Deltares

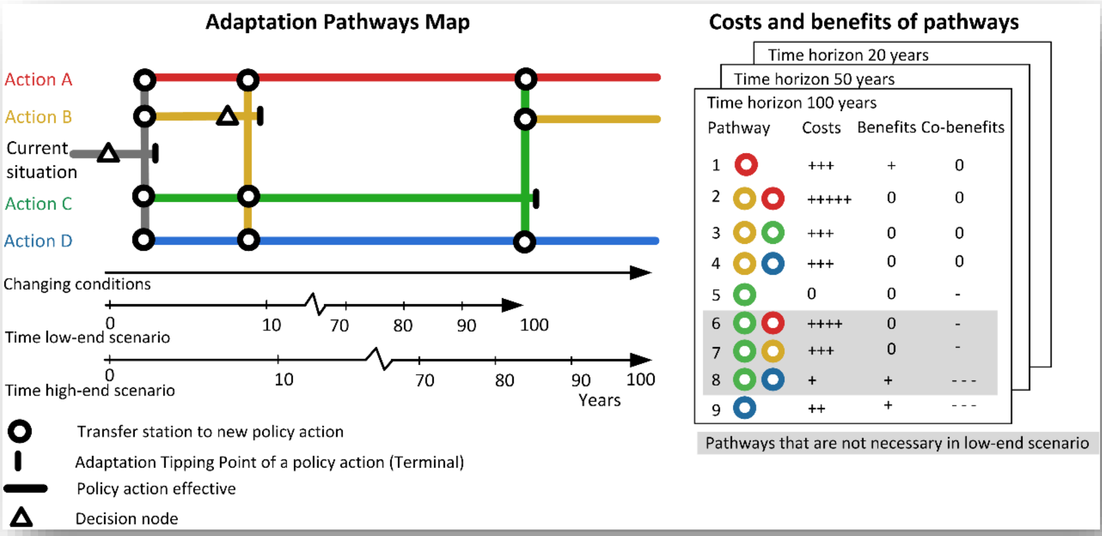
Sewage & Water Board of New Orleans
“Integrated Master Planning: Request for Information”

1 Deltares Company Profile

Deltares USA is a U.S-based, not-for-profit, applied research organization closely aligned with the Dutch national water institute, the Stichting Deltares located in Delft, the Netherlands. Deltares is an independent institute for applied research in the field of water and subsurface. We refer to Deltares USA and Stichting Deltares collectively as Deltares.

Throughout the world, Deltares is committed to our mission to develop and disseminate expert knowledge, innovative methods and software to help people live safely and sustainably in delta areas, coastal zones and river basins. Deltares maintains close relationships with governments and universities, working to accelerate the translation of scientific advances into applicable tools and methods to support the management of complex water systems. Deltares maintains its own research agenda to expand our knowledge on topics most relevant to our mission. This research focuses on flood risk, ecosystems and environmental quality, water and subsurface resources, delta infrastructure, adaptive delta planning, and enabling technologies.

Deltares is the developer of many state-of-the-art software packages, which encapsulate the depth of our knowledge on physical processes, and which are disseminated to users under our ‘dare to share’ policy without a license fee. Examples include Delft3D, a world leading 3D modeling suite to investigate hydrodynamics, sediment transport, morphology and water quality for fluvial, estuarine and coastal environments. Delft-FEWS is a world class software package used by the National Weather Service and around the world to provide a reliable and modular way to set up operational forecasting systems. iMOD is an easy-to-use Graphical User Interface with an accelerated Deltares-version of MODFLOW that facilitates very large, high resolution MODFLOW groundwater modelling. Deltares develops numerous tools to support risk reduction and adaptation planning, including damage modeling software, critical infrastructure vulnerability tools, and tools to assess the impact of nature-based solutions on risk reduction. Deltares also develops serious games, which engage stakeholders in a fun and playful way to increase awareness on serious issues.



Deltares advocates for an adaptive planning approach to water management. We developed and continuously advance the dynamic adaptive policy pathways (DAPP) approach to long-term planning under uncertainty. Such an approach acknowledges that the future is uncertain and develops sequences of actions or interventions over time that ensure community objectives are met. We were a key partner of the Dutch government in their master planning for water supply and flood risk through 2100, and have partnered with governmental organizations in New Zealand, Bangladesh, San Francisco, Miami, and Louisiana in the exploration and application of DAPP for master planning.

Deltares prides itself on the quality of our people, and the dedication to our mission of enabling sustainable living in areas vulnerable to flooding and climate change.

Deltares

2 Relevant Project Descriptions

2.1 Integrated Systems

Towards resilient groundwater & surface water management in New Orleans
New Orleans subsides several mm/y and a large part of the city is below sea level. Katrina had such an enormous impact because water flooded the low-lying areas and then had to be pumped out. The city could better cope with water and land-subsidence challenges by investing in spatial planning in order to become more resilient. It is expected that current challenges will become more intense in the decades to come because of sea level rise, intense rainfall, drought, and ongoing land subsidence. The New Orleans' NDRC plan "Reshaping the Urban Delta" proposes robust city structures and water infrastructure, which are crucial for the city's survival and economic prosperity. The plan is being funded by the National Disaster Resilience Competition (NDRC), and it will initially be implemented in the Gentilly district in the northeast of the city before being scaled up to cover all of New Orleans. The City's Office of Resilience and Sustainability is partnering with Deltares and Deltares USA Inc., to assist with the development of the plans, as well as implementation of many of the plan's scientific and technical components.

An operational, multi-scale, multi-model system for consensus-based, integrated water management and policy analysis: The Netherlands Hydrological Instrument.
Water management in the Netherlands applies to a dense network of surface waters for discharge, storage and distribution, serving highly valuable land-use. National and regional water authorities develop long-term plans for sustainable water use and safety under changing climate conditions. The decisions about investments on adaptive measures are based on analysis supported by the Netherlands Hydrological Instrument NHI based on the best available data and state-of-the-art technology and developed through collaboration between national research institutes. The NHI consists of various physical models at appropriate temporal and spatial scales for all parts of the water system. Intelligent connectors provide transfer between different scales and fast computation, by coupling model codes at a deep level in software. A workflow and version management system guarantees consistency in the data, software, computations and results. The NHI is freely available to hydrologists via an open web interface that enables exchange of all data and tools.

Parish-wide watershed planning and strategic analysis (ongoing)
The project team is applying the adaptive planning method Dynamic Adaptive Policy Pathways (DAPP) to create an adaptive strategic plan for investments over the 10 watersheds that make up Calcasieu Parish. The project involves collaboration between hydro-dynamic surge and runoff modelers, engineers and design experts, vulnerability experts, damage modelers, adaptation planners and DAPP experts. The project investigates flood mitigation and adaptation measures in ten watersheds, carried out over a period of four years. For each watershed, adaptation pathways – which show sequences of measures over time – are developed to reach the Parish's objectives and desired levels of service for a time horizon of 100 years. These are developed into an adaptive plan per watershed, with a master over-arching Parish-wide adaptive plan as the final outcome of the project.

