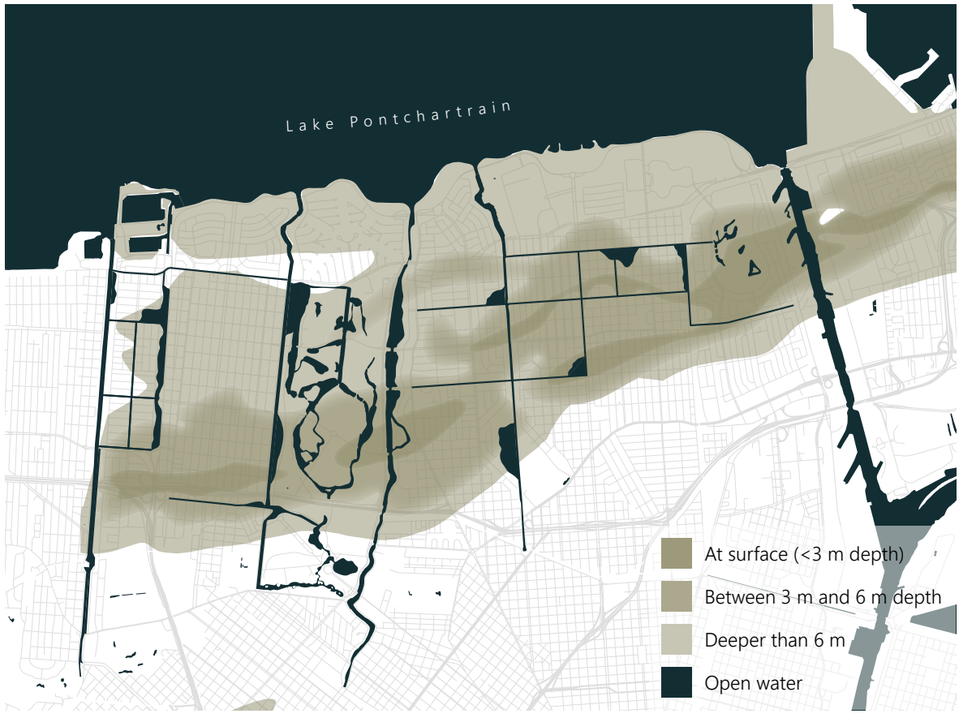


Figure 164 - Thickness of poorly drained soil on top of well drained Pine Barrier sand (adapted from Saucier (1994).

Figure 165 - Minimizing salinization of Orleans Lakeside by constructing a canal at Robert. E. Lee Boulevard.



500 m 1 km 1 km 2 km

7.1.3 Street profile typologies

With repetitive street profiles across Orleans Lakeside, the aim of this section is to present how interventions can be solved in the available space.

Narrow street profile: Arts Street

Alternative 1: Bioswale

Constructing a single bioswale along the curb does not compromise space for pedestrians, and provides ample capacity for transport and infiltration of runoff. The quality of public space is enhanced by this measure as well.

Alternative 2: Infiltration trench

Constructing infiltration trenches is the least radical solution, as this measure neither compromises on pedestrian space nor parking space. Furthermore, no extensive reconstruction of the roads is required. However, the final buffering capacity is small, especially for high intensity precipitation.

Alternative 3: Infiltration cates

Infiltration crates offer a high storage capacity and do not take up space above ground. In addition, groundwater recharge is a beneficial bonus for mitigating drought.
However, this measure does not hold any merit for improving the quality of public space, as the streetscape does not change.

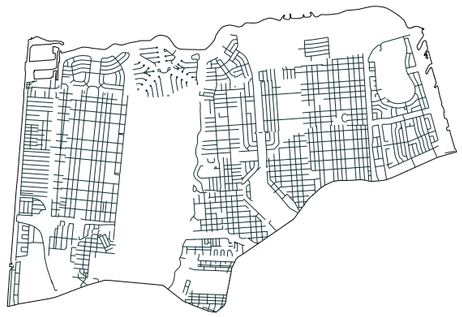


Figure 166 - Locations of small street profiles.

Figure 167 - Narrow street profile, current situation.

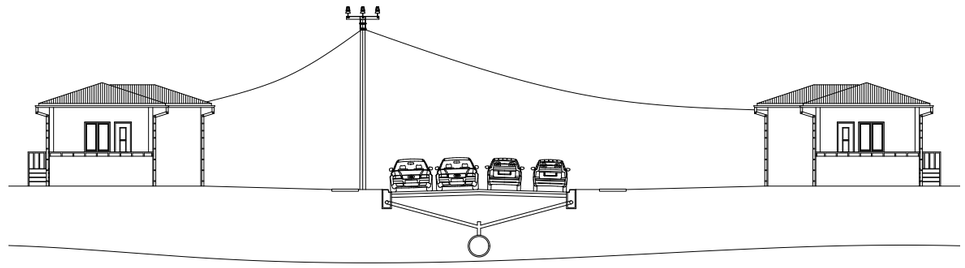


Figure 168 - Alternative 1: Bioswale.

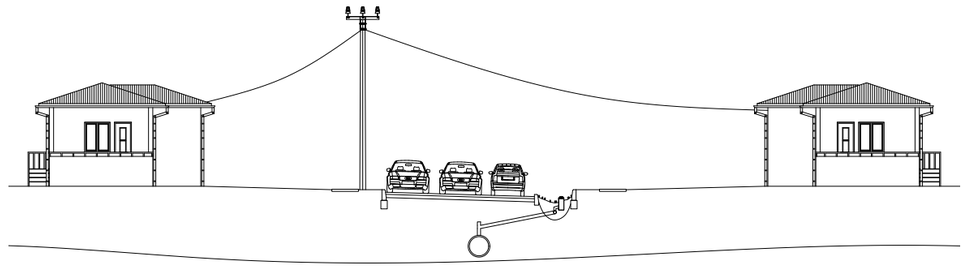


Figure 169 - Alternative 2: Infiltration trench.

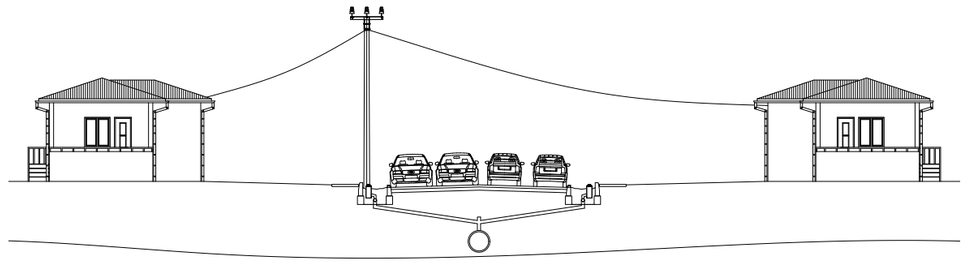
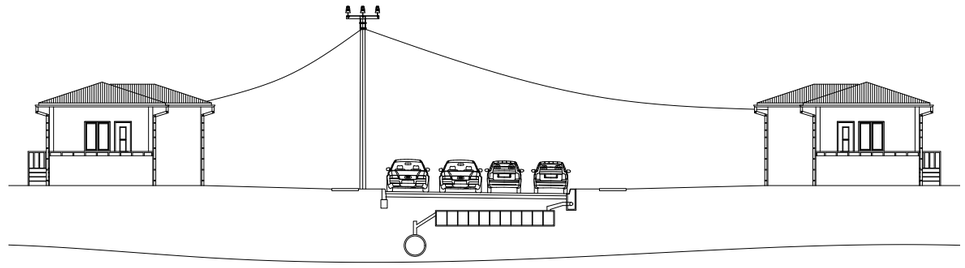


Figure 170 - Alternative 3: Infiltration cates.



Medium street profile: Franklin Avenue

Alternative 1: Bioswale

Converting the neutral grounds into a bioswale results in buffering capacity that does not compromise on space for traffic. While the contribution to the water assignment is sub-optimal, this alternative does improve the quality of public space.

Alternative 2: Infiltration cates

Similarly to the bioswale, this alternative does not reduce space for traffic. However, the storage capacity is much larger. On the downside, this alternative does not improve the quality of public space.

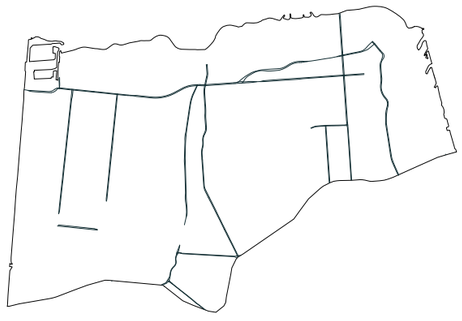


Figure 171 - Locations of medium street profiles.

Figure 172 - Medium street profile, current situation.

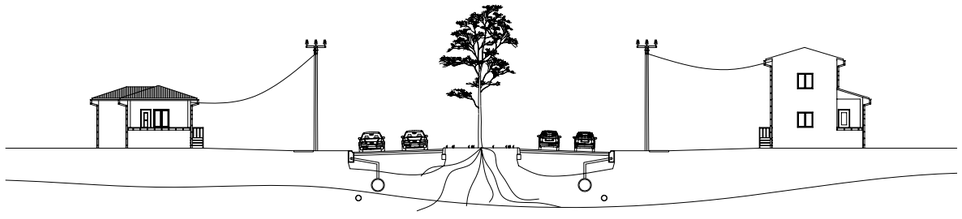


Figure 173 - Alternative 1: Bioswale.

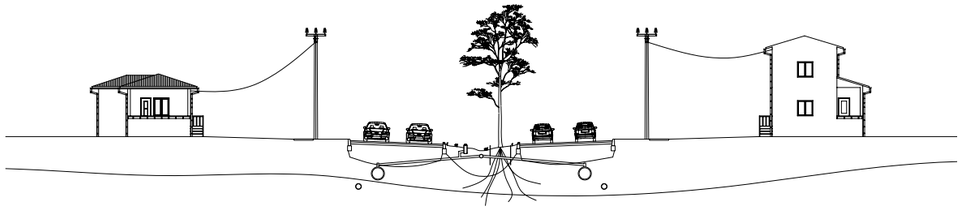
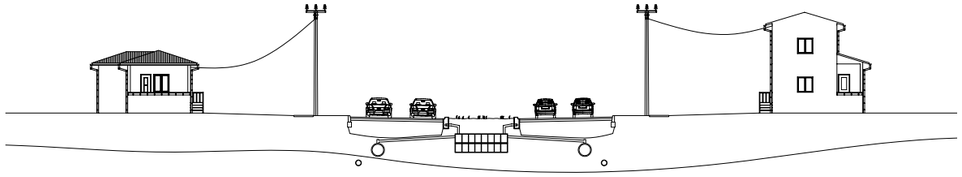


Figure 174 - Alternative 2: Infiltration cates.



Wide street profile: Prentiss Avenue



Figure 175 - Locations of wide street profiles.

Alternative 1: Bioswale

Transforming the neutral grounds into bioswales a fairly simple interventions, as the current box culvert can remain in place. Streets will have to be refitted to slope towards the middle. This alternative has added benefits regarding filtering of pollutants.

Alternative 2: Infiltration cates

Infiltration crates underneath the road allow current box culverts to stay, as well as any vegetation on the neutral grounds. However, this measure does not hold any merit for improving the quality of public space, as the streetscape does not change.

Alternative 3: Central canal

Constructing a single canal by opening the box culvert and allowing for a freeboard of at least 1 meter has a significant contribution towards the water assignment. While this alternative does not compromise on parking space or lot accessibility, the created open water has little additional value other than providing storage capacity.

Alternative 4: Side canal

A canal on one side of the street profile would offer a similar contribution towards the water assignment as a central canal, with the added value of introducing water as amenity. A significant tradeoff is that one row of parking spaces has to be sacrificed.

Alternative 5: Urbanized bayou

Similar to the side canal, this alternative introduces water as amenity. Compared to the side canal, this option improves filtering of polutants and increases legibility of a bayou-like scene. This alternative, however, requires even more space than a straightforward canal due to nature-friendly embankments.

Figure 179 - Wide street profile, current situation.

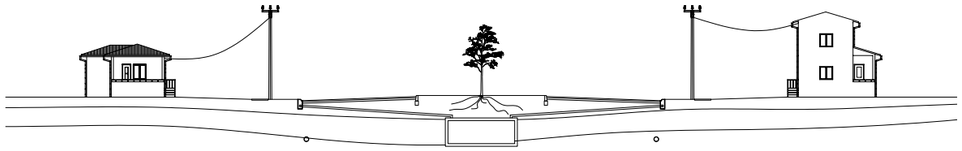


Figure 176 - Alternative 1: Bioswale.

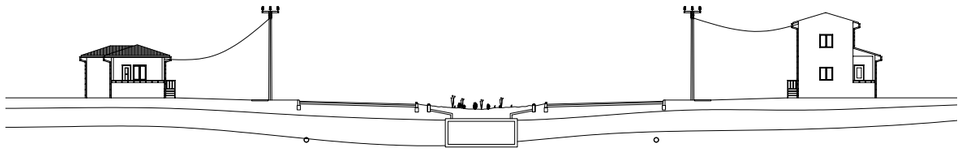


Figure 177 - Alternative 2: Infiltration cates.

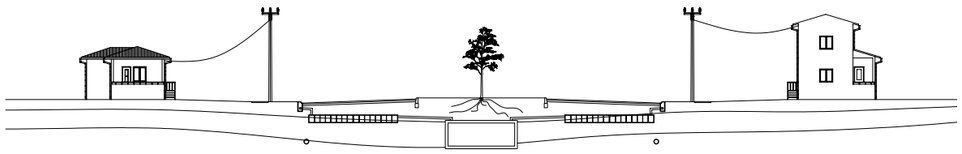


Figure 178 - Alternative 3: Central canal.

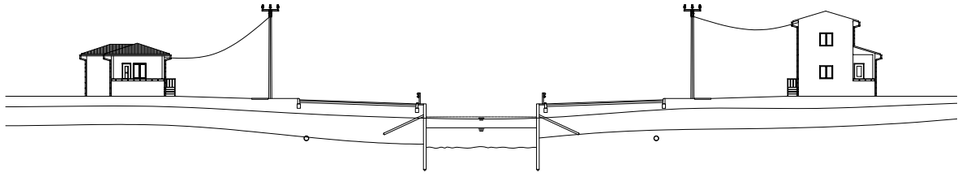


Figure 180 - Alternative 4: Side canal.

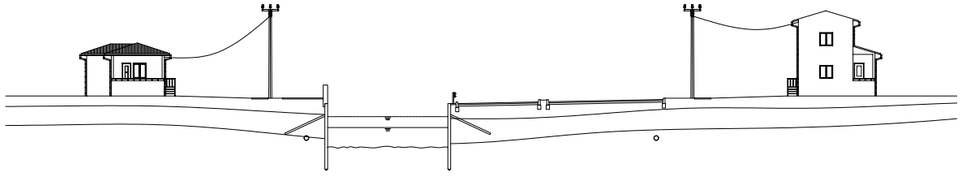
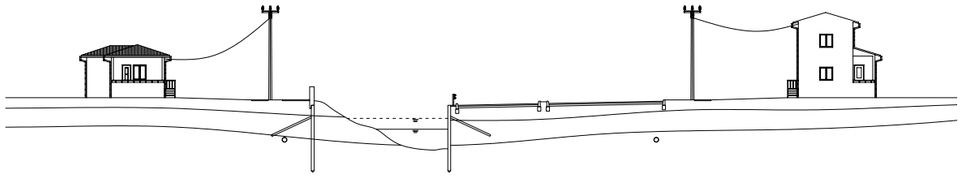


Figure 181 - Alternative 5: Urbanized bayou.



7.2 Macro-scale design

This section illustrates the macro-scale design for Orleans Lakeside in which all design frameworks and the elaborate hydrological design of Section 7.1 are integrated.

Figure 182 shows the conceived design for Orleans Lakeside with respect to the rest of the city. The map shows that the new recreational route system has the potential to extend towards the west and south, making Orleans Lakeside better connected for pedestrian and bicycle traffic. Furthermore, added commercial activity in Orleans Lakeside demonstrates a spatially diverse pattern. This reduces the need to go to the city center for employment.

Figure 183 provides a synthesis of the design frameworks of Chapter 6 and the water system design of Section 7.1. The common denominator for all layers of the design is that patterns created for the new water system have benefits for the urban environment in the form of a newly introduced, finer grained layer of public space. Blue and green corridors, part of the water assignment, form recreational routes that improve the quality of public space and connect new commercial functions. By diversifying the programming and providing new destinations for local and regional residents, these functions seek to enrich Orleans Lakeside. Furthermore, new commercial functions and proposed apartment buildings are located next to open water bodies, where excavated soil is locally used to create mounds for vertical evacuation.

In terms of connectivity, new blue and green infrastructure create opportunities for a better spatial integration. Hence, in addition to current, car-centered east-west connections, new pedestrian and bicycle-focused east-west connections take shape as part of the water system.

Educational campuses will get a more prominent role in both water management and evacuation. Their high elevation makes them responsible for retaining water on their own land, whereas their facilities to handle large crowds make them suitable for local sheltering.

