MONITORING WATER AND THE URBAN ENVIRONMENT

Greater New Orleans Water Monitoring Vision & Elaboration

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concept
Dit document is een concept en uitsluitend bedoeld voor discussiedoeleinden. Aan de inhoud van dit rapport kunnen noch door de opdrachtgever, noch door derden rechten worden ontleend.

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1 Introduction & problem conceptualization

New Orleans has been actively subsiding for decades and a large part of the city is below sea level. Frequently flooded streets resulting from high intensity rainfall events and an expected increase in tropical storms as a result of warming climatic conditions are cause for concern. A solution to help the city better cope with urban water and subsidence challenges could be to invest in spatial planning initiatives to become more resilient to extreme weather events and changing environmental conditions. Before solutions are implemented however, it may be advantageous to organize a suite of monitoring tools to provide both a baseline dataset as well as a way to quantify the results of implemented solutions.

Data collection and monitoring of the urban water environment throughout the city of New Orleans could help with building onto existing flood risk reduction knowledge, subsidence vulnerability understanding and operational water management efficiencies to the toolbox of decision makers. Currently, data is distributed (if available at all) through various sources making it difficult to draw conclusions from the information itself. In combining surface water, groundwater, subsidence and weather-related datasets into one location, risk reduction and fact-based decision making could become more easily integrated into the operational and decision-making procedures that are currently in place.

This document provides a collection of examples from the US and Europe relating to groundwater monitoring and database storage solutions, outlining both high-tech and low-tech solutions satisfying the project objectives at each of the locations. These brief examples are provided to outline the importance of program objectives and highlight the different monitoring programs that may be possible. Later in the report possible monitoring ideas are discussed and coupled with existing surface and subsurface infrastructures within New Orleans.

“You can’t manage what you don’t know” is an unfortunate, yet true statement that is echoed in urban water management meetings around the globe. Efficient, resilient monitoring systems are possible and will undoubtably provide stakeholders with confidence in knowing that the urban water data they collect and distribute can positively affect the safety of the residents and stability of structures within the City of New Orleans.

2 Urban groundwater monitoring: experiences from Europe

2.1 The Netherlands

The Dutch have been pumping to reclaim livable land for hundreds of years and continually upgrade and maintain the necessarily civil works to protect the approximately 9 million inhabitants who would be in immediate danger if major water infrastructures were to fail. 23 water authorities and 393 municipalities share in these responsibilities together with the provinces and central government.

Operational groundwater management and the care of groundwater quality is in large part the task of the water authorities. However, permitting for large withdraws (industrial withdraws, drinking water supply and ‘soil energy systems’) is the responsibility of the provincial governments who deal with the drinking water supply alongside the ten water supply companies that are treated as semi-public organizations.

In general, municipalities are responsible for hydrologic measures within public areas that will reduce, as much as possible, negative effects the groundwater level has on structures and local land use. Popular trends have included permanent municipal monitoring networks to identify high risk areas that were paired with interviews about the negative local effects relating to structural damages. From the results of these studies, areas were identified where measures may need to (or not) be implemented. More attention was given to areas where high groundwater was seen but special attention is being paid to areas where water levels were reduced during the 2018 summer dry period.

2.1.1 Amsterdam – Historic canals, a modern-day solution?

Amsterdam is the most populated city in the Netherlands and provides a world class example of urban water management. Known for its canal structure, classic Dutch architecture and biking culture, Amsterdam regularly places high on many ‘best cities in the world’ lists. But what keeps the city stable and above water is a combined national, provincial and local integrated water management plan. Throughout the 17th century the development and expansion of the canal network allowed for traders and merchants to carry their goods to every corner of the city. Today, the historic canal structure of Amsterdam is recognized as a UNESCO world heritage site and as discussions on global warming and its effects on sea level rise continue, the over 400-year-old city planning and construction effort is being looked at today as a viable, reproducible solution to modern day challenges elsewhere.

Monitoring the water levels of approximately 2500 groundwater measurement locations (in Amsterdam and surrounding areas) is completed by hand, six times a year and is made publicly available through a web-based interface (Figure 2.2). The water level at these locations measures the phreatic water level in the top layer of soil from 0 to 4 meters below surface and does not consider deeper aquifers within this framework.