NKWK
The National Water and Climate Knowledge and Innovation Programme (abbreviated to NKWK in Dutch) has been operational since 2015. It elaborates on the knowledge issues identified in the Delta Programme. This Delta Programme is published annually, rising to the challenges facing the Dutch delta. The Netherlands is a low-lying country that abounds in water, such as the sea, the IJsselmeer lake and the rivers. In the west there is a densely populated coastal zone that is home

to the Randstad conurbation – the economic heart of the Netherlands. It has a population of 9 million people and accounts for 70 percent of the total income earned. The delta must protect itself against flooding while ensuring a sufficient fresh-water supply at all times. The Netherlands must also prepare for rising sea levels, soil subsidence and higher temperatures. The initiators behind the NKWK are the Delta Programme Commissioner, the Ministry of Infrastructure and the Environment, Rijkswaterstaat, the Foundation for Applied Water Research STOWA, Dutch Water Authorities, the Netherlands Organisation for Scientific Research (NWO), Top Sector Water, Deltares, Wageningen UR, the Netherlands Organisation for Applied Scientific Research TNO, KNMI (Royal Netherlands Meteorological Institute) and the business community.

2.2 Stormwater / Drainage

Borrowed land, reframing the relation between flood and drought adaption efforts with the built environment in New Orleans (Technical University/Deltares double MSc. Thesis)
The delta city of New Orleans is dealing with a range of urban water management issues, in addition to pressing socio-spatial problems. The dual graduation work of Daan Rooze at both Urbanism (Faculty of Architecture) and Water Management (Faculty of Civil Engineering) presents a joint design-engineering approach resulting in a thorough reform of the urban water system, building on the Greater New Orleans Urban Water Plan co-created by Deltares. In this thesis called Borrowed Land, an attempt was made not only to increase water safety, but also to link reforms of the urban structure to the new water system. The proposed urban water system offers improvements in terms of connectivity, quality of public space, functional diversity and evacuation. A key outcome of the research is the transition from traditional, underground water drainage to a water system based on canals and open water bodies. During presentations in New Orleans to, among others, the municipality, the water board and an open forum for local residents, the plan was largely welcomed due to the integrated approach. The full thesis can be downloaded from the TU Delft repository (Daan Rooze, 2020).

2.3 Drinking water

COASTAR® in The Netherlands Coastal Aquifer Storage And Recovery (Deltares, KWR, Arcadis)
Use of subsurface solutions for a robust water supply and drought control by (1) closing the water gap between water supply and demand in space and time and (2) prevent salinization of ground/surface water by using brackish groundwater for fresh water production. COASTAR aims for large-scale use of the subsurface to store freshwater for industrial, domestic and agricultural use, including using brackish water for freshwater production. Benefits can be achieved by combining water supply with other functions, such as preventing land subsidence and flooding or strengthening coastal defenses.

2.4 Subsidence & Groundwater

Mirabeau Water Garden
The Mirabeau Water Garden will become a campus for water research, demonstrating best practices for construction and urban water management in the city's lowest-lying and most vulnerable neighborhoods. The site is located at a 25-acre parcel in the Filmore neighborhood of New Orleans, between Bayou St. John and the London Avenue Canal. The land was donated to the City of New Orleans by the Congregation of St. Joseph on the condition that it be used to enhance and protect the neighborhood to “evoke a huge systemic shift in the way humans relate with water and land.” The project builds upon design work from the Greater New Orleans Urban Water Plan to improve safety and investments by alleviating flooding and subsidence. The project will divert stormwater from the city’s drainage system, store and clean up to 10 million gallons of diverted stormwater, allow stormwater to infiltrate into the ground, capture runoff from neighboring streets, and provide an educational and recreational amenity that demonstrates how natural

processes can be harnessed to enable more sustainable forms of water management. As a demonstration project, Mirabeau Water Garden will be a model for other open spaces and institutional sites throughout the city and region. The initial phase of this project is funded by a FEMA Hazard Mitigation Grant Program, and the second phase is the flagship project of the Gentilly Resilience District, which leverages funding from HUD's National Disaster Resilience Competition award to the City of New Orleans. The role of Deltares was modelling the subsurface (geology) and groundwater system to better understand the possible effect of temporally water storage (and rising water levels) on the urban area around it. A project groundwater monitoring network was designed and installed, and monitoring results are analyzed.

Shallow subsidence vulnerability in New Orleans and Assessment of land subsidence in New Orleans (Deltares & Tulane University)
Two in depth studies related to the shallow and deep subsurface of New Orleans were completed and made use of shallow boreholes and laboratorial analysis (% organic matter in soil above the groundwater level). Using satellite data (InSAR) allowed us to observe seasonal and yearly surface elevation movements. These studies explain the impacts of deep groundwater pumping and shallow groundwater drainage by leaking pipes. These draft reports were completed in the summer of 2019 and will be published soon.

Living on Soft Soils: Subsidence and Society *(together with University of Utrecht*)
Many low-lying river deltas, home to over 500 million people, are under pressure due to land subsidence, with subsidence rates that for the 21st century far outweigh predictions of sea-level rise due to global warming. In the Netherlands, subsidence causes considerable damage to agricultural land, infrastructure and other public and private assets worth over 5 billion euros. Moreover, it gives rise to serious safety issues due to increased flood risks and causes considerable greenhouse gas (GHG) emissions which will further contribute to climate change. In some areas tipping points have already been reached, where current land-use can no longer be maintained without considerable costs, underlining the urgency to take action.

Land subsidence is induced by both natural and human drivers. Human-induced drivers result in relatively high rates of subsidence (typically 0.5-10 cm/yr). Subsidence and GHG-emissions can be mitigated by smart and efficient management strategies when applied to; spatial planning, extraction of hydrocarbons and groundwater, groundwater tables, and land-use. However, this requires thorough knowledge on the (interacting) processes causing subsidence, its impacts and possible integrated solutions.

This program is designed to co-create insights that help to effectively mitigate and adapt to subsidence within the Netherlands by making major improvements in measuring and modeling the processes and consequences of subsidence, identifying, developing and critically evaluating control measures and designing governance and legal approaches that facilitate their implementation. Therefore we developed a) new satellite-based technology to measure, attribute and monitor subsidence, b) a solid understanding of the interacting multiple processes contributing to total subsidence, c) sophisticated physical and economic numerical models to predict human-induced subsidence rates and impacts, and d) implementation-strategies that go beyond technical measures, to strengthen governance and financing capacities as well as legal frameworks. This fully integrated approach deals with all impacts of land subsidence on society and economy.

3 General: SWBNO & New Orleans in 2070

As we continue to march into the 21st century, the global community progresses with a predominantly “business as usual” state of mind. Although the consequences of our collective actions are unknow, the consensus among scientists is that of the likelihood of climate and environmental worsening into the future. What does this mean for New Orleans and the SWBNO to develop an integrated long-range plan for their city? This chapter looks at loosely defining the set of problems that New Orleans’ faces due to climate change and understanding what is needed for Integrated – long range planning.