Extensive interventions in the water system imply the introduction of new living environments that are much more centered around water. These new typologies are not currently present in the area, and are elaborated in Section 7.3 of this report.

By introducing new living environment typologies that are centered around water, both the count and offer of dwellings changes. Although large open water bodies are concentrated on public and vacant ground, a small number of dwellings are reorganized around the new water system. Furthermore, large open water bodies are coupled with local densification of the housing offer in order to provide a more solid basis for added commercial functions. Figure 184 illustrates the estimated nett result of interventions across Orleans Lakeside. When referring to the population stagnation scenario (range between minor shrinkage and minor growth), the proposed design for Orleans Lakeside adds a total of 500 apartments and 35 single family dwellings. Compared to the current number of households of 27,226 (The Data Center, 2017), this constitutes a minor growth of 2 percent.

Figure 185 illustrates the proposed urban design for Orleans Lakeside. This map shows the actual scale of interventions and highlights essential patterns of the design. Figure 186, Figure 187, Figure 188 and Figure 189 show how the layers of the design framework are implemented in the final design. These maps show the pivotal role of the water system and how it relates to the newly created recreation route system, commercial functions and vertical evacuation spots.

Figure 182 - Urban design for Orleans Lakeside with respect to the rest of New Orleans.

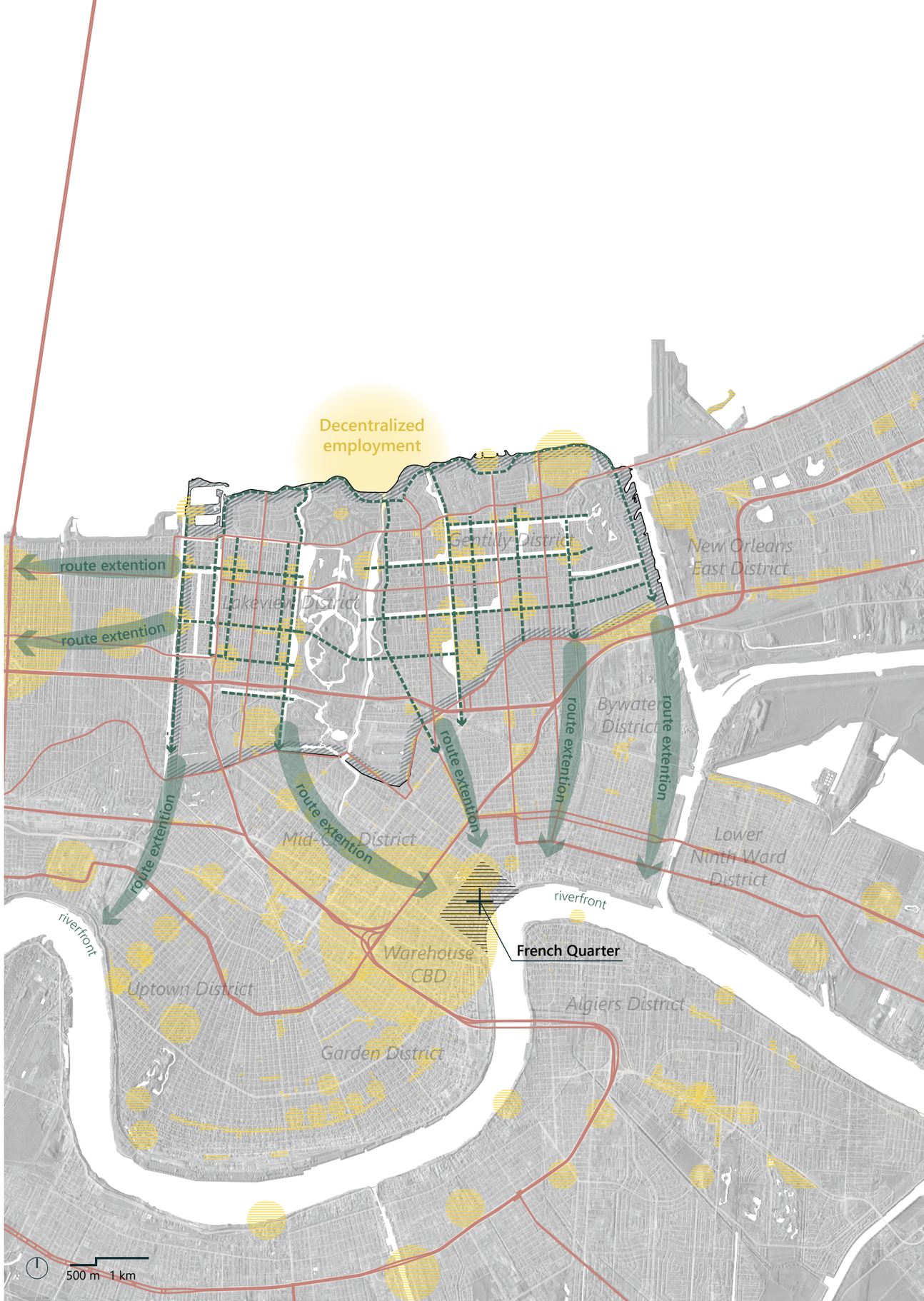


Figure 183 - Synthesis of proposed design frameworks and hydrological design.

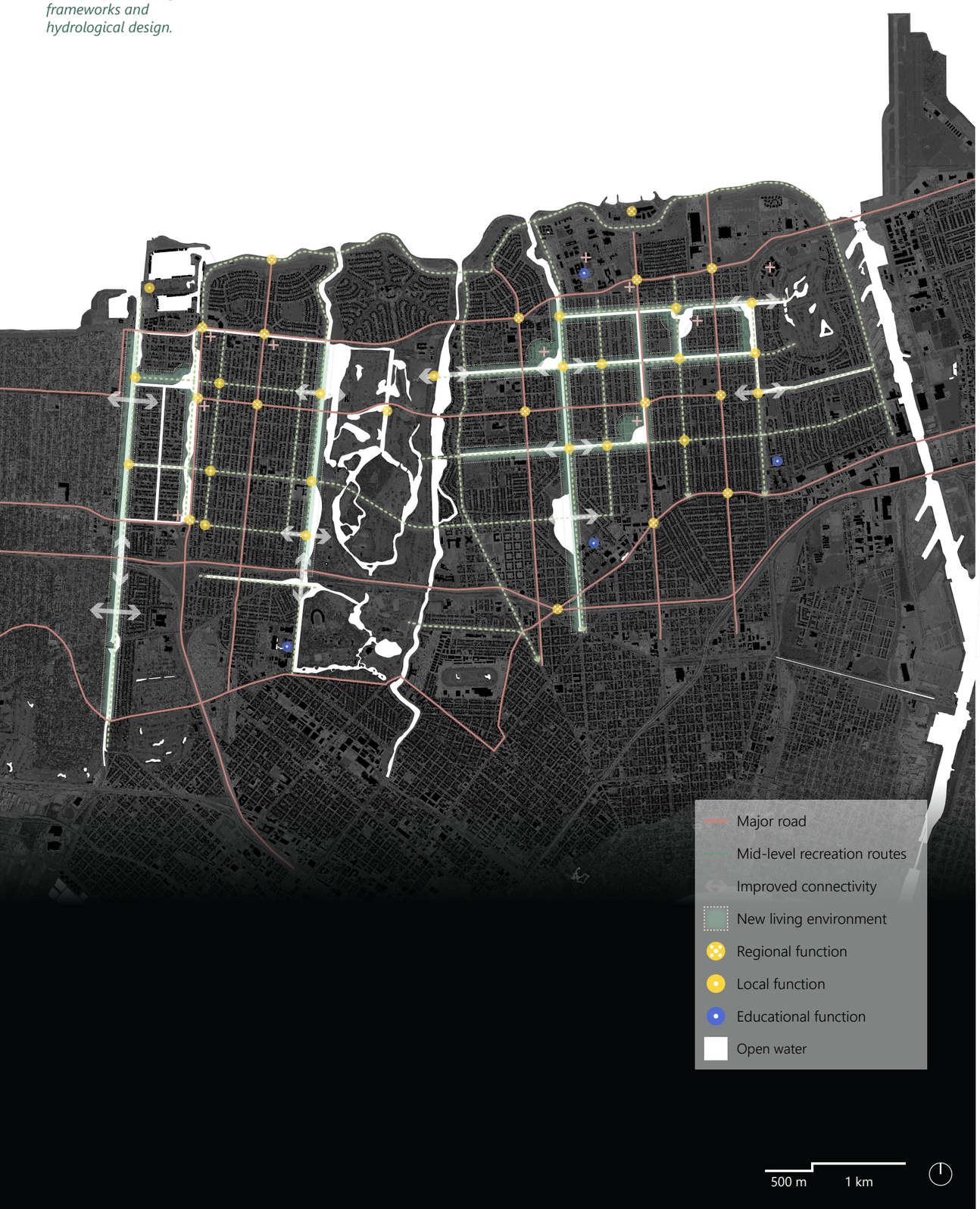
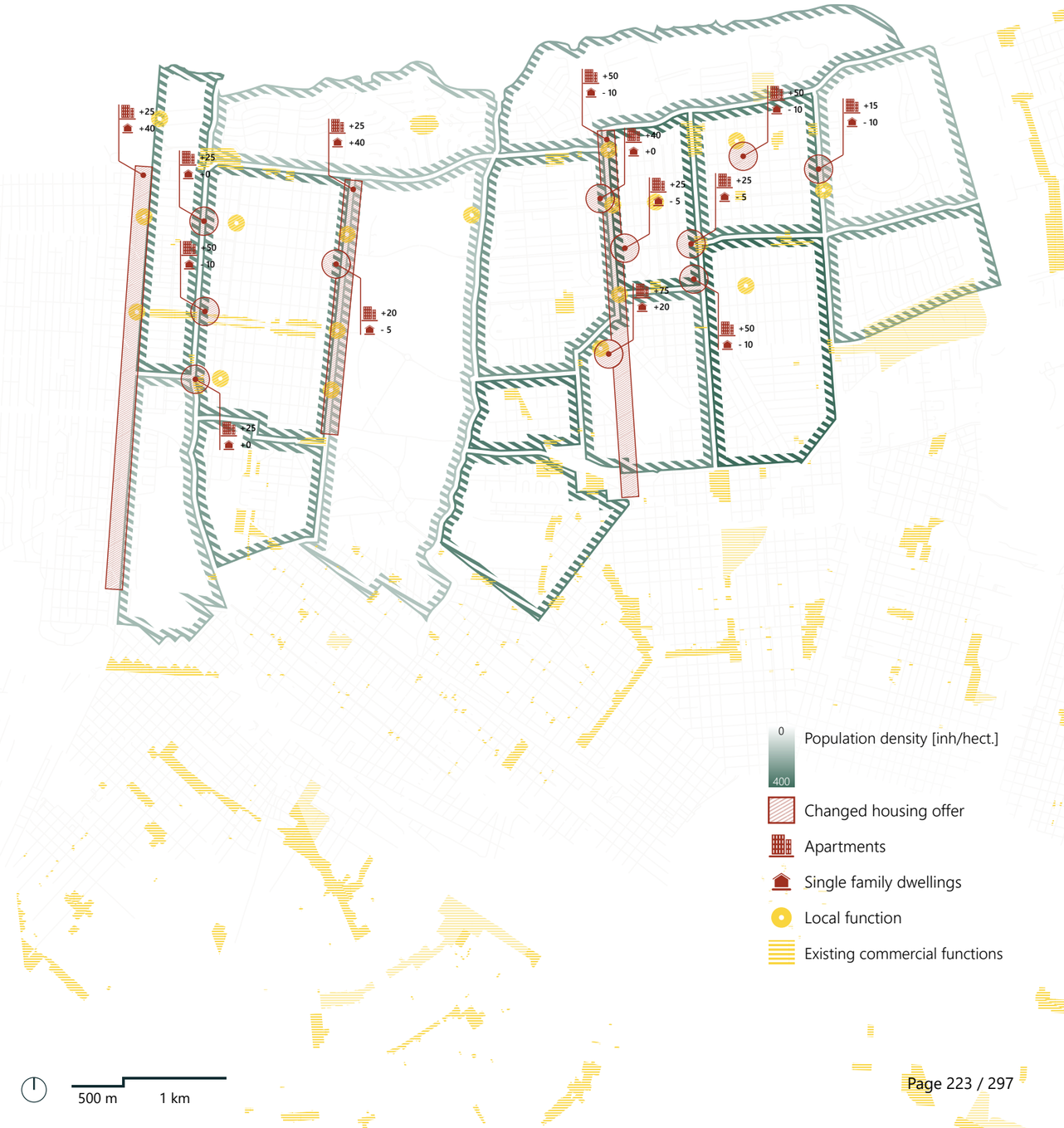


Figure 184 - Quantification of new housing offer.



Lake Pontchartrain

Improved connectivity with recreational routes.

Enriched programming decreases functional homogeneity.

Permanent open water storage on low ground for significant buffering capacity (retention).

Temporary water storage on high ground and educational campuses (detention).

New living enrivonment typologies that are centered around water.

Vertical evacuation on mounds in lower areas.

250 m 500 m

Figure 185 - Proposed urban design of Orleans Lakeside.



Figure 186 - Water system layer.



Figure 187 - Spatial quality layer.



Figure 188 - Functional design layer.



Figure 189 - Evacuation layer.

500 m 1 km

500 m 1 km

7.3 Micro-scale design

The Macro scale design in Figure 185 demonstrates the spatial implications of the reimagined water system on a large scale. The following section elaborates the consequences on a smaller scale, with the purpose to make the plan more relatable.

Since the design proposal at many locations introduces a new living environment for residents, a set of typological designs is presented that are much more centered around water.

Furthermore, to show how a set of hydrological interventions and new living environments come together, a demonstration project called St. Roch's Bayou serves to elaborate more on design consequences on a micro scale. This design is not intended as a rigid master plan for the area, but rather serves to provide an impression on what the added spatial and functional qualities are. Furthermore, it provides an example of how the new living environment typologies would develop in an actual urban environment.

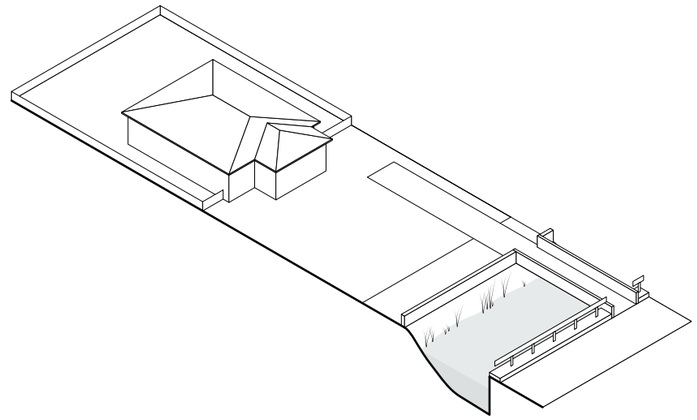
7.3.1 New living environment typologies

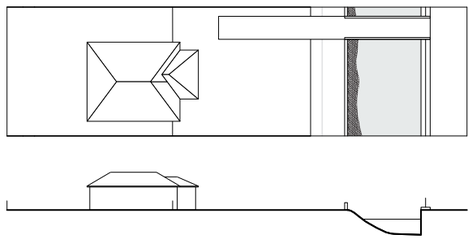
The proposed urban design for Orleans Lakeside involves the creation of new living environments that are much more centered around water. Due to the typological repetitiveness of the urban grid, the development of typologies is a powerful tool to provide widely applicable design rules.

For the proposed system, four new living environment typologies are introduced. Three of the new typologies are single-family, detached dwellings, while the fourth new typology is a multi-family apartment building.

Typology: Canal

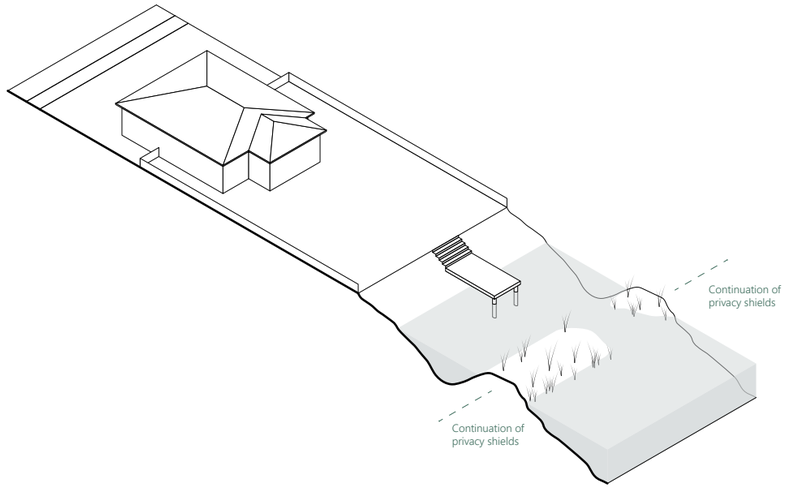
This typology consists of existing or newly built single-family dwellings bordering a canal. The main advantages of this typology are an improved view and increased distance to the street.