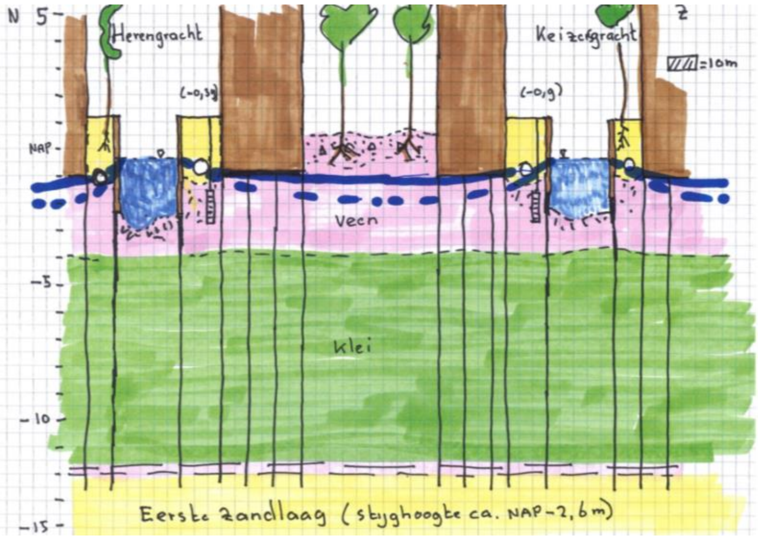
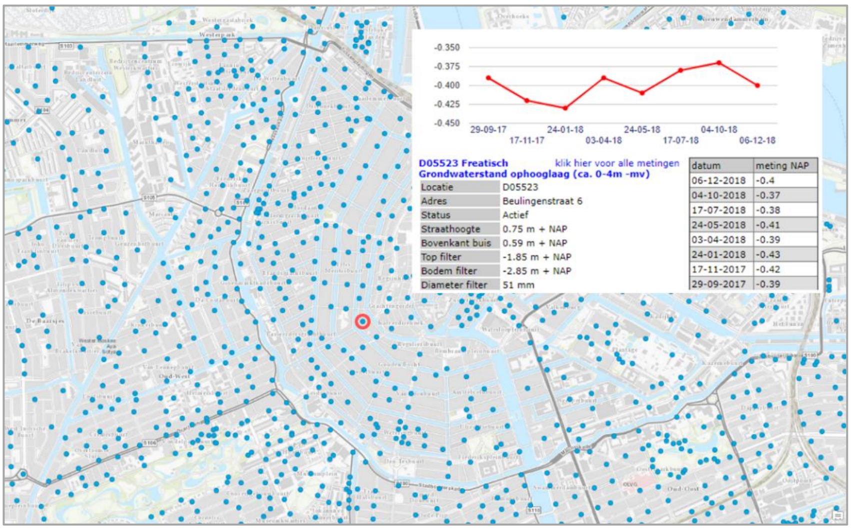


Figure 2.1 A cross section sketch of the lithology and canal structure through the City of Amsterdam. Peat (veen), Clay (Klei) and Sand (Zand) layers are expressed in pink, green and yellow respectivly. Resulting groundwater levels as an artifact of canal water levels can be seen in blue. The effects of pipe leakage and evapotranspration from trees should also be noted.

Groundwater and canal levels in Amsterdam is something that is important to get correct. With a phreatic water level that is close to the surface, an increase in groundwater level may cause low elevation gardens and crawlspaces / basements to become moist or flood. During periods of drought, a dropping water level could contribute to the rotting of wooden piles that the houses are built upon. Managing the canal water level ensures a stable groundwater level and reduces the risk of flooding. The canals are managed by pumping stations and water is discharged during times of heavy rain (to lower the water level) and added during drier periods (to raise the water level). Both actions take the local environment into consideration including the types of vegetation, land use and structures nearby, all of which may be affected by a change in groundwater level.