3.1 Climate and subsidence conditions

To best provide ideas and potential solutions, understanding the environment being faced in 2070 is necessary. “Expect the best but prepare for the worst” is an expensive mantra when it comes to emergency risk response and long-term planning but it does however, require the planers to brainstorm unlikely scenarios and prepare appropriate measures to these outcomes.

What do 2050 projections look like? (according to ClimateCentral.org)

- Louisiana is projected to see one of the nation's largest increases in heat wave days.
- Louisiana is projected to see its summer drought threat level more than double. We need to better understand the impacts on evapotranspiration.
- Louisiana's wildfire threat level is projected to nearly double.
- Sea level rise along the Louisiana coast is projected at 1.9 feet (see Figure 3-1).
- Parts of New Orleans are constantly sinking, often more than sea level is rising.
- High intensity precipitation events are likely to occur more frequently and with greater severity as temperatures rise. What is impact on future overland flow?

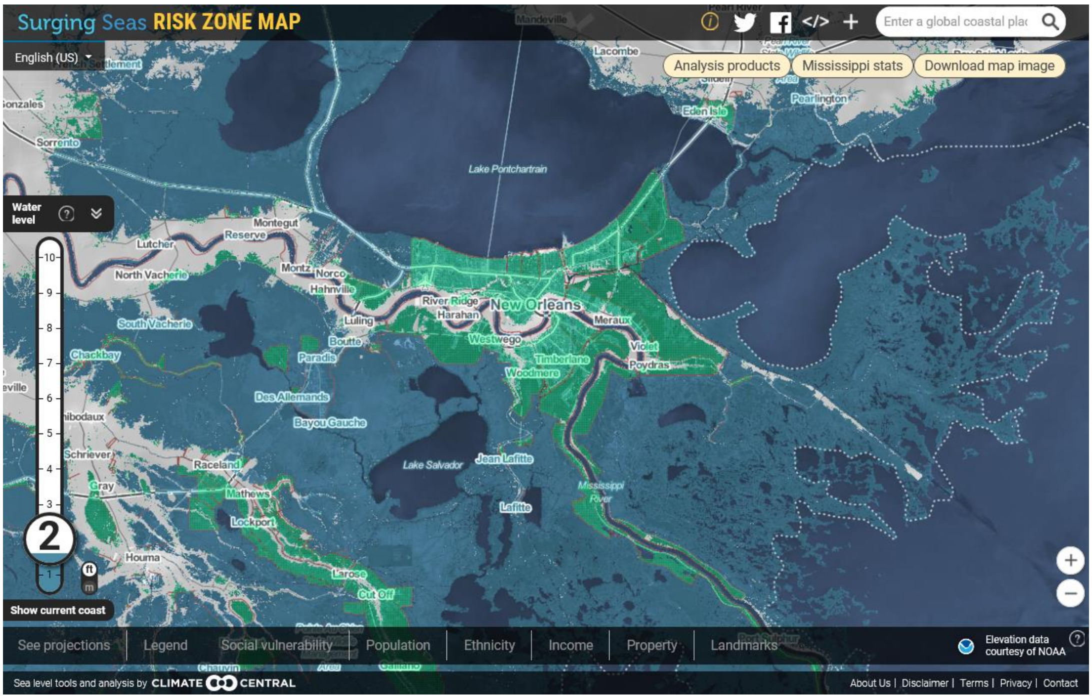


Figure 3-1 Surging Seas Risk Zone map. Blue area indicates inundated area after 2ft of sea level rise. (States at Risk, 2020)

3.2 Integrated, long – range planning

As part of an integrated approach, the identification of water sources, users and infrastructure should all be collected, and their interactions noted. Additionally, policy and adaptive measures should be included as part of the *integrated* long-term decision-making process.

Delta areas require specific attention and the interdependence of the water system and economic system requires an integrated systems approach of the delta. The inherent uncertainties regarding the magnitude and rate of climate change and socio-economic developments require an adaptive approach. The need to invest in expensive water related infrastructure on the short term requires an approach that supports decision making under uncertainty. Adaptive delta management combines these aspects and uses the Dynamic Adaptive Policy Pathways (DAPP) approach to support the development of an adaptive plan.

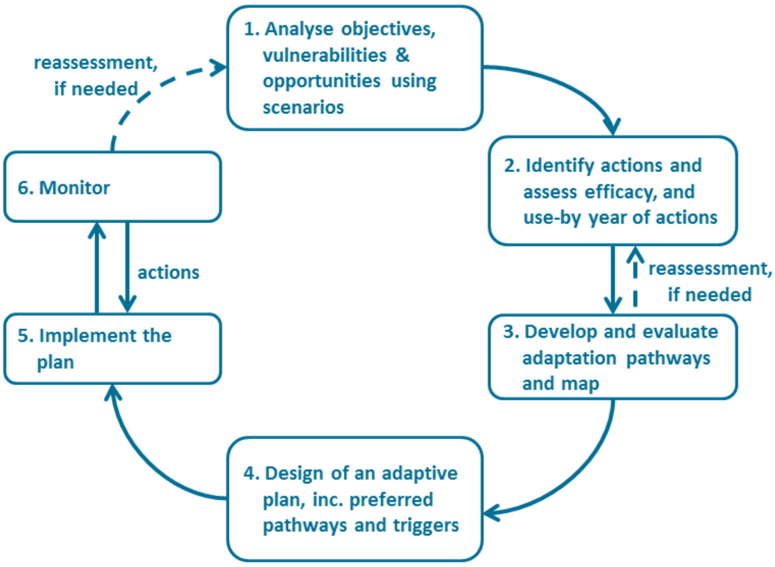


Figure 3-2 The dynamic adaptive policy pathways (DAPP) approach (simplified from Haasnoot et al. 2013)

The premise behind adaptation pathways approach is to generate a wide array of pathways (consisting of a series of measures) through which policy objectives are achieved under changing climate and socio-economic conditions. Central to the adaptation pathways concept are adaptation tipping points (Kwadijk et al., 2010), which are the conditions under which an action no longer meets the clearly a-priori specified objectives. After reaching a tipping point, additional measures are needed to reach the objectives. In this way different pathways can be designed. Mapping the wide array of possible adaptation pathways provides a portfolio of adaptation options. This type of thinking is key to the successful long-term integrated decision-making process.

Additionally, Deltares can offer different tools for evaluation of measures under different scenarios
- Cost- benefit analysis – societal costs and benefits
- Robustness analysis – performance under different scenarios and extreme events
- Multi criteria analysis – including non-tangible effects by local and experts' panels
- Implementation analysis – institutional and socio-cultural barriers for implementation

4 Specific Questions

In this chapter we provide input on the 3 specific questions raise by the SWBNO relating to stormwater drainage, waste water and drinking water. In addition, we add points of discussion about the subsurface and groundwater, monitoring, and urban spatial planning.

4.1 Specific Question: Stormwater / Drainage

What will New Orleans' biggest **stormwater / drainage** challenges in 50 years and what is the best approach to integrated, long-range planning to address those challenges? Below we answer with some ideas that we believe should be considered.