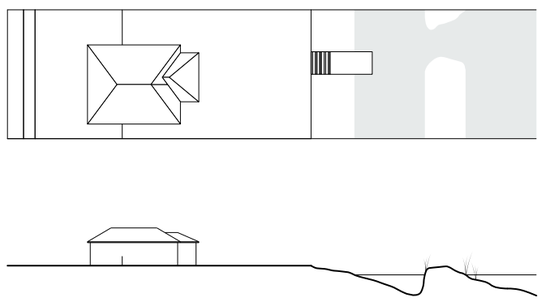




Typology: Open water access

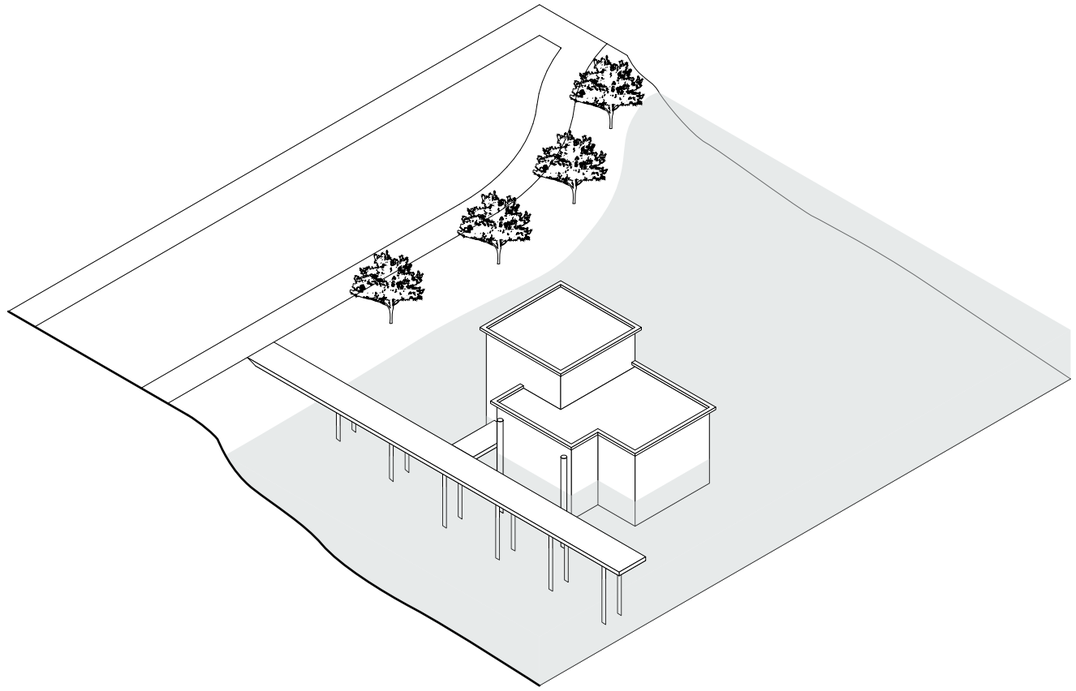
This typology consists of existing or newly built single-family dwellings that have direct access to open water on the backside. Residents are free to build a jetty. Small islands guarantee privacy, while still allowing open water access by boat.

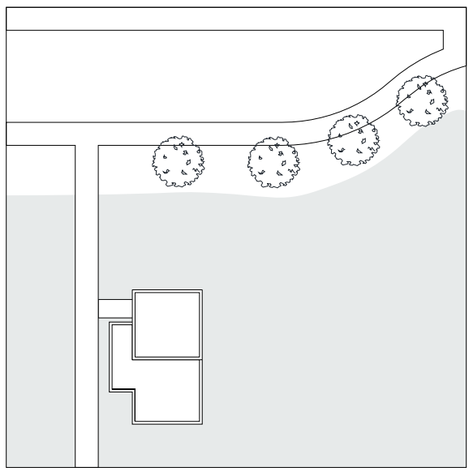


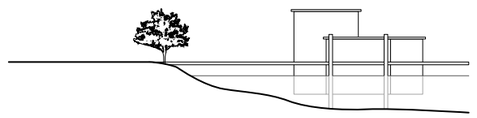


Typology: Floating house

This typology consists of newly built single-family dwellings that float on permanent retention ponds. This typology allows for an increased density without compromising on water storage capacity. Dwellings are accessible by a fixed walkway.

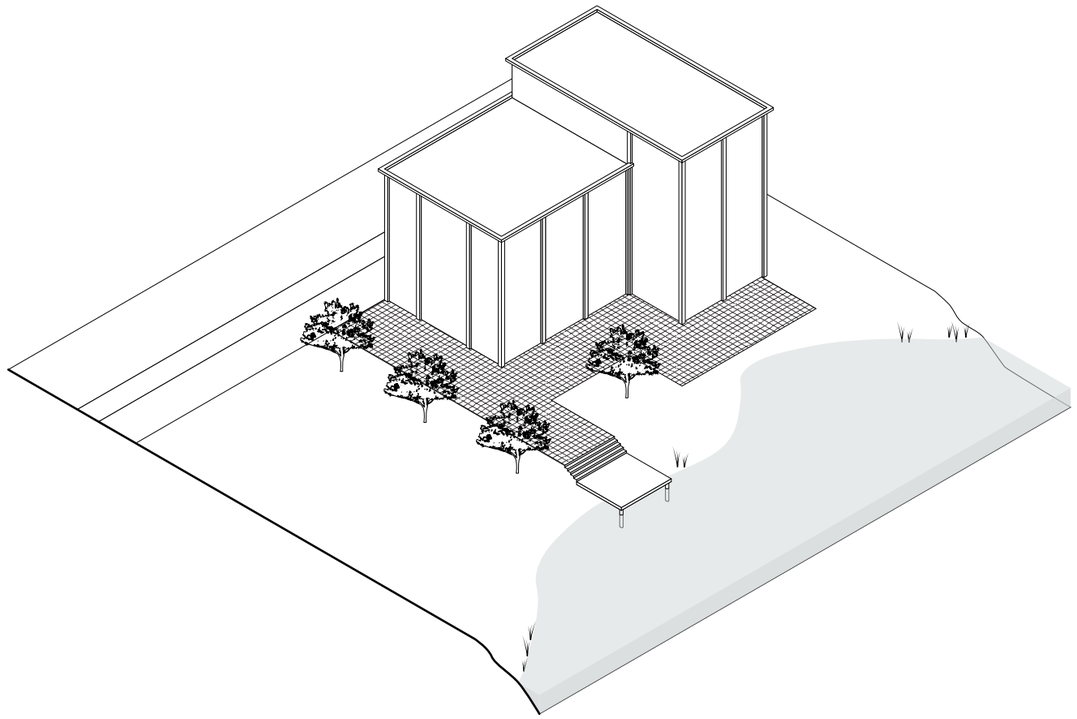


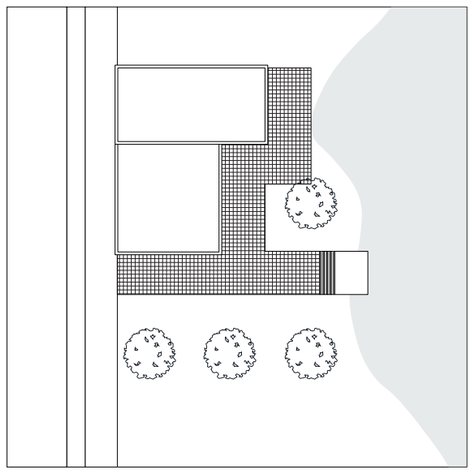


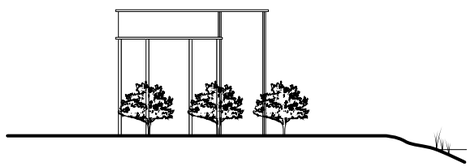


Typology: Waterside apartments

This typology consists of multi-family apartment buildings that are in direct contact with open water. Allowing for an increased density, this typology offers the opportunity to combine new functional programming with apartments.







7.4 Demonstration project

St. Roch's Bayou is a location in the proposed design for Orleans Lakeside where multiple interventions come together. As stated before, this demonstration project is not intended as a rigid master plan for the area. Rather, it serves to provide an impression on what the added spatial and functional qualities are and how these relate to the reimagined water system.

Figure 190 shows the location of St. Roch's Bayou in the larger system. The proposed bayou joins an east-west canal alongside Robert E. Lee Boulevard and a north-south canal on Elysian Fields Avenue into a larger water body which represents a significant portion of the required water storage capacity. Furthermore, the extensive overhaul of the water system and introduction of open water at this location implies a totally new streetscape. All four new living environment typologies earlier described are integrated in St. Roch's Bayou.

St. Roch's Bayou combines four key aspects of the proposed design for Orleans Lakeside: water storage, enriched programming, recreational routes and vertical evacuation (Figure 192).

Regarding the water assignment, the most significant is the creation of 40,000 m^3 ($1.4*10^6$ cf) storage in a permanent retention pond, joined by the two canals described earlier. Referring to the hydrological design (Figure 161), other interventions at this location include a 300 m^3 (10,600 cf) rain garden, 100 m^3 (3,500 cf) storage on blue roofs and 4000 m^3 (141,000 cf) storage in underground infiltration crates. St. Roch's bayou is a node in the newly proposed recreational route system and joins together an east-west and north-south route, adjacent to the canals. New, small scale commercial programming makes the area a destination and enriches the currently homogeneous single-family residential zoning. With regard to evacuation, this location is to provide opportunities for vertical evacuation. A mound created with excavated soil serves to reduce damage in case of severe flooding, while medium-rise buildings provide a safe place for nearby residents.

Figure 190 - Location of St. Roch's Bayou in the larger system.



water assignment
- 40,000 m³ retention pond
- 2x 8 m canal
- 300 m³ rain garden
- 100 m³ blue roof storage
- 4000 m³ infiltration crates

programming
- Added local commercial programming

recreational routes
- Connect recreational routes

evacuation
- Provide vertical evacuation opportunities in highrise



Figure 191 - (right) Current situation at the design location (source: Google Maps, 2019).

Figure 192 - Relation of St. Roch's Bayou to the larger synthesized design.



7.4.1 Form generation

As argumentation behind the proposed design for St. Roch's Bayou, Figure 193 shows the logical steps that lead to an illustrative design composition.

Step 1 shows the existing situation with available public and private land.

Step 2 illustrates the required surface area of elements of the hydrological design. As explained earlier, a trade-off between storage capacity and subsidence mitigation resulted in a $dH_{(max)}$ of 1 meter. As there still needs to be space for programming, not every available square meter of land is converted to open water.

Step 3 introduces the original landscape signature into the water body, while improving circulation. Most activities take place around the edges of the water body.

Step 4 integrates additional programming into the neighborhood, as well as different living environment typologies. Commercial functions are concentrated near the intersection of the main roads to optimize accessibility. However, smaller commercial functions are spread around the water body.

Step 5 illustrates the placement of building volumes in accordance to the typologies given in Step 4. The highest density buildings are placed near the intersection of two major roads to signify a new urban environment and break the endless sight of single-family houses.

Step 6 shows how the recreational routes come together in this area.

Step 1 - Existing situation
1. public parks
2. 37 vacant lots
3. wide boulevards

Step 2 - Water assignment
1. 40,000 m^3 retention pond
2. 2x 8 m canal
3. 300 m^3 rain garden
4. 100 m^3 blue roof storage
5. 4000 m^3 infiltration crates

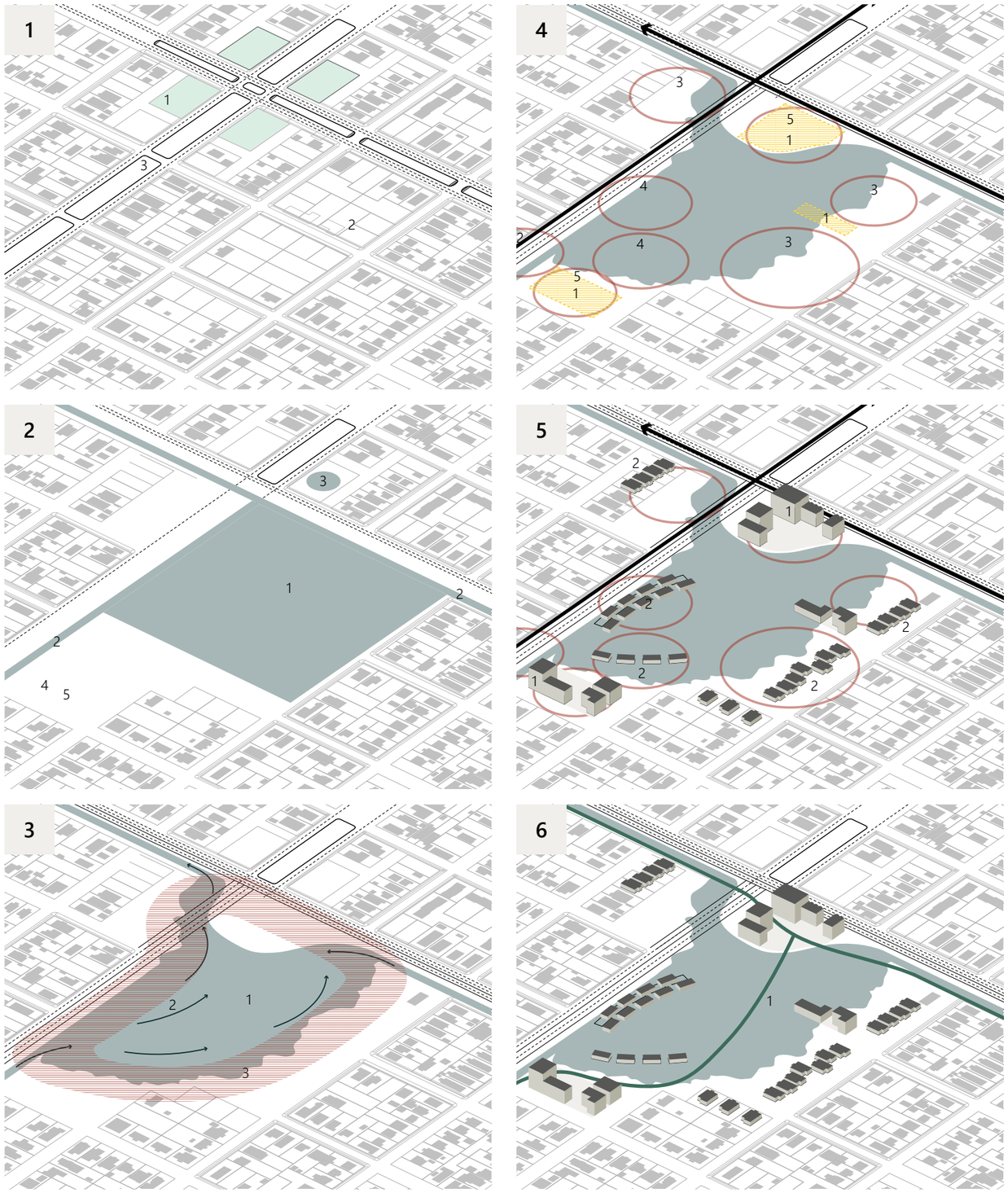
Step 3 - Landscape legibility & water quality
1. Wetland precedent
2. Proper circulation
3. Zone of functions

Step 4 - Programming
1. Added commercial programming
2. Typology: canal
3. Typology: open water access
4. Typology: floating house
5. Typology: waterside apartments

Step 5 - Building volume placement
1. Medium-high density near major boulevard
2. Single family dwellings

Step 6 - Recreational routes
1. Integrated recreational route

Figure 193 - Form generation steps.



7.4.2 Design description

The form generation steps shown in Figure 193 eventually lead to the plan view displayed in Figure 194. The plan combines all four living environment typologies into an urban area that is centered around water.

The area is divided into three zones which all have a different character. In the north, there is a medium-density urban area with concentrated commercial activity and vibrant public space. This area also provides opportunities for vertical evacuation. In the south, the water body provides a calm living atmosphere. This area consists of waterside apartments and floating houses. The center of the area is designed to provide a quiet and pleasant nature environment. The water body is connected by an east-west and north-south canal, which allow the water network to be used for light recreation.



Figure 194 - Impression of the proposed design.