Originally, the monitoring network was designed to control the negative effect of sewer pipe leakage on the groundwater levels. Nowadays, it is also used to study the effect of sewer system renovation (often causing increasing groundwater levels) and canal bank renovations.



D05523 Freatisch
Grondwaterstand ophooglaag (ca. 0-4m -mv)

Locatie	D05523
Adres	Beulingenstraat 6
Status	Actief
Straathoogte	0.75 m + NAP
Bovenkant buis	0.59 m + NAP
Top filter	-1.85 m + NAP
Bodem filter	-2.85 m + NAP
Diameter filter	51 mm

datum	meting NAP
06-12-2018	-0.4
04-10-2018	-0.37
17-07-2018	-0.38
24-05-2018	-0.41
03-04-2018	-0.39
24-01-2018	-0.43
17-11-2017	-0.42
29-09-2017	-0.39

Figure 2.2 A selection of groundwater monitoring network measurement locations in Amsterdam Centrum and surrounding areas (from Waternet online data portal (https://maps.waternet.nl/kaarten/peilbuizen.html?).

2.1.2 Delft – stakeholder engagement & understanding the system.

The municipality of Delft takes a similar approach when it comes to its groundwater monitoring network, and for similar reasons - concerns about groundwater levels affecting public safety, nearby structures and the environment. All municipal action is aimed at preventing damage and monitoring provides a way to develop a baseline dataset and track deviations when implemented measures take place.

Delfts groundwater interest group has collected a great deal of information over its 25-year existence and was founded after residents were reporting moisture problems due to high groundwater levels. The committee, municipality and the local water authority come together to discuss and collaborate in solving problems relating to subsidence (structural issues), flooding (canal spillovers) and potential issues relating to changes in groundwater levels.

The monitoring network solution implemented by the City of Delft is a modern-day example when compared to that of Amsterdam. Delfts automated system is provided by an independent operator who installs and maintains both the monitoring devices and database. Measurements are recorded twice daily and sent through a cellular enabled device to a secure cloud-based storage system. As with Amsterdam, data is also made publicly available through an online portal (Figure 2.3).

A bi-daily measurement frequency is important in Delft as the City and local water board watch closely the effects of a decision reduce the amount of water being withdrawn by an industrial water user (very comparable with the Michoud, New Orleans situation). Concerns for the city stem from idea that the rebound of groundwater levels will disturb the steady state created during the long term, high volume abstraction of the industrial user. Risk associated with groundwater related issues is reduced by increasing the frequency of monitoring events. Additionally, understanding the speed of the aquifer system helps determine operational requirements built into the system.

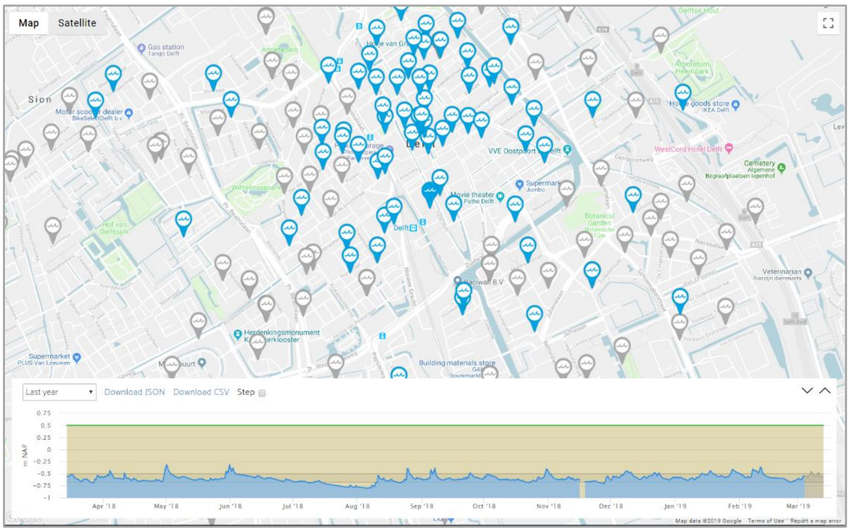
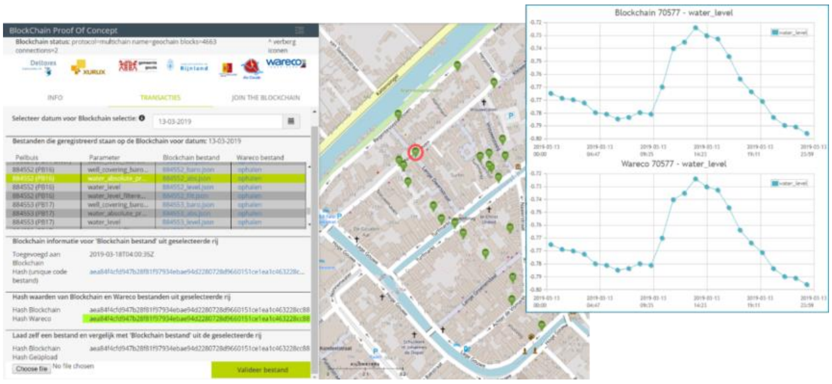