Sustainable Solutions

- Construct the urban environment to retain more water during precipitation events, this needs to be done by a number of interventions at several scales. (1) Building and private garden scale, through the use of green building and architectural techniques (2) at housing block scale, (3) at neighborhood scale and (4) at street (parking lots) scale. (see Figure 4-1)
- The water storage capacity needs a significant increase. Therefore, we believe that surface water canals are needed in the low (polder) areas.
- The retention of more water within the urban environment will help to flatten out peak discharge rates and stresses on the drainage system. This in turn, could lead to a rise in distributed treatment facilities (on a household scale).
- More water held within the system would reduce the overall size of drainage networks that would be required. How could this contribute to cost savings when future replacement take place?
- Retained and stored water can be useful as a resource (evapotranspiration, sprinkling combatting heat effects, and grey water uses e.g. to clean cars)
- The water quality of discharged storm drainage water needs to be improved to safe guard the water quality of Lake Pontchartrain. Additionally, the quality of dry weather discharge into the river needs to be studies and improved, if needed.

Figure 4-1 Deltares' urban water management strategy and philosophy of (1) retain (2) store and (3) drain is highlights in the sketch above.

Drainage

- A T10 rainstorm drops 9.7 inch of water on New Orleans. The resulting runoff can not be stored using traditional ‘grey’ drainage. Open water offers significantly more storage capacity (Daan Rooze, 2020)
- It is important to acknowledge the low-lying neighborhoods of New Orleans as former marshes. This identity must be fundamental for the development of a stormwater adaptation plan. This implies shifting from a ‘fighting against water and hide it’ approach to a ‘live with water and deploy it as an amenity’ approach.
- Preventing further subsidence is key. Continued pumping of groundwater infiltrating the (broken) stormwater drainage pipes will cause further subsidence. With rising sea levels taken into account, brackish seepage will become a more pressing problem. A stormwater adaptation plan should incorporate a system to tackle this issue.
- Fixing broken pipes will result in (permanent) flooding caused by seepage, as the current system is in equilibrium with the pumping regime.
- Becoming more resilient to flooding and drought is only achievable when all actors contribute. Actors living on higher ground must take responsibility for their runoff and prevent exacerbating flooding by rushing runoff downhill. Universities (Dillard, UNO) can play a large role in stormwater detention.
- Interventions associated with an improved stormwater drainage (Figure 4-2) system offer the opportunity to improve New Orleans on other aspects as well. A possible opening for increased collaboration between municipality departments / units could be acted on.
- The stormwater adaptation plan could contribute to the overall municipal vision.
- Create mental ownership of plans with residents by actively involving them in the development of a stormwater adaptation plan. Not just outreach in the beginning to get an overview of the problems but have re-occurring workshops for feedback on proposed designs. This way, local stories can be incorporated and takes away the ‘top-down’ character of the plan.
- It is suggested that forecasting and understanding the consequences of more intense rainstorms, such as those predicted in future scenarios, be completed to neutralize negative impacts. This is done in sequence through pre planning and strategy implementation.

Figure 4-2 The above images were generated with SWMM (Stormwater Management Model) software and shows the effects of a precipitation event on stormwater infrastructure during a given storm (Daan Rooze, 2020).

4.2 Specific Question: Wastewater / Sewage

What will be New Orleans' biggest **wastewater / sewage** challenges in 50 years and what is the best approach to integrated, long-range planning to address those challenges?

In 50 years, treatment procedures will have advanced and the reuse of wastewater and sewage may need to undergo a shift in public perception to have a higher reuse ratio within the urban water ecosystem. In combination with additional partners, studies on new treatment methodologies that allows for the use of effluent in different ways could be followed. Some questions to consider are as follows:

- What types of treatment advances will we see in the coming decades? How will this effect consumption, societal stigmas, and the use cases for treated water?
- How will the potential increased presence of chemicals and pharmaceuticals effect treatment options? Can nitrates and pharmaceuticals be processed in the current system?

- Could a different infrastructure network be used to deal with different types of discharge? Canals could help to put more control into the hands of operators in both the discharge rate and groundwater level.
- How is the shallow groundwater quantity & quality effected by sewer and wastewater networks? Future use of smart monitoring and real time control systems is likely and could be implemented to better manage/control the system. How will effluent levels change after upgrades and how will this effect the local water levels (Figure 4-3)?
- Is a decentralized treatment facility structure more feasible in relation to water re-use opportunities? A study to find out its effectiveness and feasibility could be undertaken.
- Can we integrate wetlands as a nature-based treatment step in the wastewater/sewage treatment process?

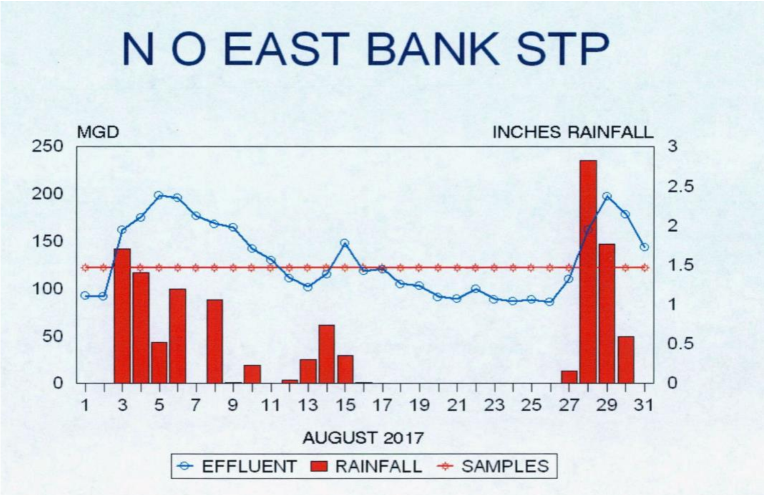


Figure 4-3 Displays the cumulative rainfall per day and the effluent discharge in one section of New Orleans East for the month of August 2017. Effluent increases correlate with rainfall events as groundwater height is increased and subsequent pressure change allows for more water to enter the wastewater discharge network.

4.3 Specific Question: Drinking water

What will be New Orleans' biggest **drinking water** challenges in 50 years and what is the best approach to integrated, long-range planning to address those challenges? Deltares collaborates with KWR (www.kwrwater.nl) and the integral water organization of Amsterdam (Waternet)

Source & Supply

More than 100 years ago the City decided to use the Mississippi river as their main water resource and the potential use of groundwater was also discussed but, in the end, turned down. Today, we advice a serious study to better understand the pro's and cons of all possible resources which would include a costs-benefits analysis of each identified water resource.

Potential resources are:

1. **River water**. Mississippi river water. The water quality of the Mississippi depends on land use and on (industrial) waste water discharge of nearly 2/3 of the United States and therefore making it very vulnerable. Perhaps less vulnerable river water can be used from the north side of Lake Pontchartrain.
2. **Groundwater**: Despite enormous ground water extractions during the last century there still exists volumes of fresh groundwater. Over last decade at many locations in the world the use of **brackish groundwater** has started. New purification methods have made this possible at reasonable costs. Groundwater below New Orleans is hundreds to thousands of years old and therefore not polluted by humans. A study of the possibility of introducing brackish groundwater extraction and desalinization as an alternative (or

buffer) to drawing from the Mississippi could be completed. A detailed understanding of the groundwater flow and water quality is needed to safely use and manage groundwater as a resource. Understanding the paleo history represented in the subsurface will also help estimate the water type that will be found below. This may help reduce the cost of drilling and sampling.