Open water bodies have a $dH_{(max)}$ of 1 meter, and a total freeboard of 1.5 meter. Figure 195 shows how a rising water level affects the embankments. Floating buildings move vertically with a rising water level, while the natural islands are allowed to flood during heavy precipitation.

zoom 1

zoom 1

zoom 1

zoom 1

Floating house

zoom 2

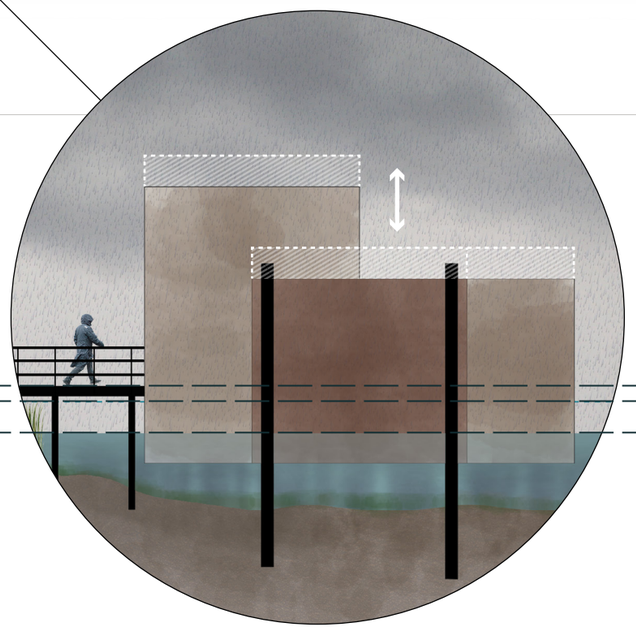
Submersible islands

zoom 3

General embankment

Water level variations

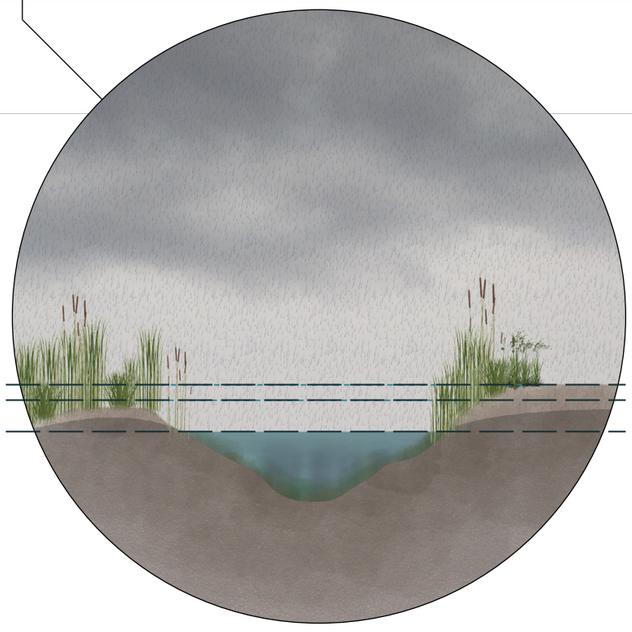
+1.5 m freeboard
+1 m $dH_{(max)}$
0 m target water level



Buildings move vertically with rising water and do not compromise on storage capacity.



Islands have a high groundwater table and support native vegetation. Heavy precipitation will submerse the islands, as the ground level is below the $dH_{(max)}$ of the urban area.



The general embankment has a $dH_{(max)}$ of 1 meter, with a total freeboard of 1.5 meter. This ensures proper drainage towards the open water bodies in the event of heavy precipitation.

Figure 195 - Section showing the impact of a rising water level in open water bodies.

Figure 196 shows the quality of the newly introduced recreational route. The standpoint for this image is taken in the middle of the water body, which is designed to provide a quiet environment, whilst giving residents an exciting view on the denser urban center across the water.



Figure 196 - Perspective (A) from the central water body towards medium-rise buildings.

Referring back to the spatial design framework of Chapter 6.2, one of the aims was to create a more interesting sequence of spaces within the grid. Figure 197 shows the view from Robert E. Lee for the proposed design. By composing medium-density buildings next to open water, an interesting exception to the ubiquitous single-layer dwellings takes shape in the grid. This image also shows well the qualities of the recreational route. By constructing an asymmetrical road profile and placing the canal in between automobile traffic and the recreational route, a safe space is created for all users of the road. Furthermore, this configuration enables direct water access for users of the recreational rout system.



Figure 197 - Perspective (B) from Robert E. Lee Boulevard. Source of current situation image: Google Maps, 2019.

Figure 198 provides an impression of the quality of waterside apartments and their relation to public space. The image shows a versatile public space that connects to the main water body as well as commercial functions in the plinth. Furthermore, the raised ground level on which the buildings are built is constructed using excavated soil for creating the open water body. This ground level is above hurricane-level floods and provides a safe haven for vertical evacuation

1. Space for community activities
2. High quality public space at a human scale
3. Added commercial programming
4. Vertical evacuation
5. Mound above hurricane flood level
6. Freeboard = 2.5 meter, dHmax = 2 meter.



Figure 198 - 3D section (A-A') through waterside apartments near the urban center in the north.

Surrounding the open water body are single family dwellings that have open water access at the backside. Figure 199 shows a section through such a typology. This section illustrates that the open water is well accessible for residents, which allows for multifunctional use. With this composition, desired traditional American neighborhood qualities (detached house, privacy from neighbors, free occupation of the building plot) are merged with a new, water-centered urban environment. In terms of drought resilience, Figure 199 shows the high constant groundwater level to mitigate subsidence through peat oxidation.

1. Open water access
2. Single family dwelling
3. Freeboard = 1.5 meter, dHmax = 1 meter.



Figure 199 - 3D section (B-B') through open water access single family dwellings.

As a new building typology in Orleans Lakeside, the floating houses in Figure 200 add a novel way of living with water to the project area. These floating dwellings have a setback from the embankment, with a vegetated strip as privacy shield. Residents living in this typology have an undisturbed view of the open water body. On the downside, cars have to be parked in a nearby facility

1. Floating house
2. Waterside apartments
3. Natural embankments
4. Submersible islands



Figure 200 - 3D section (C-C') through floating houses.

7.5 Design evaluation

Using the evaluation framework outlined at the start of this chapter, this section elaborates on the performance of the proposed design.

7.5.1 Evaluation based on the vision

Regarding the threshold capacity, the proposed design is able to cover the entire T10 water assignment for each subcatchment within Orleans Lakeside. The approach, however, differs per catchment, which also has consequences for the implementation. Some catchments might be left vulnerable for a longer time than other catchments due to the nature of the required interventions.

For the coping & recovery capacity the proposed design offers vertical evacuation possibilities across the low-lying areas, which gives residents safe alternatives to evacuating by car. On a smaller scale, this manifests in a mound constructed using excavated soil, creating an elevated ground level above hurricane-level floods. This offers residents a safe place to stay. A downside of the plan is that recovery of single-family dwellings remains unchanged from the present situation.

In the adaptive domain, the proposed design aims to provide a roadmap to a more flood and drought resilient Orleans Lakeside. By introducing a water system that is adaptive over time, the design promotes flexibility. In addition, increased functional diversity further improves flexibility.

The design proposal for Orleans Lakeside is focused on increasing internal connectivity. By enriching the urban grid with recreational routes tied to the water system, the area becomes more internally connected. The proposed design does not inherently improve external connectivity, although the recreational route system can be connected to the rest of the city towards the south and west.

Quality of public space is primarily enhanced near the reimagined water system: retention ponds and canals provide high quality public space. However, in between open water elements the streetscapes only change minimally. Granted, green corridors provide a more pleasant recreational experience, but small-scale green infrastructure projects and underground storage facilities do not significantly improve the quality of public space.

By adding commercial functions and creating versatile public space for community activities, the plan offers multiple new destinations in Orleans Lakeside. As for the quality of public space, all new functions and activities are concentrated around the water system, leaving the areas in between largely unchanged. On the other hand, by increasing walkability, existing and new destinations become more easily accessible for residents.

7.5.2 Evaluation from stakeholders

During two visits to New Orleans (one in April 2019 and one in November 2019), key aspects of this project research and design proposals were presented to a wide range of stakeholders. The first visit focused on the research approach, whereas the second visit revolved around the design proposal. This section provides a summary of the most relevant feedback and general comments received during these sessions.

Feedback from designers

Include references to existing and historic open canal examples in the Greater New Orleans area (Jefferson Parish, City Park lagoons, Bayou St. John, New Orleans East, 1950's open canals in Gentilly) to show differences between high and low quality of public space.

A good way to address equity without expanding the scope is to focus on decreasing homogeneity of zoning to enable different kinds of development and housing.

Feedback from the City of New Orleans

When creating open water, make sure to rebuild at least the same number of houses as you take away. It is a good idea to focus on concentrating open water on vacant and public land.

The concept in this report could be well transferable to New Orleans East, as the local Vietnamese community is more receptive to having open water bodies.

Consider diving deeper into the maximization of hydrological interventions. Elaborate on bandwidth of potential.

Financial feasibility will be an issue. Although the plan of making developers pay a share of the costs is possible, the biggest financial responsibility still lies with the government. Perhaps there are (emergency) funds available.

Feedback from the Sewerage & Water Board

The design considers the addition of green infrastructure on top of existing grey drainage infrastructure. What is the potential of merely upgrading grey infrastructure?

Feedback from residents

Refer to Bayou St. John when presenting the plan to residents. As this is the only remaining natural water body in Orleans Lakeside and generally associated with high quality public space, likening the design proposal to Bayou St. John's qualities makes the plan easier to implement.

Make sure to connect the design to local stories. How can residents be integrated in the design proposal as to allow for a more bottom-up approach?

How to deal with general trust issues between residents and government departments? Current roads and drainage infrastructure are in a poor state, which makes residents hesitant to trust the government with adequately maintaining a system of canals.

Figure 201 - Evaluation framework based on the vision.

Engineering	
Threshold capacity	Does the design cover a T10 rainstorm?
Coping & Recovery capacity	Does the design mitigate damage during flooding and does it improve recovery capacities?
Adaptive capacity	Does the design promote flexibility?
Design	
Improved spatial integration	Does the design make Orleans Lakeside more spatially connected, both internally and externally?
Enhanced quality of public space	Does the design increase the quality of public space by offering a high-quality urban environments?
Added local and regional destinations	Does the design add local and regional destinations as to provide a more diverse programming?

7.6 Implementation

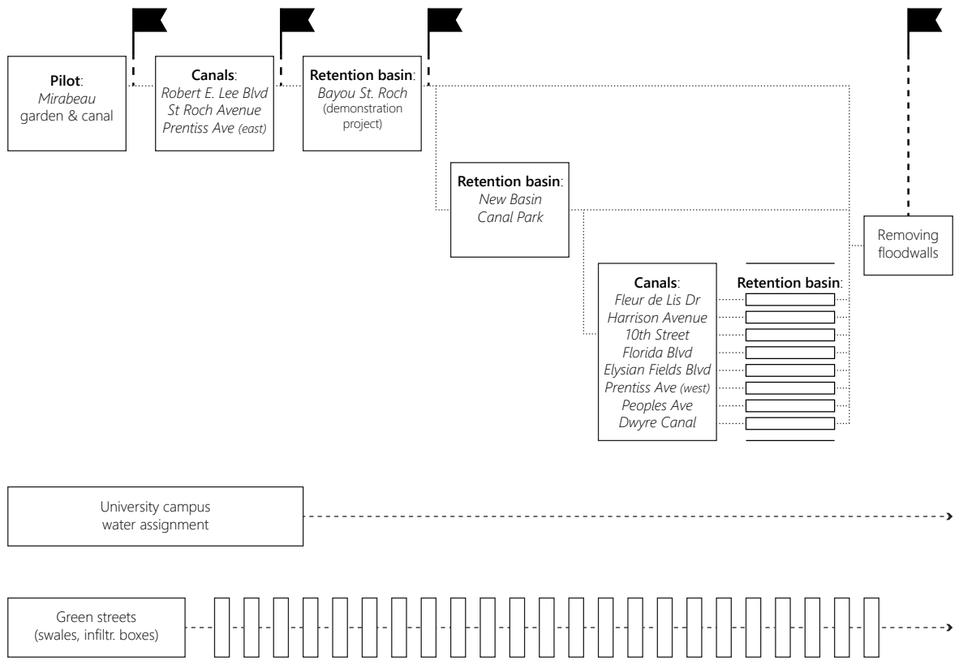


Figure 202 - Schematic implementation strategy.

The leading thought behind the implementation phasing is that the plan cannot be superimposed on the area in a top-down manner. There will be resistance amongst residents against key elements in the plan, with introducing open water being the most radical proposal. With this in mind, the plan proposes to incrementally build towards the final design and convince parties of the added value the proposal offers.

As a start, the Mirabeau Water Garden along with the proposed canal on Mirabeau Avenue are to provide a first milestone project to kickstart a different approach towards water management. The vicinity of Bayou St. John will provide a first step towards bringing high-quality public green further into the neighborhood. At the same time, universities are requested to develop programs for students to satisfy their storage needs on campus. Additionally, work can start on improving the buffering capacity of the City Park lagoons.

Without a clear timeframe, small scale green infrastructure projects such as constructing grassed swales and infiltration trenches alongside roads are completed whenever roadworks are planned. Figure 203 shows which roads are due to be opened for either drainage infrastructure replacement or a full road reconstruction.

With a successful precedent of Mirabeau Avenue, the next step is to extend high-quality public space further into the neighborhood by constructing canals on Robert E. Lee Blvd, St. Roch Avenue and Prentiss Avenue. This will also make a significant step towards addressing the water assignment and reducing flood vulnerability. When these canals are completed, it is proposed to construct the open water body as elaborated in Section 7.4. This milestone project serves to provide another positive precedent to residents that high-quality public space does not have to be limited to the existing Bayou St. John. In addition, this project will display how the new living environment typologies as suggested in this report would take shape in the current urban environment.

Considering the significant water assignment of pumping station catchment 12 (Lakeview), the next milestone project is redeveloping the New Basin Canal Park into a retention pond in combination with new urban development as elaborated in Section 7.2.

With one keystone project of the reimagined water system on both sides of City Park, the next phase is to construct the other proposed canals and open water bodies. This phase is an important step towards making an integrated water system and making the most significant contributions towards solving the water assignment.

Finally, once the major canals and open water bodies are completed, preparations can be made for removing the concrete floodwalls and lowering the water level in the outfall canals. As the outfall canals currently provide a sense of safety to residents, this radical step is postponed until the end to give residents the time to be supportive of high-quality water environments introduced earlier in the project. This phase also involves the introduction of new living environments alongside the outfall canals.

Figure 203 - Planned drainage replacements and full road reconstructions (source: City of New Orleans, 2019b).



8 Conclusions

8.1 Answers to the research questions
8.2 Recommendations
8.3 Reflection

8.1 Answers to the research questions

This section returns to the main research question and its sub-questions, stated in Chapter 2.1.3. First, an elaborate answer to the main research is given, supported by brief answers to the sub-questions.

8.1.1 Main research question

How can Orleans Lakeside be made more flood and drought resilient by integrating multi-layered resilience capacities of the built environment, whilst safeguarding consistent design of technical adaptation measures within the urban space?

New Orleans is becoming increasingly vulnerable to extreme weather events and has persistent socio-spatial issues. Along with pressing inequities, stalling repopulation and poor spatial quality, the city faces threats such as rising sea levels, subsidence of low-lying neighborhoods through groundwater pumping, increasing peak precipitation and longer dry spells.

Plans for alternative stormwater management after Hurricane Katrina were a good step towards a new urban water management paradigm, but left two key aspects uncovered, which is the twofold knowledge gap this thesis addresses. The first shortcoming in existing proposals is that they do not consider beyond designing a threshold capacity (preventing damage). Hence, while it is certainly relevant to research how runoff from a T10 rainstorm can be stored, this ignores the reality that New Orleans will be exposed to storms that are far beyond a T10 design storm. The second shortcoming relates to the lack of integration of the proposed interventions with the built environment across scales.

The aim of this thesis was to research how Orleans Lakeside can be made more flood and drought resilient by exploring how a holistic vulnerability framework and consistent design of adaptation measures would translate into a spatial plan. In this plan, the focus is on flood resilience, with drought resilience playing a smaller role.

A thorough vulnerability analysis of Orleans Lakeside on the capacities to prevent damage (threshold capacity), mitigate and recover from damage (coping & recovery capacity) and flexibility (adaptive capacity) provided valuable conclusions on immediate challenges to flood and drought resilience.

Hydro-dynamic modelling exercises and conceptual water balance calculations found that only by totally reimaging the water system from an out-of-sight drainage system to a water system revolving around open water, Orleans Lakeside will be able to handle severe rainstorms. Current practice of incremental, small improvements is by far insufficient. Concerning drought effect mitigation, the most important measure in the proposed design concerns stabilization of groundwater levels by introducing open water bodies. This prevents further exposure of organic soil contents to oxygen, therefore mitigating additional subsidence.

Orleans Lakeside suffers from a high degree of spatial segregation. North-south outfall canals and railroads impair east-west connections, principally for non-automobile modes of transportation. Moreover, Orleans lakeside has lost its sense of place. Open water is completely hidden behind tall floodwalls and there are no traces of the landscape that was before this basin became urbanized. Rigid homogeneous residential zoning increases reliance on automobiles and provides little functional flexibility. As for evacuation, residents are completely reliant on leaving by car as there are no opportunities for local vertical evacuation.

The proposed design for Orleans Lakeside deploys a reimagined water system not only as a way to increase flood and drought resilience, but also act as accelerator for spatial development. Boundary conditions derived from the water assignment calculations result in a heavy presence of open water in the urban environment. With a system of canals and permanent retention ponds, complemented by green infrastructure projects, the design aims to provide the required storage capacity and stabilize groundwater levels for drought and subsidence mitigation. Hence, the designed system moves towards the natural state of wetlands.

As a way to create added value (merger of interest) and address the coping, recovery and adaptive resilience capacities, the design connects improvements to the area's connectivity, quality of public space, programming and evacuation system to the new water system.

The proposed design conceives a new form of urbanization in Orleans Lakeside, one that is much more centered around water. Moving away from homogeneous, rigid suburbia, the proposed design introduces living environments that are offer high quality public space and accessible amenities. These interventions imply consequences for residents' living environment. The proposed plan aims to successfully fuse the new water-based urban environment with desired traditional American neighborhood qualities.