Figure 2.3 Location and distribution of groundwater monitoring locations within the city of Delft, NL. Data made publicly available by the municipality of Delft through (https://opendata.munisense.net/).

2.1.3 Gouda – towards accountability and transparency

Subsidence relating to the consolidation of soft peat and clays in the city center of Gouda is often blamed on the steady reduction of groundwater levels over the past centuries. The historic homes built between the 16th and 20th centuries were not constructed on foundations, so they are subsiding as well. As a proof of concept combining groundwater monitoring, Internet of Things (IoT) monitoring devices, and blockchain technology, a small group of wellbores were fitted with a groundwater level monitoring device that records and transmits data directly to a distributed blockchain ledger. With no single point of storage and no human interference within the system, residents can be assured that data manipulation is not taking place within this closed system. As a second step towards insuring transparency, the blockchain protocol was built to check the recorded and stored data against the values that the water utility provider posts online, allowing users to monitor recorded data against what is being showed to the public.



BlockChain Proof Of Concept

Blockchain status: protocol=multichain name=geochain blocks=4663 connections=2

INFO | TRANSACTIES | JOIN THE BLOCKCHAIN

Selecteer datum voor Blockchain selectie: 13-03-2019

Bestanden die geregistreerd staan op de Blockchain voor datum: 13-03-2019

Peilbuis	Parameter	Blockchain bestand	Wareco bestand
884552 (PB16)	well_covering_baro...	884552_baro.json	ophalen
884552 (PB16)	water_absolute_pr...	884552_abs.json	ophalen
884552 (PB16)	water_level	884552_level.json	ophalen
884552 (PB16)	water_level_filtere...	884552_filt.json	ophalen
884553 (PB17)	well_covering_baro...	884553_baro.json	ophalen
884553 (PB17)	water_absolute_pr...	884553_abs.json	ophalen
884553 (PB17)	water_level	884553_level.json	ophalen

Blockchain informatie voor 'Blockchain bestand' uit geselecteerde rij

Toegevoegd aan Blockchain: 2019-03-18T04:00:35Z
Hash (unique code bestand): aea84f4cfd947b28f81f97934ebae94d2280728d9660151ce1ea1c463228c...

Hash waarden van Blockchain en Wareco bestanden uit geselecteerde rij

Hash Blockchain: aea84f4cfd947b28f81f97934ebae94d2280728d9660151ce1ea1c463228cc88
Hash Wareco: aea84f4cfd947b28f81f97934ebae94d2280728d9660151ce1ea1c463228cc88

Laad zelf een bestand en vergelijk met 'Blockchain bestand' uit de geselecteerde rij

Hash Blockchain: aea84f4cfd947b28f81f97934ebae94d2280728d9660151ce1ea1c463228cc88
Hash Geüpload

Figure 2.4 Small scale Blockchain proof of concept groundwater monitoring network in Gouda. Each green marker represents a location of a web interfacing recording device. The device measures the water level and transmits it directly to the blockchain ledger and compares the recorded measure with the data being presented on the water companies' website. Data available at: https://geoblockchain.nl/blockchain/

2.2 Other examples from Europe

From subsidence to groundwater flooding, risk identification, infiltration opportunities or urban planning, the reasons *why* (or how) a city would want to undertake the installation of a groundwater monitoring network is dependent on the location. The following subsections briefly describe the monitoring networks in Hamburg, Oslo, Dresden and Antwerp.