3. **River bank (ground) water:** Study the benefits of riverbank infiltration and pumping schemes to increase the water quality of Mississippi source water. River bank infiltration uses the in situ geological strata to naturally filter pollutants, reducing the cost of treatment prior to the distribution to end users (Figure 4-4). Infiltration wells can be located 50 -100 meters from the river bank to ensure a proper amount of time elapses before the water is pumped to the treatment facility. This ensures an adequate degradation of contaminants. In support the river bank geology, groundwater quality and salt contents need to be studied.

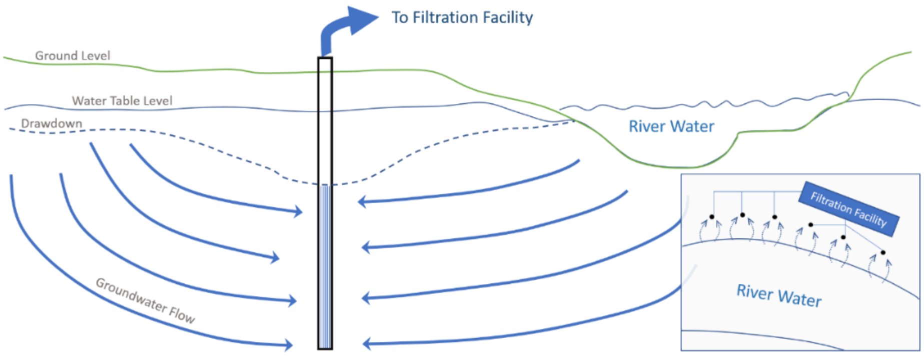


Figure 4-4 Conceptual river bank cross section and infiltration flow lines. Positive effects could include: Groundwater enrichment, natural redox reactions, natural sediment filtration, and biodegradation of contaminants.

4. **Artificial recharge and recovery,** making use of the aquifers systems below the city (Figure 4-5). Potential sources can be (a) treated storm drainage water, (b) river water extracted during "good water quality" periods, (c) completely treated waste water (4-5 treatment steps, including pharmaceuticals).

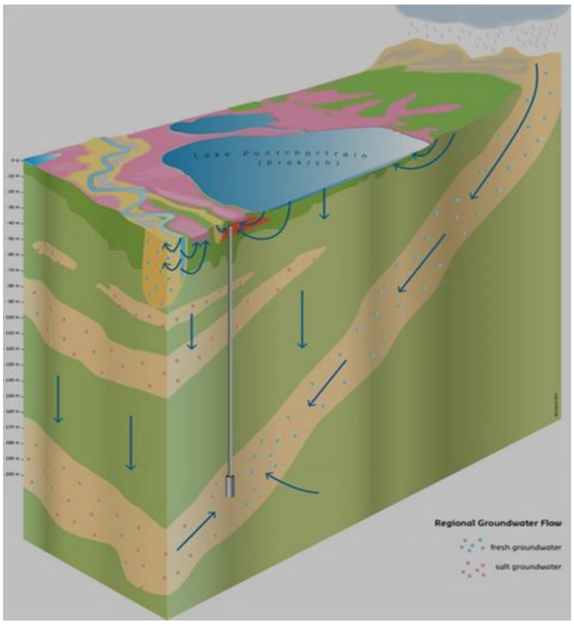


Figure 4-5 A block diagram showing a hydrogeological conceptualization of the subsurface beneath New Orleans. A properly organized and managed groundwater aquifer storage and recovery system could make use of this system, providing a buffer or alternative drinking water source and/or water storage solution.

Salinization risk of the Mississippi
How does the effect of sea level rise impact the salinity of the water at the pump intake locations? Will this effect the cost of treatment prior to distribution? As sea level rises and migrates upstream, a salinity wedge is formed (*Figure 4-6*). During the droughts of 2012 a ~9ft drop in the Mississippi water level allowed the toe of the salt water wedge to come within 20 miles of the freshwater intake for New Orleans. What will the combination of sea level rise and drought conditions have on the saltwater wedge intrusion? How will this effect operational costs at the treatment facility? Is the treatment facility capable of treating brackish water? What will be the effect of deepening of the river?

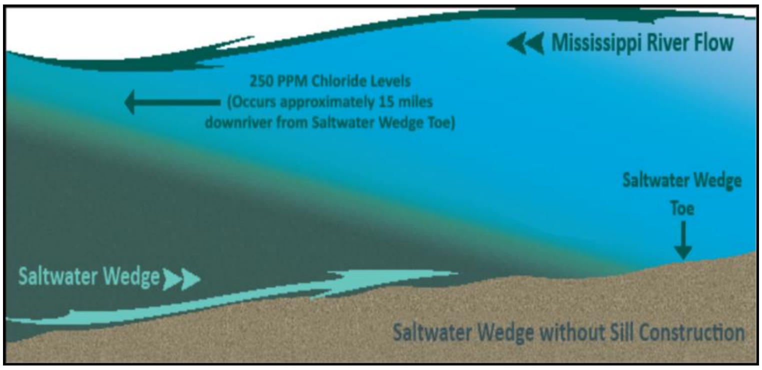


Figure 4-6 Saltwater wedge conceptual diagram shown intruding upstream into the Mississippi River. More dense saline water wedge sits underneath the freshwater river flow.

- Do climate change scenarios impact the seasonal high and low water levels and can this impact supply rates? If warmer, dryer conditions are present within the Mississippi river basin, what are the expected river levels? River and climate model scenarios could help determine appropriate measures.

Drinking water
- Cross-parish collaboration of agencies on water quality: are consequences of waste water discharge taken into consideration for downstream parishes?
- As the Mississippi River drains large amounts of the US mainland, it is important to acknowledge New Orleans' position as drain of the Mississippi watershed. How does SWBNO deal with hormones and other difficult to remove elements in drinking water? Offering high quality drinking water could reduce the use of single-use plastic containers.
- In 50 years, smart metering and Internet of Things devices will be deeply embedded in control & monitoring systems. This will most likely include drinking water metering, from a quantity perspective, and potentially a quality perspective as well.
- Is there a backup supply/buffer (groundwater?) in case of emergency situations?
- Is population growth expected within the area and can the current supply network cope?
- If higher temperatures are expected, is the critical infrastructure related to drinking water filtration capable of operating at higher peak temperatures during the summer months?

5 Subsurface

At Deltares, our core focus is on water and the subsurface, so naturally we approach the questions provide by SWBNO with this in mind. In 2070 we will be more connected, have a different set of technology at our disposal and have a different relationship with the way we think about water use and its distribution. The following general points run parallel to the (3) specific questions requested by the SWBNO.