In conclusion, the project makes an effort to contribute to the discourse on climate resilience of New Orleans by showing that a paradigm shift in urban water management not only makes the city more climate resilient, but also holds merits in terms of spatial quality.

Figure 204 - Final proposed design for Orleans Lakeside.



8.1.2 Sub research questions

Urbanism

How can Orleans Lakeside be restructured in a way that reduces vulnerability to flooding and drought?
A new paradigm of urban water management is introduced by restructuring the water system to move towards the natural state of wetlands. Overhauling the urban water system introduces new living environment typologies that are centered around water. Furthermore, by using the hydrological design as accelerator for spatial development, new commercial functions and recreational routes enrich the urban grid of Orleans Lakeside.

How can flood and drought adaptation measures be consistently integrated with the built environment through all scales?
Consistent integration of adaptation measures with the built environment can be achieved through a constant design iteration between large scale and small-scale interventions. The scale of required water buffering capacity implies significant changes to residents' living environment. Only by simultaneously considering macro and micro scale interventions, can a design for Orleans Lakeside be consistent through all scales. This thesis found that by linking improvements in connectivity, spatial quality, programming and evacuation to the water system, a strong link between the macro and micro scale can be achieved.

How to deal with uncertainty regarding the rebuilding and repopulation efforts in New Orleans?
The scenario of high climate change and stagnating population growth implies that changes to the water system should not alter the amount of dwelling significantly. By concentrating open water on vacant and public land, minimal relocation of residents is required. Around open water bodies, however, density is increased to support added commercial programming. Uncertainty in the development of Orleans Lakeside implies that the proposed design for Orleans Lakeside does not have to be implemented as a single project, but is conceived as flexible water system that is adaptive over time.

Water Management

Which areas of Orleans Lakeside are the most vulnerable to flooding and drought?
A SWMM modelling exercise revealed that the lowest areas in Orleans Lakeside suffer the most from flooding due to the absence of local stormwater buffering capacity. However, this is also party attributed to high ground unable to retain water upstream. Figure 74 shows the most vulnerable areas.

How can existing urban features such as city parks be used in managing the water supply?
Extensive, centralized open space offers opportunities for storing water without the need of interfering with private property. However, the two largest parks (City Park and Pontchartrain Park) can only store water of relatively small residential districts that directly drain to these parks. This implies that the majority of the required water storage has to be realized in smaller public parks, in streets and on private property.

What is the performance of finished and currently implemented green infrastructure projects such as rain gardens?
Finished green infrastructure projects currently have an insignificant contribution towards the water assignment. Per catchment the contribution does not exceed 1% of the total required volume. Costs of green infrastructure facilities are around $1000 per cubic meter of storage, while the annual maintenance is about 100 $/m^3.

How can green infrastructure be deployed in managing water surplus and shortage on a small scale?
Water assignment calculations showed that green infrastructure has a large potential in storing runoff from a T10 rainstorm, although the potential differs per catchment depending on the availability of public parks and vacant lots. An additional benefit of green infrastructure facilities is that they can also be constructed on high ground, providing opportunities for local storage instead of only relying on major retention capacity downstream. Finally, with a high infiltration capacity, local recharge of groundwater provides benefits for drought mitigation.

8.2 Recommendations

Recommendations are divided in a section on transferability and a section on further research. The first section elaborates on the applicability of the proposed design for other (delta) cities, while the second section indicates areas for further research which fell outside the scope of this thesis.

8.2.1 Transferability

Although the approach in this report was largely inductive and not deductive of nature, the analytical part as well as the methodology of designing across scales are transferable to other cities. This increases both the societal and academic relevance of this thesis.

The issues facing New Orleans are not unique to this city. The socio-spatial problems and environmental vulnerability defined in this thesis are applicable to many delta cities around the world. Within the American context, Figure 205 shows major cities on the U.S. coastline that are vulnerable to sea level rise and severe precipitation.

There are several factors that make the approach to flood and drought resilience inherently transferable to other American delta cities. Firstly, the widespread use of grids in American cities allows for the development of a powerful typological toolbox. Problems relating to poor quality of public space, homogeneous zoning and spatial segregation are similar to those in New Orleans. Second, like New Orleans, most American delta cities rely on mechanical drainage and heavy use of grey infrastructure to handle stormwater. Finally, the geographical context of New Orleans and its resulting challenges (seepage, low slope gradient, subsidence) applies to several other cities as well.

The analytical part of this thesis, exploring flood and drought resilience considering all capacities, is well transferable to other delta cities. The approach taken in this report covers the full spectrum of climate resilience, from resisting small weather events to adapting to extreme weather events.

Using interventions in the water system as accelerator for urban development with the intent on creating a merger of interest is one of the primary outcomes of this thesis. While design decisions specific to the context of New Orleans are not transferable to other cities, this is an approach that hold a large potential in any flood resilience project.

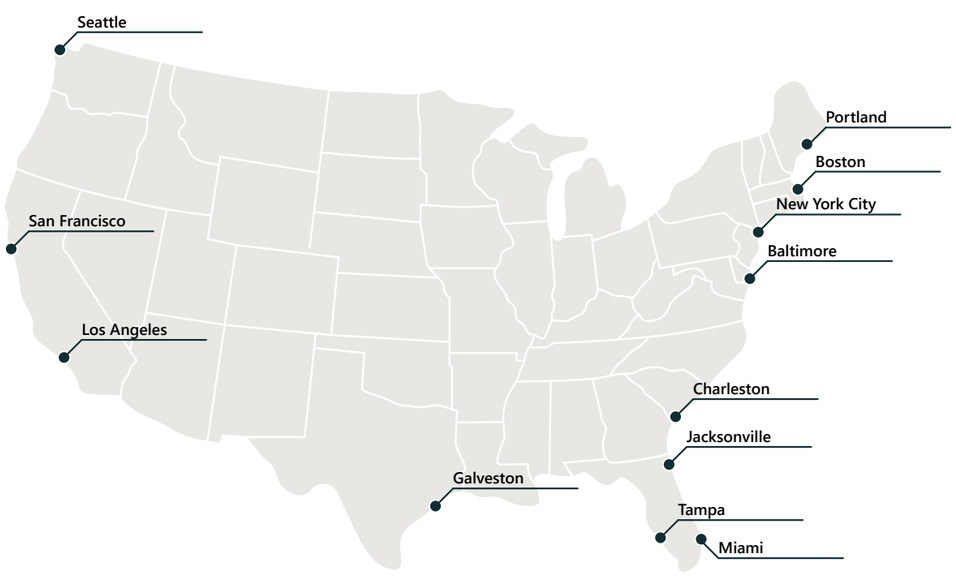


Figure 205 - Climate Central (2012), elaborated by author.

As in New Orleans, interventions in the urban water management system will have far reaching implications for the living environment of residents. Dealing with this issue appropriately is key to making a design successful, and requires adaptation and sensitivity to the local context. This thesis can act as precedent for how basin scale interventions can be translated into spatial consequences for residents.

8.2.2 Further research

During two field trips to New Orleans, it has become apparent that no project is feasible without the cooperation of all relevant stakeholders. The issues of property rights and lack of trust in government agencies and utilities require a synergistic design approach that involves all stakeholders. Only by creating mental ownership of the plans and full support of residents, far-reaching interventions as proposed in this report are attainable.

In addition to social feasibility, additional research has to be done with regard to financial feasibility. While this plan incorporates a concise strategic component in which developers would carry a share of the financial burden, the majority of the financial responsibility still lies with the government. It would be worthwhile to study how the large-scale interventions as proposed in this thesis can be made bankable to reduce the reliance on municipal, state or federal funds.

In addition to the quick scan on green infrastructure in this report, it is advised to carry out extensive green infrastructure tests in the field to obtain a more reliable estimation on their contribution to the water assignment. The performance of such facilities might be significantly better or worse than the findings in this report conclude.

As this is a joint Urbanism/Water Management project, this thesis only addresses resilience against extreme weather events such as hurricanes within the urban context. Much of this resilience, however, depends on efforts outside the urbanized area. An even more holistic approach involving hydraulic engineering would allow for a better coordination between resilience projects within and outside the urban perimeter. An example is to research to what extent wetland nourishments and artificial islands in Lake Pontchartrain can increase flood resilience.

For reasons earlier argued in this report, the proposed design for Orleans Lakeside is based on a T10 rainstorm. However, it would be worthwhile to dive deeper into what effects climate change may have on the intensity of rainfall. Currently there are discussions on the validity of the stated probabilities of rainstorms. Some argue that what once was a T10 rainstorm, now occurs multiple times per year. Shifting from a T10 rainstorm to a T25 rainstorm would likely imply large changes to the proposed design.

It is advised to validate the performance of the used SWMM model with actual measurements. Once this is done, elaborate modelling research on the effectivity of the proposed measures in the design is made possible.

8.3 Reflection

8.3.1 Reflection on scope of the project

The complex problem field of flood and drought vulnerability in New Orleans resulted in a broad initial scope. Many different fields that touch upon this issue are in some way related to urbanism and water management. However, to make the thesis manageable in one year, a selection of key variables was made that allow for an integrated approach between both studies. As the thesis became centered around combining an engineering and design approach to increasing flood and drought resilience, issues of social equity and financial feasibility became less important. This is illustrated in Figure 1, where the green circle indicates the broad problem field manifested in six key areas. The thick green line shows the reach of this thesis, which is dominated by urban design and civil engineering, complemented with a small portion of implementation and feasibility studies. The fields of social science and policy development are not covered in this thesis at all.

During the process, and especially during the two visits to New Orleans, the importance of the other fields increased again. The discrepancy that followed from these encounters is explained further in the reflection on stakeholder engagement.

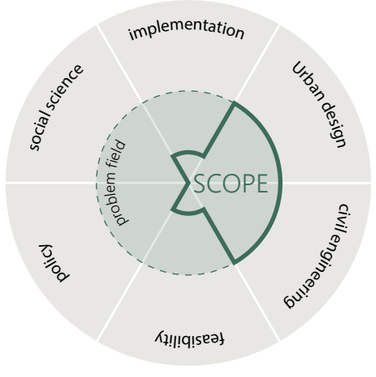


Figure 206 - Scope of the thesis versus total problem field.

8.3.2 Reflection on methodology

Integration of design and engineering

A combined thesis between Urbanism and Water Management resulted in a methodology that contains both engineering and design-focused methods. The methodological chapter in this report presented six main methods to address the knowledge gap and arrive at a design proposal. The six methods are: literature review, mapping, fieldwork, modelling, creating scenarios and research by design. This section discusses the main roles of each method and includes a paragraph on the encounters between engineering and design.

Literature review
The three main theoretical themes (climate vulnerability, urban regeneration, green infrastructure) provided a solid basis for the project and proposed designs. Furthermore, the more elaborate theoretical study into the potential of denser forms of urbanization in reducing flood risk yielded insight that formed the basis for the final proposed design. In the course of the project the focus of the literature review changed for certain themes. While green infrastructure became less critical to the project, the importance of subsoil processes increased, requiring more research in this field.

Mapping
Mapping, in the broadest sense of the word, was a key method during this thesis. It provided tools to overlay spatial aspects concerning both Urbanism and Water Management, revealing interesting synergies and potentials.

Fieldwork
Two visits were made to New Orleans: one in the early stages of the thesis and one near the end. The first visit was intended to get acquainted with the project area and meet stakeholders, while the second visit would yield measurement data on green infrastructure facilities. Due to contract related difficulties between Deltares and the municipality of New Orleans, no actual field testing of green infrastructure projects took place. While it is a pity that this peril reduced the importance of green infrastructure in this report, it made it possible to use the second visit as an opportunity to validate the proposed design for multiple groups of stakeholders. Apart from the direct feedback given in Section 7.4 (Evaluation), these sessions helped to regain sight on the core of the proposal. In this sense, both visits to New Orleans were very fruitful.

Modelling
An advantage of the SWMM model was the opportunity to carry out an independent flooding analysis. Complemented with the new conceptual urban water balance model, this gave the project more credibility. Unfortunately, the usefulness of the SWMM model was significantly reduced due to the absence of any validation data. Hence, the models primary use was to provide a qualitative flooding analysis. In combination with the counter-intuitive user interface of SWMM, it proved to be not feasible to model the entire proposed design.

Creating scenarios
As the analysis conclusions reiterated the complex problem field and many boundary conditions for design, the creation of different scenarios eventually took a smaller role than initially planned. The final design is based on a simple scenario using two primary variables: population and climate change.

Research by design
The extensive problem field contains issues and processes that are individually well researched, but rarely come together in a single design. In order to have a successful research by design process, it was required to first conduct in-depth analyses on individual processes.

The research by design phase became more prominent upon completion of the modelling exercises. As a starting point, the hydrological design layer provided anchor points during the design cycles. When aligning the hydrological design layer with all other layers of the design (connectivity, spatial quality, functional design & evacuation), adjustments followed from an iterative approach. This continued on smaller scales. For instance, the elaboration of a demonstration project changed the role of permanent detention ponds in this segment of the hydrological design, as the initially estimated value was found to be unrealistic. A second example of interaction between research and design is the process of designing street sections containing elements of the hydrological design. A constant exchange took place between boundary conditions found in literature and locations specific design requirements.

Overall, there was a strong dialogue between research and design in this project, although the broad scope and intended merger of interest made it difficult to compress the design cycles into a chronological report.

Urbanism – Water Management synergy in methodology
Figure 207, which was produced for the methodology chapter, gives an overview of how both studies relate differently to the methods in this project. While some methods, such as literature review, modelling and conducting fieldwork were carried out individually for both domains, a strong synergy started to emerge during mapping and research by design exercises.

Data collection

While some data was easily accessible, certain datasets took determination and a long time before they were acquired. Most publicly available datasets, such as DEMs, demography statistics and municipal zoning ordinances, were directly accessible due to the abundancy and openness of American public databases. However, data that might have controversial contents, took much more effort to obtain. An example is data on the construction and maintenance costs of green infrastructure facilities. As no field testing of green infrastructure took place, this research was reliant on data provided by other actors for the green infrastructure analysis. Companies were hesitant to share design, construction and maintenance costs, perhaps with the fear of being marked 'too expensive' or 'inefficient'.

Having the SWMM and urban water balance model helped to gain independence from external actors. Being able to autonomously carry out flooding analysis and water assignment calculations greatly reduce dependency on other companies. Furthermore, this helped to validate the results found by the Urban Water Plan.

	URBANISM	WATER MANAGEMENT
METHOD 1 literature review	• Studying US planning culture. • Determining boundary conditions for urban regeneration.	• Defining the technical state of the art. • Investigating ways to analyze adaptation measures. • Defining possible technical solutions.
METHOD 2 Mapping	• Overlaying maps for spatial analyses. • Combining socio-spatial and technical data. • Uncovering the scales of the system and their interrelations	• Simplifying to understand the water system.
METHOD 3 Fieldwork	• Grasping socio-spatial processes. • Studying spatial quality. • Interviewing designers & residents.	• Gathering data. • Understanding the water system through field measurements. • Interviewing engineering experts.
METHOD 4 Modelling	• Determining the relative climate vulnerability.	• Determining dimensions. • Producing a hydraulic & hydrological design.
METHOD 5 Creating scenarios	• Evaluating socio-economic development. • Developing a vision for the future.	• Determining hydraulic & hydrological boundary conditions.
METHOD 6 Research by design	• Deploying urban design in iterative design loops to explore socio-spatial interventions.	• Intensive design process to design effective systems.

Figure 207 - Differing perspectives on methods.

8.3.3 Reflection on success of the design

Concessionist standpoint for interventions

This thesis, being a university project, provided the liberty to expand on the concessionist stance taken in Chapter 5 (Scenario & Vision). It is no surprise that the current course of action in New Orleans is much more conservative, where even replacing traditional grey drainage infrastructure can lead to a backlash and possibly lawsuits. As this sensitivity around changing people's living environment already became clear during the first visit to New Orleans, the proposed design highly values treating this issue with respect and subtlety. However, as the concessionist stance advocates, New Orleans needs an overhauled water system to keep from flooding multiple times per year.

Success of interventions

With the proposed design, the author is of the opinion that Orleans Lakeside will not only become more flood and drought resilient, but that it also improves upon key aspects such as connectivity and quality of public space. From this perspective, this project is deemed to be successful.

However, it is crucial to identify possible unwanted side effects of the proposed design. An example is displacement through gentrification, which is already a concurrent issue in New Orleans. By making Orleans Lakeside safer and a more pleasant neighborhood, unintentional gentrification by increasing value of properties presents a very real threat to the current population. Moreover, even within the project area there are stark differences. Wealthy Lakeview, west of City Park, would have less trouble with a gentrified living environment than Gentilly. By concentrating large water bodies on vacant or public land and rebuilding a large share of the existing housing typologies, this plan aims to minimize displacement.

8.3.4 Reflection on stakeholder engagement

The two visits to New Orleans made it clear that before a plan such as the one advocated for in this thesis has a chance of succeeding, a lot of work has to go into community involvement and restoration of trust in government departments.