2.2.1 Hamburg (Germany)- for a secure water supply

Hamburg is a city 100% reliant on groundwater for its public water supply and a good example of how through optimizing a groundwater monitoring network it is possible to reduce operational costs without sacrificing data quality or reliability. As a first step towards their program implementation, an in depth understanding of the geological and hydrogeologic systems to be monitored was put forefront. Understanding and prioritizing what they wanted to monitor allowed the involved decision makers to reduce the monitoring network from over 1000 monitoring boreholes locations to 539 in the shallow aquifer and 109 locations within the deep aquifer. The shallow aquifer took priority of over its deeper counterpart because of its susceptibility to contamination and potential impact of flooding if groundwater levels become too high. In addition to the shallow and deep groundwater level recording devices, 157 boreholes were selected as locations to collect groundwater quality information and were divided between both the shallow and deep aquifers.

Sampling method and frequency were also altered. By implementing a combination of dataloggers and telemetry devices, fast pace changes to groundwater levels resulting from tidal influence and precipitation events trigger an automated alert system so the appropriate response measures can be taken in time. Something that would not have been possible if they were still using their previous system of manual measurements twice per month. The updated monitoring network increases the amount of information received by city planners, response teams and planners while reducing maintenance costs and providing the public with a tool to better understand the groundwater related risks within the area.

2.2.2 Dresden (Germany) – in preparation for, and in response to flood risk management

Groundwater flooding is likely a significant contributor to overland flooding where hydrologic and hydrogeologic conditions permit - occurring when groundwater levels rise above ground level (i.e. in depressions / topographic lows). When this happens, the subsurface system cannot drain infiltrating waters fast enough and the resulting pooled body of water on the surface will remain in place until evaporated, pumped or drained naturally when storage within the phreatic groundwater system becomes available. This relatively poorly acknowledged flooding type has gained the attention of scientists, water managers, and insurance agencies over the past few years and is gaining recognition as serious contributor to flood related damages.

Dresden's groundwater monitoring network records and transmits daily level measurements and through their online portal allows the public to see how close the groundwater level is to the surface. Map symbols in Figure 2.5 show multiple pieces of information; the organization responsible for the monitoring device is indicated by the symbol shape, while the risk at the defined location is indicate its color. Dresden provides different maps to show groundwater information, precipitation data, flood forecasting and river flood risk maps at different alarm levels.

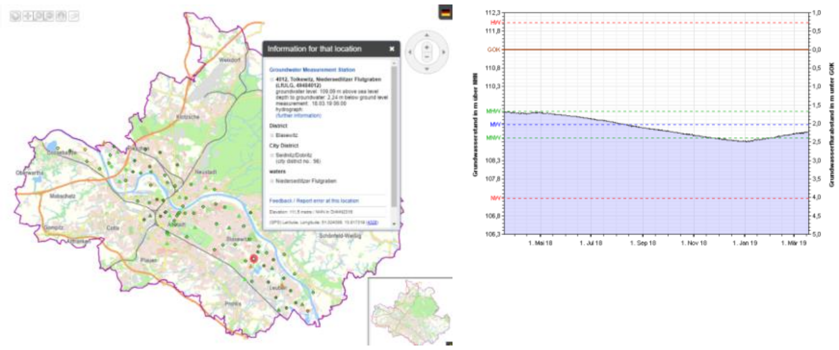


Figure 2.5 (left) Locations and levels of select groundwater monitoring location from multiple different monitoring departments (right) Raw hydrograph data as recorded by the measurement device and displayed with the high/low water level (HW/NW) as well as means of the high / low groundwater level and the median (MHW, NHW, MW) data available to the public at: http://stadtplan2.dresden.de.