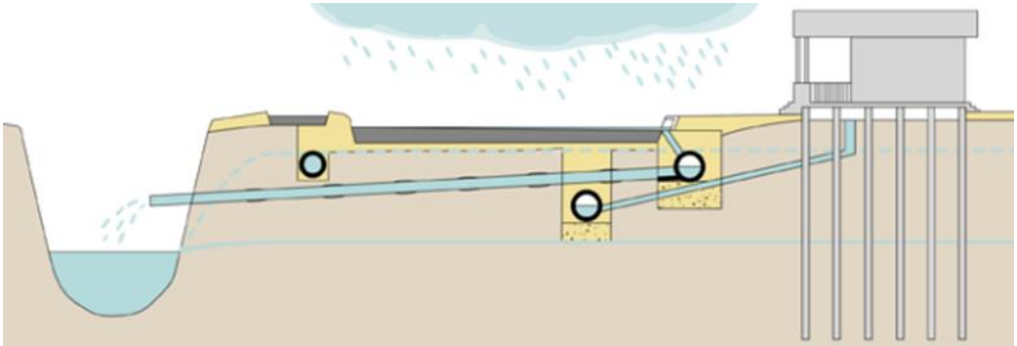


Figure 5-1 Current cross section schematic of the drinking water, sewer and stormwater pipes in New Orleans and associated (low and high) mean groundwater levels.

Groundwater

- What will the effects of water/sewer/drinking line replacement have on groundwater level fluctuation (Figure 5-1)? The city is currently undertaking a massive, 2-billion-dollar capital improvement program to restore parts of the city's damaged infrastructure. What effects might this have on groundwater levels? And what will be the lessons learned that can be passed on to future replacement plans?
    - Fixing leaking drink water pipes may cause the localized groundwater level to fall as a reduction in the amount of water lost from drinking water pipes will be realized. What are the environmental concerns associated with this?
    - Replacing Sewer/Drainage pipes that are currently removing groundwater from the system may cause the groundwater level to rise. Are there buildings / residents in the area that may be affected?
- How is groundwater currently being measured and monitored within the system (Figure 5-2)?
    - Developing an integrated long-range plan should include observation and monitoring of all potential water sources.
- How does overland flooding with salt water effect the local groundwater and surface environment?
- 50 years into the future, an evolved understanding of the dynamics between groundwater flow and drainage will hopefully be present. This could lead to the groundwater system being used as part of the stormwater drainage network. As mentioned in the previous section, if the built environment were to hold onto more rainwater it would reducing the peak discharge on the drainage system, shallow groundwater storage may act as a second temporary reservoir and part of the drainage solution.
- What will be the impact on the built environment. because of temporally groundwater drainage during construction activities?

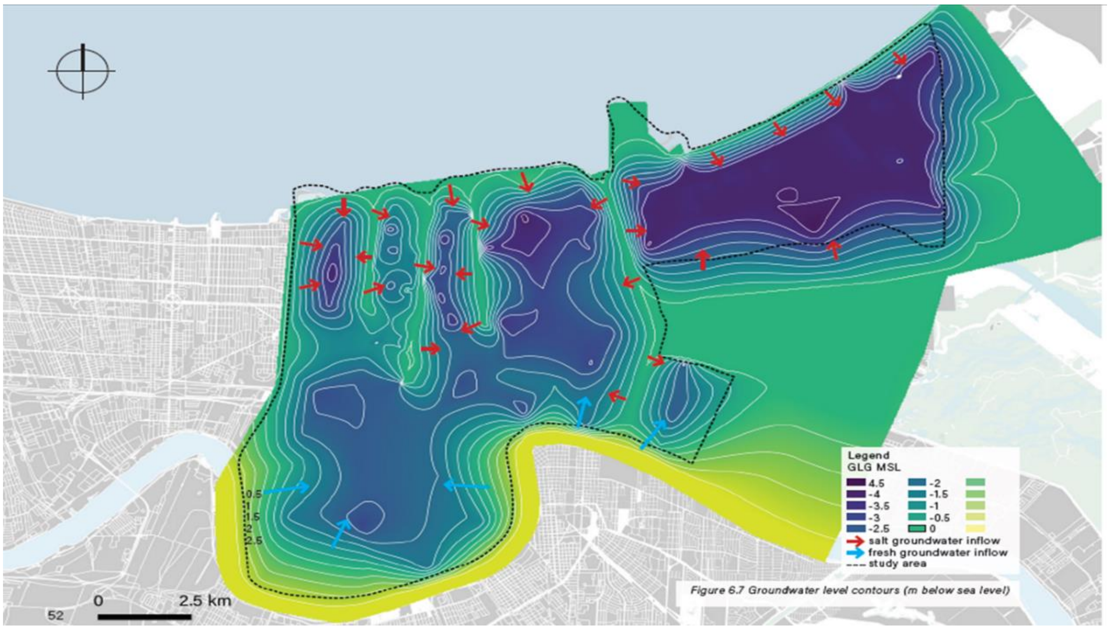


Figure 5-2 Shallow groundwater model generated for New Orleans showing the groundwater flow directions (from areas of light to dark), areas of potential salinization due to saltwater inflow, and areas of freshwater inflow from the Mississippi.

Subsidence

- Subsidence issues related to groundwater extraction and peat oxidization are risks within New Orleans. What is the effect of subsidence in a delta setting facing sea level rise (Figure 5-4)?
- Can house water connections have a breaking risk applied to them through the use of remote sensing data? Is the house founded and is subsidence occurring in the area? Is it possible to use remote sensing to determine a maintenance work schedule?
- What is the impact of shrink-swell on pipes and streets, and how can we neutralize these impacts during future renovations?
- How are dykes, levees and seawalls effected by subsidence?
- Which areas are most effected? Understanding the at-risk areas could better help with adaptive planning, budgeting and maintenance schedules relating to civil infrastructure construction and operating costs. The images below were generated from the shallow subsidence vulnerability in New Orleans that was completed by Deltares in 2019.

Figure 5-3 (left) shallow soil map displaying types of soil within New Orleans, this information is combined with other to generate the subsidence risk map (right). From the shallow subsidence vulnerability in New Orleans report.

- How are founded vs unfounded buildings going to react with local subsidence? Can discussions with building regulation officials help reduce the number of residential and commercial subsidence related issues?