The bold interventions suggested in this thesis sparked a debate on several concerns that residents of New Orleans have regarding the implementation and maintenance. One issue brought up during a resident feedback session was that if people do not trust the government in maintaining traditional drainage infrastructure and roads, they will most likely not trust the municipality in adequately maintaining canals, bridges and open water bodies. This lack of trust illustrates the disconnect between residents and municipal plans. An other concern was that open water will bring about danger of mosquito-borne diseases. While this issue can be mitigated by proper circulation of surface water, it is a legitimate concern of residents.

New Orleans has a strong civic society that consists of numerous groups and organizations to fuel bottom-up initiatives across the city. On the topic of flood and drought resilience there is also no lack of community initiatives. An example is ISeeChange, a website and app that allows residents to upload real-time weather observations with the aim of creating a grassroots platform to monitor climate threats to communities. A second example is The Blue House, which is a not-for-profit organization that hosts presentations and debates on relevant topics. While this broad collection of community initiatives certainly gives a voice to residents, this is rarely put to use in the development of municipal policies and plans.

Due to time constraints and limited resources, it was not possible to extensively test the proposed design in this thesis with actual residents. However, it is extremely important for the municipality of New Orleans to pick up where this thesis left: to have intense co-creation sessions and create true ownership amongst residents. Therefore, this thesis strongly advises the municipality of New Orleans (and preferably regional partners as well) to involve the enormous civic society that New Orleans has to offer into actual decision-making processes. Only by

integrating local stories it is possible to create a broad support base for a different approach to water management. Actively involving residents in design sessions helps to spread awareness about the vulnerable location of New Orleans and how interventions can create a safer urban environment that improves on other qualities as well. Ideally, co-creation sessions create a sense of mental ownership of the plans amongst residents.

Reflecting back on this thesis, the lack of community testing makes it only a partially successful plan. The aspects that were originally placed in the background to make this thesis manageable in one year are essential if this plan is ever to be implemented. This opens many possible topics for further research. By reconsidering this project from different standpoints, such as community integration, implementation strategy or financial feasibility, the outcome would definitely change.

8.3.5 Reflection on transferability

As stated in the recommendations on transferability in Section 8.2 (Recommendations), the analytical approach as well as the method of designing across scales is well transferable to other American delta cities. This approach can be conducted independently from political interference. However, carrying out a research and design methodology is something completely different than the actual implementation of a plan. As earlier stated, deeply rooted trust issues between residents and government departments and utilities obstruct the implementation of a provocative design proposal.
During a presentation at the Municipality of New Orleans, it became clear that the concepts introduced in this thesis might better suit the large Vietnamese community in New Orleans East. This provides an interesting retrospect on implementation. This thesis advocates to start development near Bayou St. John, as connecting new water-centered development to existing high quality public space would likely convince residents of the added value of the proposed design. However, it is worthwhile to research opportunities for implementing such inventions in New Orleans East as a pilot, as this could make implementation in Orleans Lakeside more feasible.

As it stands, the suggested approach and design might work better in cultures where there is generally more trust in the government. In the Netherlands, for example, high taxes result in a well-maintained road and drainage network. In addition, there is more collective acceptance and awareness of the role of water in the urban environment. Open water is often seen as amenity instead of potentially dangerous urban feature. However, this does not mean that there will not be resistance from current homeowners against changes to their living environment. The issue of property rights and relocation is as valid in the Netherlands as it is in New Orleans.

Aside from a different cultural setting, the proposed design might become more feasible in the future. Generally, the two visits to New Orleans made it clear that there is a sense of urgency amongst the younger generation that large scale interventions are needed to keep the city livable. However, most proposals are blocked by institutional rigidity and traditional values, which only allow for conventional, incremental improvements to the water system. The acceptance of a new paradigm in water management takes time. It could take decades before significant action is being taken, but that leaves the city vulnerable to flooding and drought for a long time.

8.3.6 Reflection on alternative viewpoints

Not surprisingly, the combination of water management and urbanism results in a project in which water has a dominant role. For evaluation purposes, it is valuable to construct other possible paths if not water management, but other disciplines would take a leading role. Although there are unlimited possible approaches to this project, this subsection discusses the viewpoint of a landscape architect, financial feasibility, social feasibility and mobility.

(Figure 208) From the view of a landscape architect, the most fundamental principle underlying the project would be to return to the natural state of wetlands. In order to significantly increase landscape legibility, a system of bayous would traverse the rigid urban grid. This creates local tensions between two extremes: the natural system and the geometrical urban system. Corresponding with the natural system, an open connection to Lake Pontchartrain would introduce brackish water into the city. This supports local biodiversity, but requires a total shift away from the current fresh water-focused approach to landscaping in Orleans Lakeside.

(Figure 209) From the view of financial feasibility, the focus would be to design profitable public-private partnerships that do not depend on municipal funds. Interventions would be concentrated in locations that offer a high chance of return on investment, while financially risky project are to be avoided. In this scenario, the outfall canals would most likely remain untouched. Projects that are attractive for developers to invest in are likely to be focused alongside major boulevards that currently attract high amounts of traffic, and on public land.

(Figure 210) From the viewpoint of social feasibility, the focus would be to include local stories in a bottom-up approach. In this case, the displacement of residents is absolutely unwanted, which only leaves acupuncture interventions as a desirable approach. Furthermore, as the creation of communities is key in giving value to local stories, it is key to dive deep into the different communities and subtle differences between neighborhoods. Regarding inequity, the focus should be to prevent displacement by gentrification through policies that protect financially vulnerable residents. This is especially relevant for Gentilly, the area to the east of City Park.

(Figure 211) From the viewpoint of mobility, the focus would be on diversifying the modal split and reducing automobile dependency. Ideally, all residents of Orleans Lakeside would be able to carry out all trips without the need to use a car. This requires a vastly expanded public transport network, spreading commercial functions to increase walkability and the implementation of ‘complete streets’ (streets that accommodate automobiles, bicycles and pedestrians). A major condition to better connection by public transport is that a higher density is required around transport hubs in order to provide sufficient potential users. This contradicts the projected scenario of population stagnation.

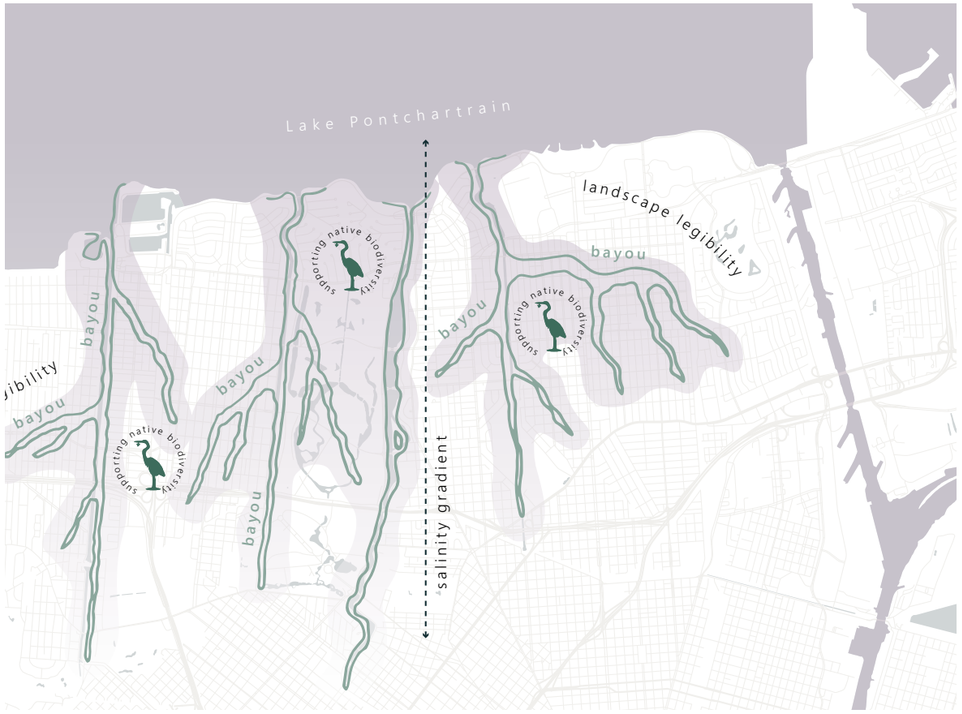


Figure 208 - Project concept from the view of a landscape architect.



Figure 209 - Project concept from the view of financial feasibility.



Figure 210 - Project concept from the view of social feasibility.

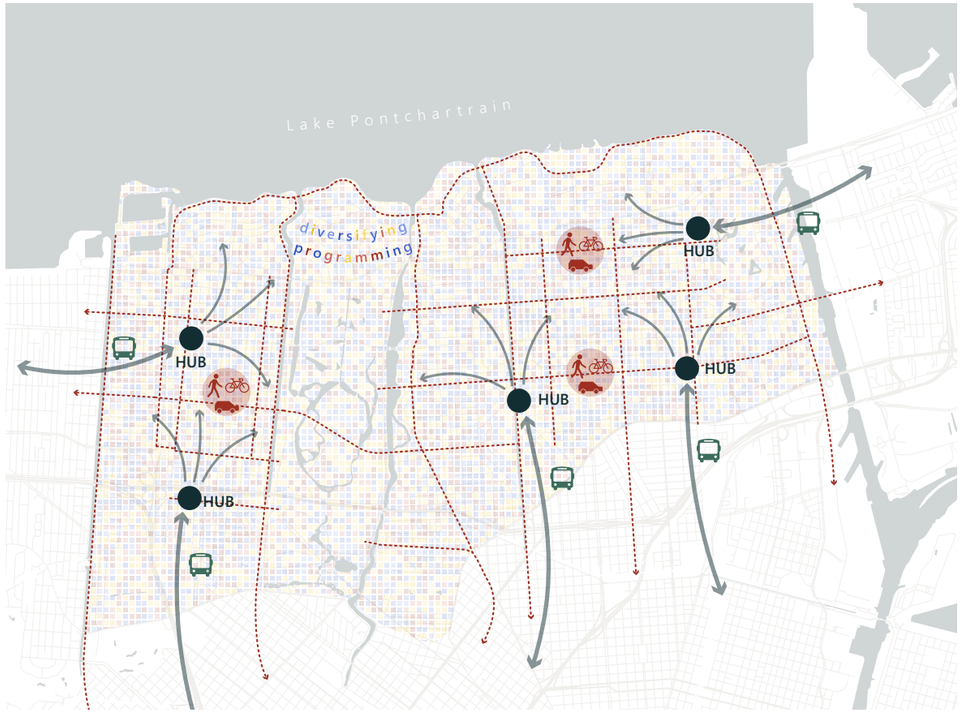


Figure 211 - Project concept from the view of mobility.

500 m 1 km

500 m 1 km

8.3.7 Reflection on academic, societal and ethical relevance

Scientific relevance

The scientific relevance of this research project lies within the power of actively combining an engineering and design approach. There is a growing body of research available on how to deal with urban stormwater, as well as on adaptive urban planning. However, the potential of combining these two fields and creating a strong synergy is largely unexplored. This thesis aimed at closing this gap.

In the proposed design, the synergetic relationship between engineering and design is present from the larger scale to the smallest scale. At many occasions boundary conditions from one discipline influenced the contribution of the other discipline. This thesis shows that joining engineering and design can be fruitful for the final design. However, it should be noted that these two disciplines do not make for a perfect, water-tight proposal. As stated before, the involvement of community engagement programs and simultaneous development of appropriate planning schemes is equally important in creating a feasible plan. This is something that cannot be done in a single thesis.

Societal relevance

The intended societal relevance of this project was to address the acute threat of flooding and drought in New Orleans using an approach that demonstrates a merger of interest. When presenting this plan to different groups of stakeholders in New Orleans, the integration of design and engineering yielded a positive response. Design proposals such as constructing canals were not only perceived as purely an engineering-based intervention, but were met with an at least partially positive response due to the added benefits in terms of recreation and quality of public space. Furthermore, calculations behind the hydrological design demonstrated that New Orleans will not become flood and drought resilient with the current approach of small, politically safe interventions. Also, by connecting to the Urban Water Plan and elaborating on previously untouched parts of the proposal, this thesis aims to continue the argumentation in favor of radical changes to the urban water system.

Ethical relevance

The major ethical dilemma manifested in this thesis relates to inequity. The omission of a socio-economic based approach and subsequent minimal coverage in this thesis raises a question of who would benefit the most from the proposed design. Upgrading the water system and making Orleans Lakeside more flood and drought resilient is in everybody's interest, but local dynamics in the housing offer might heavily favor some residents more than others. The issue of displacement through gentrification, as earlier stated, presents a real danger. Here lies a major responsibility for the government; protecting current residents from displacement should be a key focus when implementing such far-reaching interventions. The final design does not discriminate between neighborhoods of different income levels, as it assumes an equal effort by the municipality regardless of the location.

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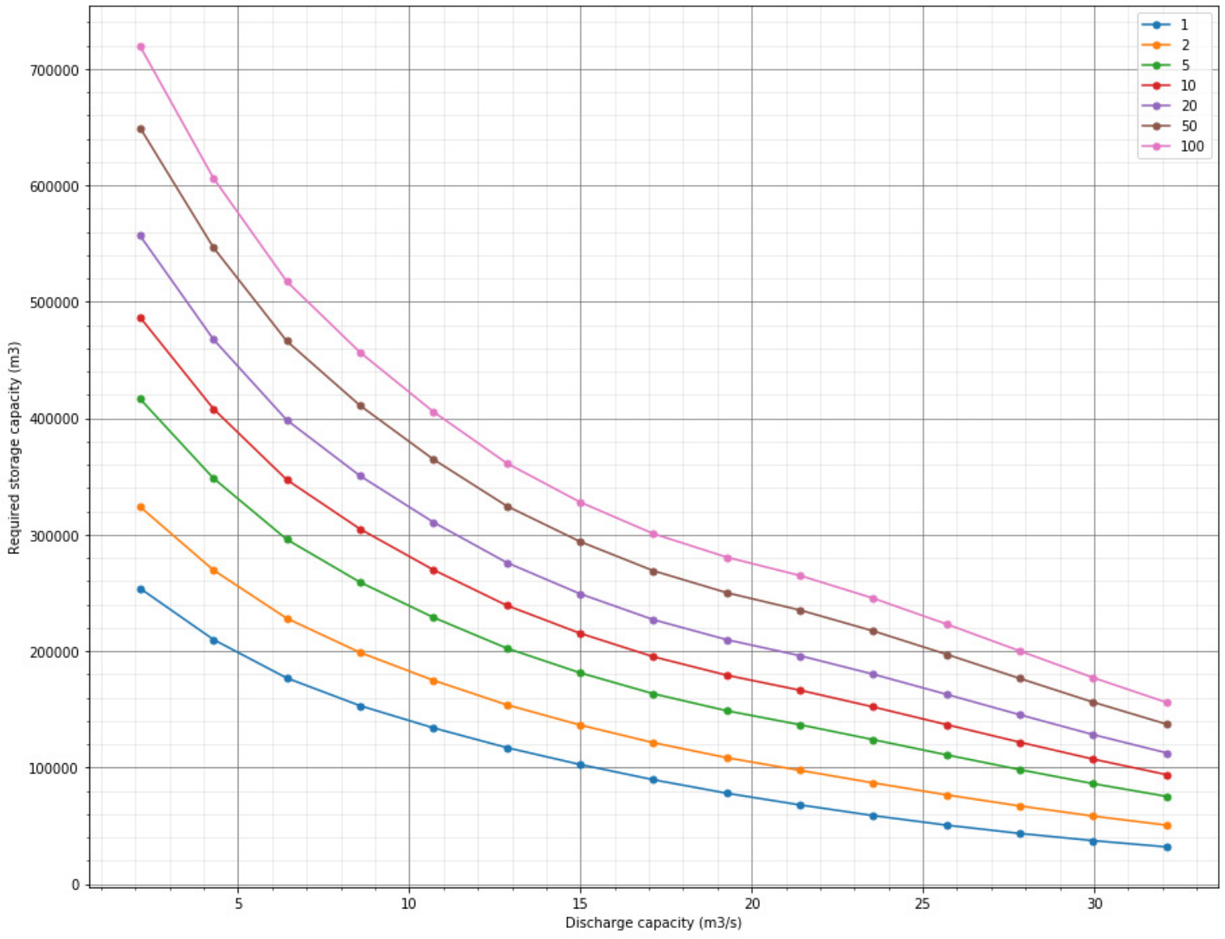
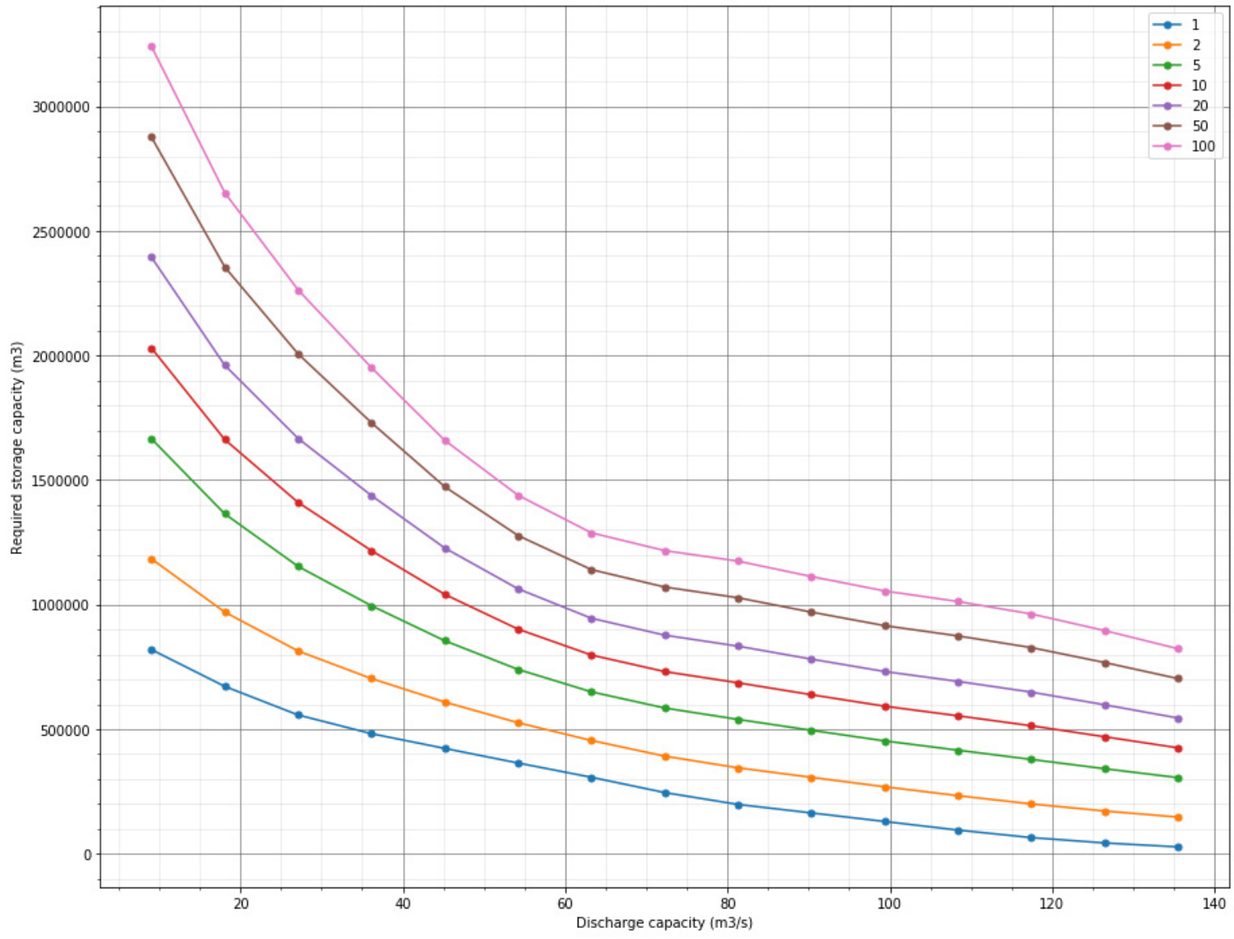
Appendix