Groundwater monitoring locations record a daily water level when river stages and precipitation events are considered normal. Frequency is increased to several daily recordings during periods of intense rainfall and elevated river levels to better understand the situation and manage the associated risk.

2.2.3 Antwerp (Belgium) – identifying risk and urban planning

Antwerp acknowledges the prosperity that water has brought to the region but also its inconveniences. In 2013 supplementary monitoring wells were installed to bring the total network size to 150, covering the nine districts of the city. The main directive of the monitoring networks is for comparison between current levels and historic datasets, looking for abnormalities and potential ‘sensitive’ zones where flooding, subsidence or negative environmental effects may be caused by groundwater level fluctuations.

From an ecological and parks/environment perspective, the monthly data stream has built up to where seasonal trends are emerging. This information proves helpful to city planners and urban architects who are selecting what type of trees or vegetation should be planted in new developments. Understanding the seasonal fluctuation of water depth helps them to select plants with root depths penetrating deep enough to tap into the groundwater source, reducing the maintenance costs of the department.

Additionally, infiltration opportunities could be observed from the dataset, potentially allowing for land use classification and rezoning to take place if the land type is considered high risk for flooding. Figure 2.6 presents a collection of maps made publicly available through the external portal of the city of Antwerp.

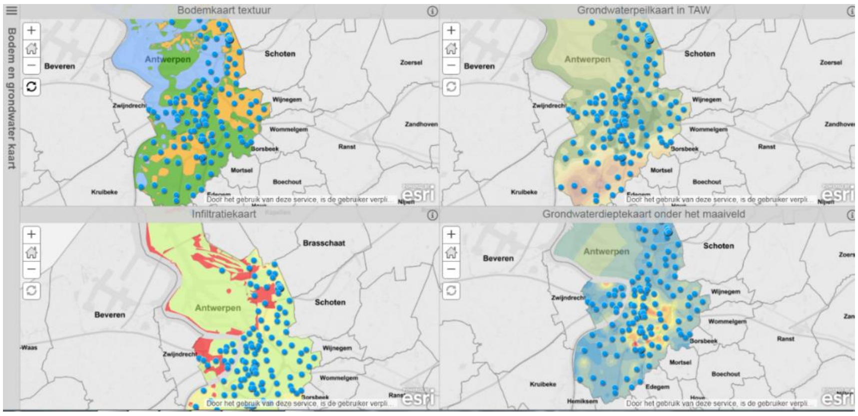


Figure 2.6 Location of boreholes overlaid with different layers. (top left) soil texture map, (top right) groundwater level map, (bottom left) Infiltration capacity, (bottom right) groundwater depth chart. From the city of Antwerp website (http://stadantwerpen.maps.arcgis.com/home)

2.2.4 Oslo (Norway) – a national water well database

Through the Norwegian geological survey, a national registry nicknamed GRANADA (the national groundwater borehole database) stores and makes available a national collection of groundwater knowledge. This includes well data and reports on groundwater investigations and pumping locations for water and boreholes drilled for energy needs.

The Database acts as a publicly accessible repository for drilling records and is currently not set up to compare or analyze the data within the framework in which it is displayed. Many states or state agencies within the United States have similar standalone datasets available on their websites.