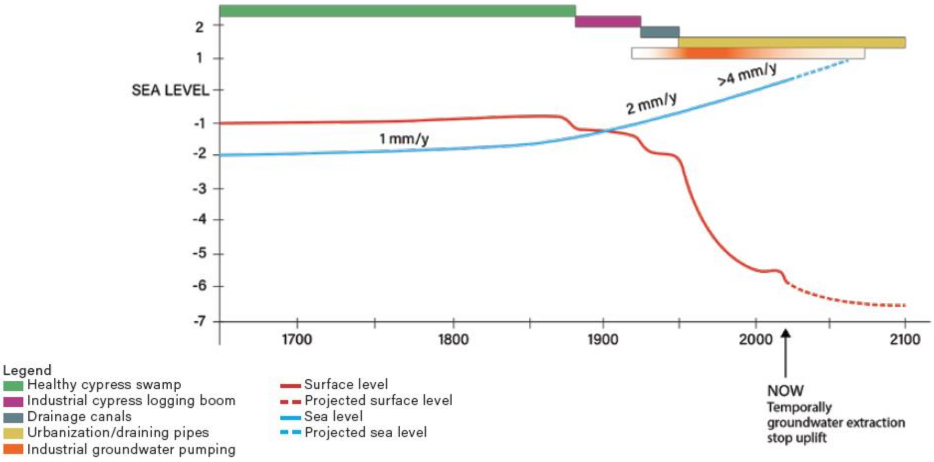


Figure 5-4 New Orleans subsidence process over time. Until the end of the 19th century, the northern part of New Orleans was covered with fresh water cypress swamps. These swamps raised gradually in equilibrium with sea level rise. After the start of the industrial cypress logging boom and the creation of the cypress wood transport canals, serious subsidence began (due to dewatering). A next subsidence phase started after the construction of the (urban) drainage canals at the beginning of the 20th century. Significant subsidence acceleration began during the urbanization of this area. The main contributing factor was groundwater drainage by underground storm drainage and sewage pipes. Groundwater pumping starting at the beginning of the 20th century with the highest extraction rates occurring between 1950 – 1980 added to subsidence but with a much smaller significance. The stop of the Michoud groundwater extraction generated a temporary uplift event.

Infrastructure

Infrastructure adaptation with a climate change context in mind is essential to securing the safety of the residents of New Orleans

- How will the vulnerability to flooding of critical infrastructure be assessed?
- What is the vulnerability to heat stress of critical infrastructure be assessed? Will increased temperatures cause problems to pumping stations?
- Modelling peak discharge rates for future climate scenarios, is the current discharge rate enough for 10, 100, 1000, 10000-year storms? What level or protection is considered acceptable by decision makers?
- Have climate model predictions (drought, flood risk, rainfall, heat, fire, subsidence, ect) and a risk score associated with key infrastructure (ie pumping stations) been applied?

6 Monitoring and asset management

Our advice: Start as soon as possible, many years before the start of large renovations, interventions or new constructions with integral monitoring and report yearly. The objectives for this monitoring are:

1. To better understand the artificial and natural water systems and use this information in design and to prevent unforeseen situations;
2. To follow the results and consequences of interventions
3. To quantify groundwater drainage (and/or groundwater recharge) by leaking (broken) waste water transport and storm drainage pipes
4. To (monthly, yearly) quantify the loss of drinking water,
5. To understand the impact of drinking water loss, drainage or loss of sewer water and storm drainage water on the groundwater system.
6. To map, monitor and understand which houses, roofs etc, drain storm water directly into the streets of storm drainage system
7. To understand the impact on groundwater levels (Figure 6-1) when the pipes systems are renovated.
8. To follow the quality of storm drainage water and the future effectiveness of measures taken. Including the (sea water) salt contents because of groundwater flow from Lake Pontchartrain and the connected canals (Figure 6-2), perhaps useful information to determine materials or measures to reduce negative impacts of groundwater salinization.

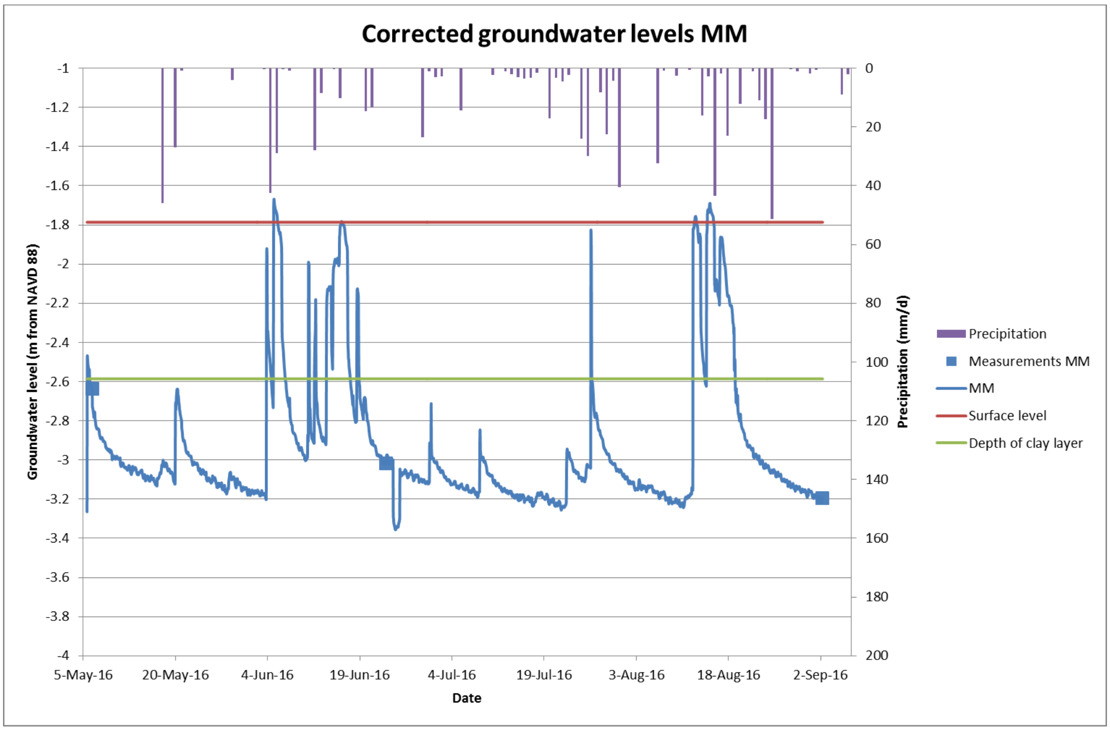


Figure 6-1 Groundwater fluctuation in relation to precipitation events in an observation well in the center of Mirabeau. A number of groundwater monitoring wells are already active within the city. The time series indicates that the groundwater level decreases immediately after a rain event towards the depth of storm drainage pipe and sewer pipe below the streets.

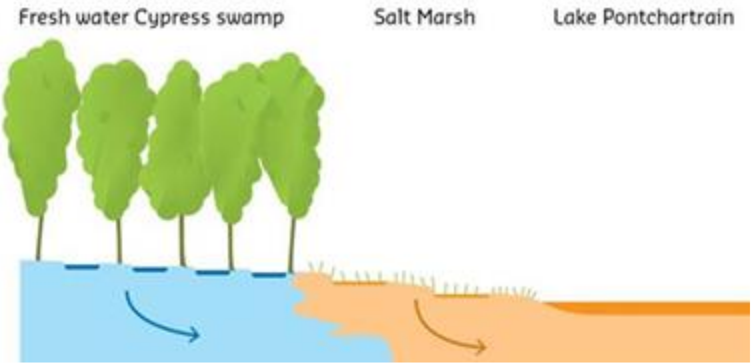
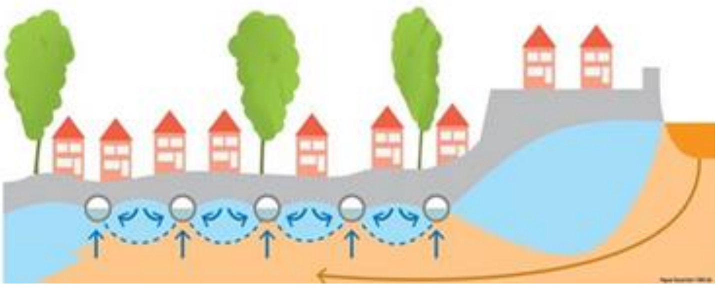


Figure 6-2 (a) Stage 1 - Original ecosystem dynamic between the fresswater cypress swamp (now New Orleans) and Lake Pontchartrain. Fresh water flows from the South to the north (from swamp to lake), following the elevation and pressure gradients through the salt marsh system.