Appendix A - new SDF curves

Pumping station 3 north

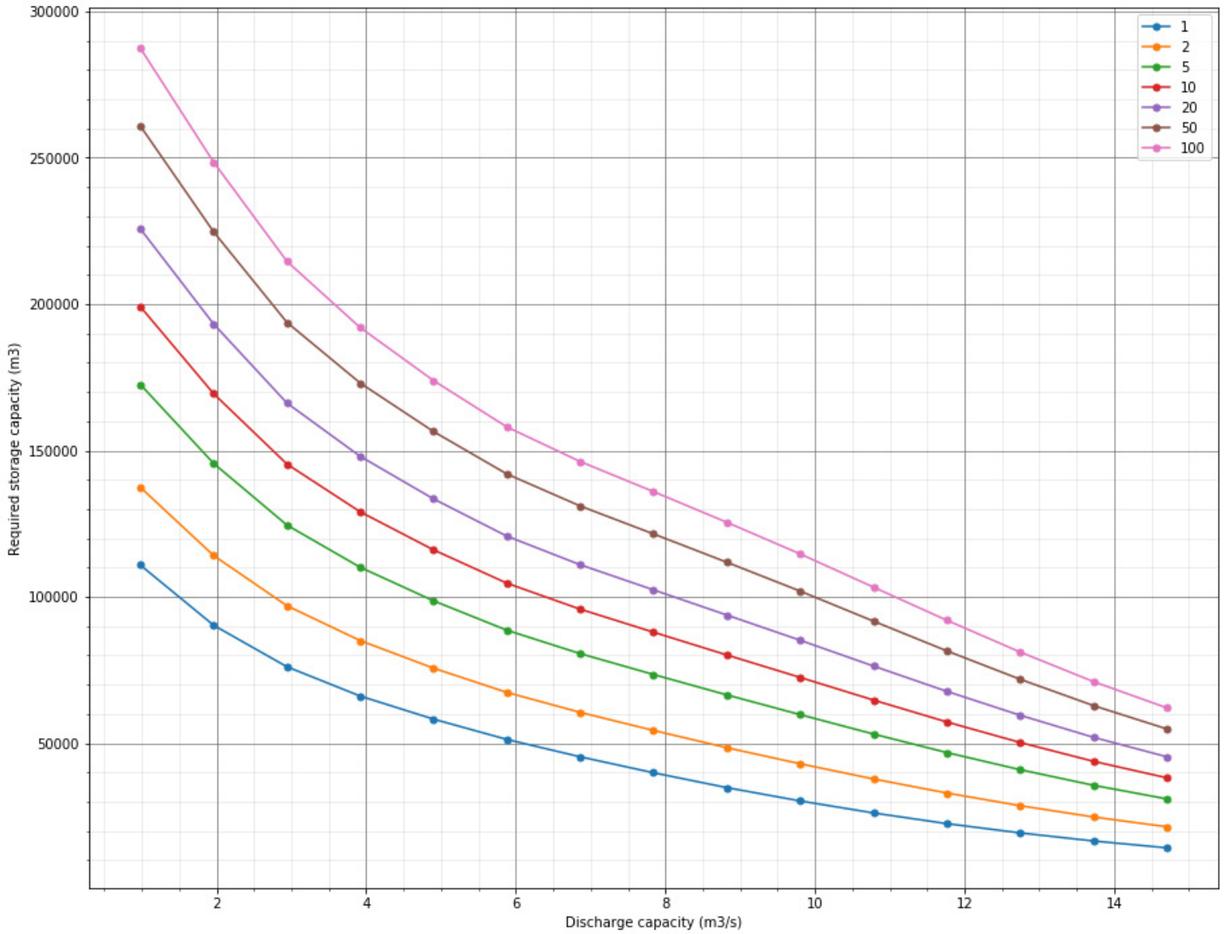


Pumping station 4

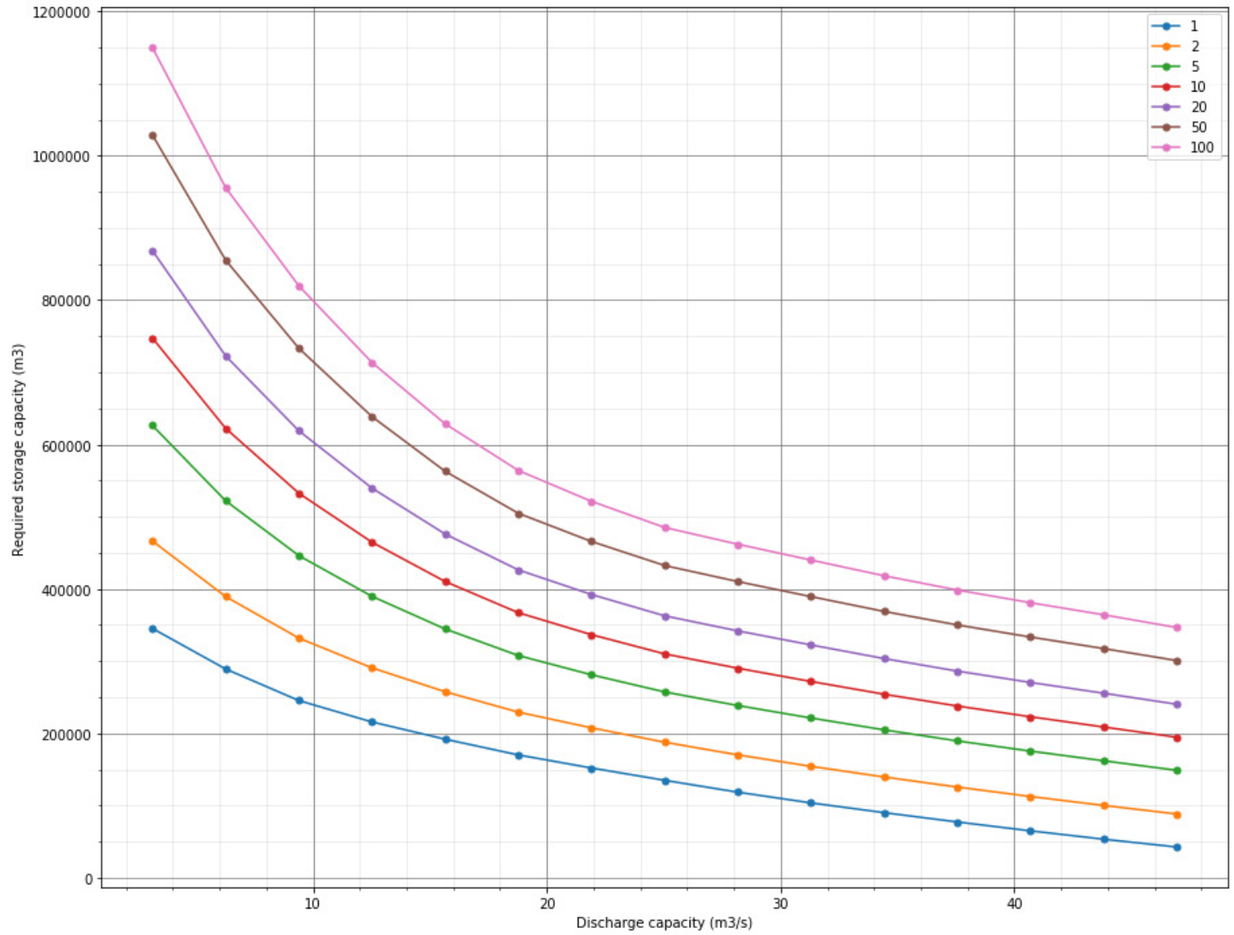


Appendix A - new SDF curves

Pumping station 6 north

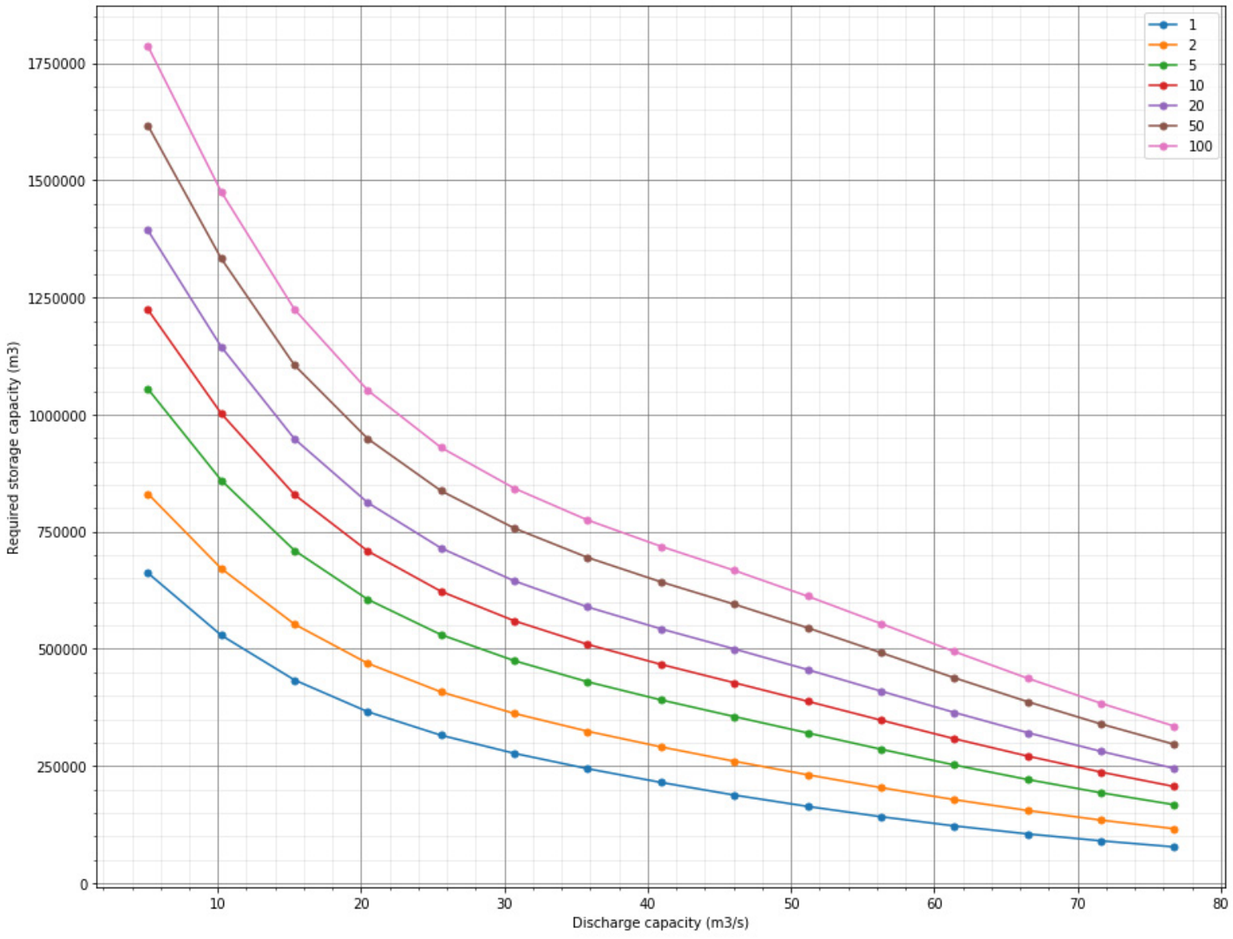


Pumping station 7 north



Appendix A - new SDF curves

Pumping station 12



Appendix B - green infrastructure master file

Designer	Name	Address	Longitude	Latitude	Shape	Material	Subsoil	Description	Catchment	Size surface area [sf]	Size surface area [m2]	Designed Capacity [cf]	Designed Capacity [m3]	Estimated capacity [m3]	Deepest depression [m]	Construction costs [$]	Annual maintenance costs [$]	Design cost [$]	Costs per cubic meter [$/m3]	Costs: annual costs per cubic meter [$/m3]
Linfield, Hunter & Junius, inc.	Carrolton Shopping Center	510-550 N. Carrollton Avenue	-90.09616	29.97723	Linear	Gravel		Rain garden, Ditch garden, Pervious pavement	adjacent parking			12268	347			523177.00	6900.00		1506.02	19.86
Dana Brown & Associates	City Park Golf Course Mainte	1059 Filmore Ave, New Orleans, LA 70124	-90.09143	30.01535	Linear	Grass, shrubs		Bioswale	adjacent grass	5046	469	4037	114		0.15	50248.00	9120.00		439.56	79.78
		3403 Freret	-90.09594	29.93654	linear	Grass		ZONING DOCKET 064/16 – Request by 2500 LOUISIANA LLC, for a Conditional Use to permit medical facility in an HU-MU Historic Urban Neighborhood Mixed Use District on Square 595, Lots T, X-2 and 7, in the Sixth Municipal District, bounded by Louisiana Avenue and Freret, Delachaise and South Robertson Streets. The municipal addresses are 2500-2526 LOUISIANA AVENUE. (PD 2)	building roof, site runoff	776	72	2880	82		0.55	82747.00	7000.00		1014.65	25.45
Dana Brown & Associates	Milne Municipal Boys Home	5420 Franklin Ave, New Orleans, LA 70122	-90.05145	30.01433	Linear	Grass, shrubs		Bioswale	adjacent parking			7214	204			117873.00			577.02	
FutureProof	Medard Nelson school	3121 St. Bernard Avenue	-90.0746	29.98994	Linear	Gravel		Bioswales, rain gardens, bioretention cells	site runoff				0							
-	The WEB	3601 General Taylor Street	-90.10122	29.94615				Stormwater Lot	site runoff and adjacent street				0							
Mathes Brierre Architects	Blood Center parking lot	2609 Canal St, New Orleans, LA	-90.08598	29.96555	Linear	Lush green		Bioswales	adjacent parking				0							
Broadmoor Design Group	Columbia Parc Health Center	3943 St Ber	-90.07897	29.99722	linear	Native vegetation		Stormwater Management Plan for the Columbia Parc Health Center		22308	2072	2722	77		0.30	37620.00	5000.00		488.07	64.87
		1902 St Ber	-90.06774	29.97563				Stormwater Plan for the City of New Orleans.		3780	351	1936	55			172242.00	6165.00		3141.87	112.46
Reed-Hilderbrand	New Orleans Museum of Art	1102 City Pa	-90.09504	29.98858		Native vegetation		Stormwater management improvements and water features to be added to NOMA sculpture garden.		954	89	1983	56		0.30	26000.00	1200.00		463.03	21.37
Ascension Group	Ochsner emergency room	4100 Canal	-90.10139	29.97449	linear	grass		Design Review and Stormwater Management Plan Review for new emergency medical facility.												
Raymond C. Bergeron Jr. Architects	Key's Fuel Mart	4401 N Rob	-90.02984	29.96892	Linear	native vegetation		Stormwater Management Plan review for new construction of a gas station				1287	36			107500.00	30000.00		2949.75	823.19
Spackman Mossop & Michaels	The Good Shepherd School	1817 Agricu	-90.06735	29.98744				Stromwater Management plans for a new two story elementary-middle school in a MU-1 District												
Eskew+Dumez+Ripple	Rosa F. Keller library	4300 S Broad Ave, New Orleans, LA 70125	-90.10354	29.94879	Other	Grass, Louisiana Iris		Rain garden	building roof				0							
Trapolin Peer Architects	Good Counsel Apartments	1215 Louisiana Ave, New Orleans, LA 70115	-90.08915	29.92473				Rain garden				2221	63		0.15					
Daly Sublette Landscape Architects	1508 & 1524 Orleans Avenue	1508 Orleans Ave, New Orleans, LA 70116	-90.07203	29.96318				Rain garden with multiple elements.		705	65	1589	45		0.46	48020.00	3600.00		1067.22	80.01
Dana Brown & Associates	Tri-Centennial Place parking l	53 Dreyfous Dr, New Orleans, LA 70119	-90.09677	29.98569	Other	Native vegetation		Rain garden	adjacent parking	12820	1191	9869	279							

Appendix B - green infrastructure master file

Dana Brown & Associates	NORA stormwater detention	5019 Press Drive	-90.04187	30.01076	Linear	Grass. native vege	muck	Rain garden	site runoff and adjacent street			4694	133		0.60					
Dana Brown & Associates	NORA stormwater detention	5302 Wildair Drive	-90.06698	30.01228	Linear	Grass. native vege	clay	Rain garden	site runoff and adjacent street	10432.74	969	11898	337		0.60					
Dana Brown & Associates	NORA stormwater detention	8641 Forshey Street	-90.11841	29.96651	Bowl	Grass. native vege	clay	Rain garden	site runoff and adjacent street			855	24		0.40					
Eskew+Dumez+Ripple, Daly-Sublette Landscape Architects	L. B. Landry high school	1200 L. B. Landry Avenue	-90.03996	29.94245	Other			Retention ponds, stormwater detention, irrigation tanks,	building roof				0							
Mathes Brierre Architects	Muses apartment homes	1720 Baronne Street	-90.07918	29.93854				Rain garden, bioswales, curb cuts, pervious concrete	adjacent parking				0							
Eskew+Dumez+Ripple	Bioinnovation Centey	1441 Canal Street	-90.07462	29.95776		Gravel		Bioswales, pervious concrete, water recycling air conditioning unit, underground retention systems	building roof				0							
Global Green USA. FutureProof. Gro	Community Development an	5400 Douglas St., New Orleans. LA	-90.02034	29.95562				Bioswales, Permeable pavers, Raised catch basins for infiltration, Raingardens, Cistern storage		2700	251	5000	142							
Dana Brown & Associates	Dillard University	2601 Gentilly Boulevard	-90.06654	29.99344				Bioswales, pervious concrete, pervious pavers, biorentention basins, green roof, rainwater harvesting	building roof			245349	6948							
Dana Brown & Associates	Central City GI Project	2415 South Galvez Street	-90.09488	29.94835				Stormwater Lot	site runoff and adjacent street			2769	78							
Gaea Engineering Consultants, LLC	Aurora Raingardens	6000 Carlisle Ct.	-89.99136	29.91355	Bowl	Small planting		Rain garden	site runoff and adjacent street				0							
Waggonner & Ball Architects, Future	Sacred Heart Arts & Athletics	4529 Carondelet St., New Orleans, LA	-90.10384	29.92755	Linear	Gravel		Rain garden	building roof	18000	1672	2400	68							
Waggonner & Ball Architects. Future	Brother Martin Chapel	4401 Elysian Fields Ave, New Orleans. LA	-90.05921	30.00302	Bowl	Grass		Rain garden	building roof	24000	2230		0							
Waggonner & Ball Architects. Avegn	City Park Administration Buil	1 Palm Drive, New Orleans. LA	-90.09938	29.99259	Bowl	Grass		Bioswale. rain garden. pervious concrete	building roof	24000	2230	8150	231							
Dana Brown & Associates	Capital One Bank	4625 Airline Dr., Metairie, LA	-90.18061	29.97582	Linear	Gravel		Rain garden	adjacent parking	13100	1217		0							
Evans + Lighter Landscape Architect	Carlson residence	2137 South Lopez St., New Orleans. LA	-90.10753	29.94968	Other	Native vegetation		Constructed wetlands, for more consistent soil moisture and groundwater recharge	building roof	5600	520		0							
Evans + Lighter Landscape Architect	Klingman residence	1309 Harmony St., New Orleans. LA	-90.08755	29.92618	Other	Native vegetation		Constructed wetlands. detention ponds	building roof	2500	232	227	6							
Dana Brown & Associates	Abrams Elementary	6519 Virgilia	-90.01629	30.02075				Bioretention Cells. Bioretention planter				1272	36							
Dana Brown & Associates	Campus Federal - Tulane Ave	2200 Tulane	-90.08543	29.95905				Bioretention Cells, pervious concrete				966	27							
Dana Brown & Associates	Cherokee Street	Cherokee St	-90.13097	29.93777				Bioretention Cells			0	183	5							
Dana Brown & Associates	City Hall Bioswales. WEF 201	1400 block	-90.07841	29.95046				Bioswale. rain garden				800	23							
Dana Brown & Associates	City Park Wetlands	4 Golf Drive	-90.09287	29.99267				wetland				134667	3813							
Dana Brown & Associates	Lafitte Greenway Implementa	2200 Lafitte Ave., New Orleans, LA 70119	-90.07958	29.96617				bioswales, bioretention cells, pervious concrete. street basins (not completed)				153765	4354							

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Dana Brown & Associates	Mid City Townhouses	3701 Bienvi	-90.09577	29.97419				Bioretention Cells and Pervious pavers				6308	179								
Dana Brown & Associates	NO DPW Multi-Purpose Site	755 South J	-90.09894	29.965				Bioretention Cell, aggregate parking with pervious pavers, retention				7315	207								
Dana Brown & Associates	NORA Lot - N. Claiborne Aver	5703 N. Clai	-90.01291	29.96618				detention basin				2455	70								
Dana Brown & Associates	Port Orleans Brewery	4124 Tchou	-90.09826	29.917				Bioretention Cells				1617	46								
Dana Brown & Associates	S&WB Galvez Lot	2423 & 242	-90.09509	29.94814				Rain garden				20768	588								
Waggonner & Ball Architects	K-8 Charter school	3815 St Ber	-90.07783	29.99631	bowl			Design Review and Stormwater Managemrnt for a K-8 charter school within the Columbia Parc Development		2127.6	198	2517	71		0.61	46788.00	7200.00		656.46	101.02	
Office of Jonathan Tate		1917-1923 I	-90.06717	30.00835	Bowl			Stormwater Management Plan Review for a scattered site housing development over 1 acre.		7752	720	3397	96			37255.00			387.30		
Spackman Mossop & Michaels	Edna Karr High School	4400 Gener	-90.00859	29.93525	Bowl			Applicant seeks stormwater review for the new construction of a 158000 sf high school building Lot is currently undergoing subdivision per the Orleans Parish School Board.		14988	1392	7494	212		0.15	331991.82	10839.49		1564.48	51.08	
Mithun	Louisiana Children's Museum	1102 City Pa	-90.09504	29.98858	bowl			Applicant is requesting a stormwater management review to construct a Louisiana Children's Museum Village within City Park	7 north			4424	125		0.37	11600.00	3600.00	3600.00	92.60	28.74	
Studio WTA	Mussafer Hall - Tulane Univer	6750 Freret	-90.11738	29.94337	bowl	Native vegetation		Mussafer Hall - Tulane University Stormwater Management Plan		396	37	198	6			2055.00	1000.00		366.52	178.36	
Spackman Mossop & Michaels	St Thomas & 9th	3108 St Tho	-90.08276	29.91989				Stormwater management review for property with more than 5,000 sq. ft. of impervious surfaces.		1349	125	292	8			27270.00	2400.00		3298.05	290.26	
		1800-1892 \	-90.06788	30.00825				Stormwater Management Plan for a new construction of a site housing community comprised of 20 two-family residences with an associated private community facility.		5934	551	4939	140		0.30	37130.00	5600.00		265.49	40.04	
NANO Architects	Youth Study Center	1100 Miltor	-90.08394	29.99519		Native vegetation		Stromwater plan for a juvelnile detention center adjacent to the existing Youth Study Center. Total GSF 322.430.		694	64	487	14		0.38	48984.00	1200.00		3552.06	87.02	
Spackman Mossop & Michaels	2228 Gravier St.	2228 Gravie	-90.08682	29.9582	linear	Native vegetation		Application for a stormwater management plan		21275	1977	2644	75		0.15	58802.00	1846.00		785.39	24.66	
Williams Architects	New Orleans Parade Tickets	1601 Lafitte Avenue, New Orleans, Louisiana	-90.07319	29.96318				Pervious pavement leads to catch basins and public storm system.		5967	554	3444	98		0.38	88960.00	7100.00		912.19	72.80	
Dana Brown & Associates	Nick's Bar	2400 Tulane	-90.08774	29.96006				Bioretention Cells, pervious pavers		290	27		0			5220.00	1415.20				
CCWIV	2618 St Louis St renovations	2618 St Lou	-90.08359	29.96782	cistern	-	-	Greenway Corridor - adaptive reuse of an existing structure	building roof												
Trapolin-Peer Architects, Woodward	Design Group, Donald Fant A	730 Julia St.	-90.0721	29.94578								6585	186								
Coleman Partners Architects	Canal Street Hostel	1028-1030 (	-90.07277	29.95513				SMP for the redevelopment of a Hostel with 5,000 sf+ of impervious surface.													
Pelli Clarke Pelli Associates, Mannin	Goldring/Woldenberg Compl	6750 Freret	-90.11738	29.94337				Stormwater Management Plan for an addition to theTulane Business School at 6823 St. Charles													
Spackman Mossop & Michaels	The Rendon, historic renovati	800 N Rendon St, New Orleans, LA	-90.08727	29.97514				Permeable pavers	adjacent parking			4106	116								
HCI Architect	Mondy Apartments	2327 St. Philip Street, New Orleans LA 70119	-90.07685	29.97067				Permeable pavers with overflow in gravel swales		4507	419	4375	124			73525.00	5000.00	5000.00	593.49	40.36	
Christopher Kidd & Associates, LLC	2908 Gen. De Gaulle Dr.	2908 General De Gaulle Drive, New Orleans, Louisiana	-90.02779	29.92847				Pervious pavement		23168	2152	3167	90			84293.00	300.00		939.94	3.35	
Spackman Mossop & Michaels	1320 Magazine St	1314 Magaz	-90.07115	29.93781	-	Gravel		Stormwater management plan for a property with over 5,000 sq. ft. of impervious surface.		900	84	1665	47		-	26735.00	1200.00		567.05	25.45	

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Spackman Mossop & Michaels	Adaptive Reuse/Addition	820 Dauphi	-90.06504	29.96049				Stormwater Management Plan for project on site 19,046 square feet.		463	43	333	9		0.10	11575.00	1200.00		1227.53	127.26
Spackman Mossop & Michaels	Southern Rep Theatre	2541 Bayou	-90.07624	29.9769				Renovation of St Rose de Lima church into theatre, performing arts space.		6671	620	3224	91			107457.00	1200.00		1177.05	13.14
Studio WTA	1131 Tchoupitoulas St	1131 Tchou	-90.06753	29.93983	-	Permeable pavers		Site over 5,000 sf in size		8704	809	3685	104		-	24000.00	500.00		230.00	4.79
RRC Power & Energy	Eno Solar and Battery Storag	5400 Dwyer	-90.02547	30.01595				Design review in CT / Stormwater address for solar power generation facility												
Rozas Ward Architects	3925 Burgundy St	3925 Burgu	-90.03627	29.96378				Stormwater Management Plan review for site with more than 5,000 square feet of impervious surface.												
Hewitt Washington & Associates	Booker T. Washington School	3201 Erato	-90.08923	29.94992				Booker T. Washington School Redevelopment; greater than one acre in size												
bdg Architects	Regions Gentilly Branch drive	3836 Elysian	-90.05959	29.99759				Stormwater Management Plan for Regions Bank												
HCI Architect	Iberville Onsite Phase VII	400-444 N \	-90.07321	29.96057				Stormwater management plan for Phase 7 of Iberville Housing												
Morphy Makofsky Inc.	Andrew Higgings Plaza	945 Magazi	-90.07073	29.94215				SMP for a new pedestrian plaza and the reconstruction of Andrew Higgens Blvd adjacent to the WWII Museum								145753.00				
Mullin Landscape Associates	Family Dollar	2900 Gener	-90.02832	29.92869				Design review and stormwater management plan for new retail development in Corridor Transformation Overlay District.		47872	4447					98329.00				
Visioneering Studios	Franklin Avenue Baptist Chur	8181 Lake F	-89.9955	30.027				Site plan and Stormwater Management Plan review for new construction of Franklin Ave. Baptist Church, located in the CT Corridor Transformation Overlay.												
Sauviac + Dang	Green Tea Restaurant	3001 Napol	-90.1031	29.94069		TRUEGRID		Design of a standard restaurant with addtional rental space. Sqaure 694 Lot 1,2,3 and pt 4												
Billespartners	Artspace New Orleans Bell Sc	1010 N Galv	-90.07522	29.96918				Design review and stormwater management review for a development over 40k on a site of 1 acre or more.												
Herb Rogers	Clinic Elysian Fields Avenue	6121 Elysian	-90.06048	30.02144				Stormwater plan for a site over 5,000 square feet on impervious surfaces. Previously submitted on 3/12/2017.												
m2 studio	Shell & Suite B Interior Build	4221 Old Ge	-90.03907	30.00306		TRUEGRID		Stormwater management review for a project exceeding 5,000 sq. ft of impervious surface. The applicant intends to construct a new retail center on the site.												
Albert Architecture	Parkway Apartments	131 S Jeffer	-90.09518	29.96971				SMP for the adaptive reuse of a church as a 20 unit multi-family residence												
ONE to ONE	6262 Pontchartrain Developr	6262 Pontcl	-90.11609	30.00542																
Eskew+Dumez+Ripple	1730 Tchoupitoulas	1730 Tchou	-90.06629	29.92833				Stormwater review for site with more than 5,000 square feet of impervious surfaces.				4059	115			159309.00			1386.04	
Titan Engineering Consultants, LCC	Burst Commercial no.2	214-218 Rol	-90.11199	30.01973	-	ChamberMaxx		SWM plan review		1098	102	900	25		-	16563.00	1000.00		649.91	39.24
Gouldevans	Elysian Fields Health Campus	1638 Mariet	-90.05652	29.9744		R-Tank		DR & SMP for proposed 65,000 sf health clinic												
HMS Architects	Woman's New Life Center Ad	4612 S Clait	-90.10626	29.93958				Design review for new medical office building in an EC Design Corridor. Stormwater required but not included in this submission.												
Trapolin-Peer Architects	Sazerac House	101 Magazi	-90.0676	29.95169				Stormwater management for Sazerac House												
Campo Architects	1600 Canal St - Marriott - Ble	1600 Canal	-90.07729	29.95825				SWMP for site with 5,000 sf + of impervious surfaces												
Studio WTA	801 Magazine Street	801 Magazi	-90.06952	29.94521				Renovation of a 2 story masonry building												
Wisznia Associates	Stephens Garage	848 Carondi	-90.07285	29.94528				SMP for the redevelopment of existing parking structure into a mixed-use building.												
NBWW	Higgins Hotel & Conference C	1000-1008 I	-90.06958	29.94245				Stormwater management plan for construction of hotel and conference center												
Verges Rome Architects	Allie Mae Williams Multi-Ser	2216-2230 S	-90.08543	29.93821				Substantial renovation of site with more than 5,000 square feet of impervious surfaces.								28550.00	5430.00			

Appendix B - green infrastructure master file

Duplantis Design Group	Renovations to 818 Howard /	816-818 Ho	-90.07441	29.94386				Storm Water Management Plan												
HCI Architect	1601 Orleans Ave.	727 N Robe	-90.07223	29.9641				Stormwater management review for property with more than 5,000 square feet of impervious surfaces.												
Design Jones	Sankofa Nature Trail and We	6401 Florid	-89.99996	29.97451				DAC and stormwater review for wetland park in lower ninth ward												
Stanley Beamer & Sears	Children's Hospital of New O	200-220 He	-90.12778	29.91792		Grass		Children's Hospital Clinic Pavilion & Bridge SWMP		11095	1031	27789	787		0.28	170120.00	10000.00		216.19	12.71