Figure 6-3 (b) Stage 2 – Anthropogenic activities begin. A water retaining structure is built protecting the inland area from the the lake waters. No change to subsurface flow patterens occur at this step.

Figure 6-4 (c) Stage 3 – Civil structures and water management practices begin to transform the local ecosystem, reclaiming land by draining a section of the cypress swamp and inducing a flow reversal in the process. Now, the salty groundwater system stemming from Lake Pontchartrain now drains towards the freshwater of the cypress swamp.

Figure 6-5 (d) Stage 4 – Freshwater lenses develop over time as an equilibrium is reached in the new subsurface flow system. Less dense freshwater sits on top of the more dense saltwater originating from the Lake. Drains and sewer systems remove water from the urban groundwater environment.



7 Urban planning

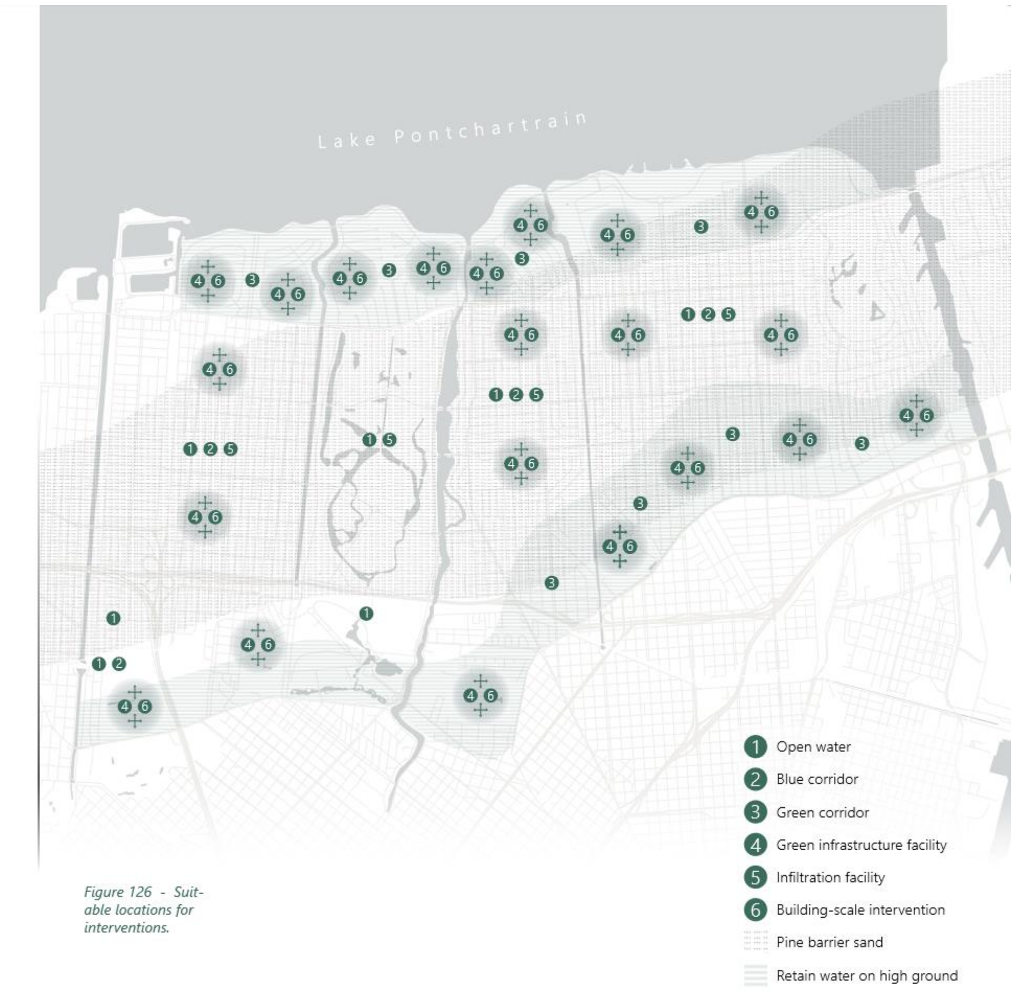


Figure 7-1 Advice for urban water storage based on the geomorphology and drainage networdks.

Spatial Planning

- Combining the City's agendas on spatial planning and on drinking water, sewage and storm water can create synergies by for example linking investments in time and space.
- Smart spatial planning and urban design can contribute to solving storm water challenges, preventing expensive storm water solutions.
- (Spatial) planning of the underground can prevent future planning problems above ground.
- Spatial planning and combining networks should avoid lock in for future developments due to inaccessibility of subsurface networks.
- Spatial planning can decrease chances of water pollution and thereby decreasing required investments to create high level water quality.
- Underground planning can identify locations suitable for water infiltration, energy storage, etc.
- Combined corridors for drinking water, sewage and storm water networks can result in easy access in times of maintenance or repair of these networks.

8 General conclusions & observations

The unknows associated with 50-year projections are substantial but a few general questions and observations are listed below:

- Is a culture of open-mindedness and willingness/ability to change imbedded within the decision-making teams? Is new technology going to be adopted early to help in the problem solve process?
- Is a top down proactive mentality present within the driving organizations?
- Technology is undoubtedly going to continue to progress but sitting back and thinking that future tech will solve future problems could be a challenge. Although we believe future tech will have a massive impact on operational effectiveness, we also believe in building with nature, sustainable solutions, nature-based solutions and a reduction on the reliance of mechanical mechanisms is a possibility.
- A 2-billion-dollar infrastructure investment is currently underway in New Orleans. Providing detailed notes on lessons learned from this process and imbedding this knowledge in future projects to prevent knowledge loss across generations is essential.
- In 50 years, real time monitoring, remote sensing, Internet of Things devices, and yet to be imagined tech will likely be integrated within many business processes.
- Is the digital GIS and storage space expandable, searchable and accessible? A discussion with stakeholders and policy surrounding open data sources, access rights and use cases should be had early on so future ground rules will have already been outlined.
- To expand climate awareness within the SWBNO supply chain, company standards could be set requiring businesses being contracted by SWBNO are to provide proof of a company climate action response plan. This will make sure they have thought about the climate and its impacts on its business. If they do the same for their suppliers, the trickle down effect could be large.

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