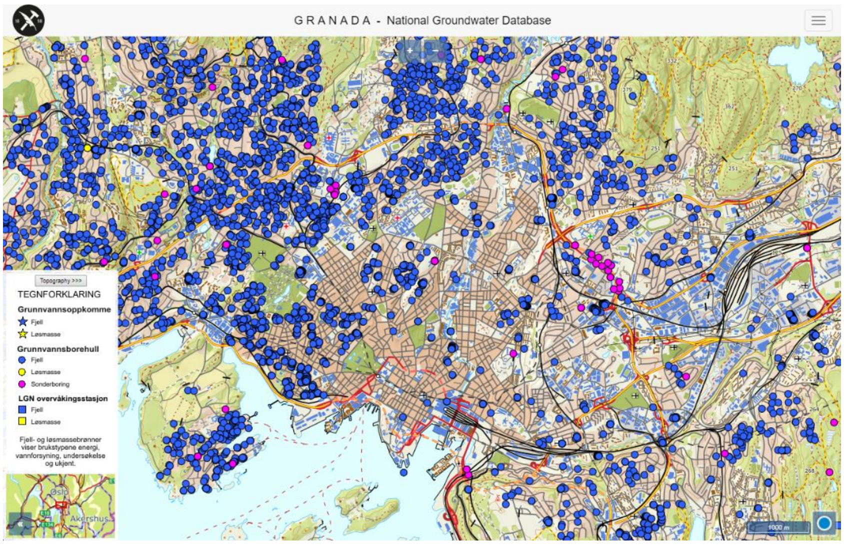


Figure 2.7. Groundwater bore hole locations in Oslo, Norway. Borehole information stored at each location includes location, depth and additional drilling information if available (http://geo.ngu.no/kart/granada/).

2.3 Concluding observations

Although out of sight, groundwater should not be out of mind. Within the correct geologic setting, an aquifers ability to provide a high-quality water source to domestic, agricultural or industrial consumers in a way that is safe for the users and the environment has been proven to be feasible for centuries. From the examples above, a realization that each system was built around specific requirements for the city (or adapted to new challenges), country or area of interest should be apparent. Depending on what is sought after by the client, may it be water quality, record keeping, or a real-time groundwater level monitoring system, a network can be developed and optimized to meet the desired function.

A publicly available (and easily searchable) information data-source is ideal, not only for operators & regulator transparency, but also for the distribution of information during emergency situations and educational opportunities for the community. With the current state of database management for operational systems and spatial plotting within dashboards, a smooth display with multiple layers of data is achievable.

3 Urban groundwater monitoring - experiences in the USA

A 2001 report commissioned by the USGS on groundwater level monitoring and the importance of long-term water level data outlines crucial pieces of information needed to develop a successful monitoring network but focuses on regional (basin or state scale) case studies. While the concepts needed to define such a monitoring network are the same, differences in scale should be considered when implementation on a more local scale and within an urban setting is to take place.

Additionally, the American Geosciences Institute (AGI) provides an interactive map of groundwater monitoring information, including over 7000 groundwater wells collected from state and federal agencies. Each interactive wellbore provides information on well construction and lithology, allowing for a high-level overview of aquifer health but too few details to be able to make decisions at a local level.

The vastness of the United States makes monitoring on a national level where insight into local systems within urban centers unviable. State based water resource acts, such as that in California place ownership of water monitoring and management on the water districts, municipalities and cities themselves where local knowledge of the surficial and subsurface systems can be implemented more efficiently. Through this appropriate use of local systems knowledge as well as the individual problems linked to each urban center a much more efficient monitoring and management plan can be realized.

3.1 San Francisco groundwater management program

In 2016 the San Francisco Public Utilities Commission prepared an urban water management plan for the City and Country of San Francisco in response to the drought and corresponding local state of emergency where at the time, represented the driest period in the hydrologic record. This plan considers (among other points) the local water supply and demand dynamics, shortage contingences and climate considerations. The plan requires all its urban water suppliers to update and prepare their urban water management plans every five years and these (and the overall program itself) needs to fall in line with the 1983 California Urban Water Management Planning Act. The purpose of the act is “to assure water suppliers plan for long-term reliability, conservation and efficient use of California’s water supplies to meet existing and future demands”.

Included as a section within the Urban Water Management Plan, The Groundwater Management Program is in itself one third of the total groundwater program which also consists of the San Francisco Groundwater Supply Project and the Regional Groundwater Storage and Recovery Project. The program looks at providing data and advice to prevent overdraft, pollution or contamination in any of the 7 groundwater basins in San Francisco and is devised in line with the urban water management plan.

Groundwater monitoring within the area of interest provides both chemical properties and physical water levels within the area of interest. When combined with pumping information from key locations (ie. San Francisco Zoo, local groundwater supply projects and regional groundwater and storage recovery projects) changes may be correlated to certain actions, driving a better understanding of the subsurface system. Surface water and storm water systems are also included within this plan and the link between the systems is not missed.

3.2 Nassau County groundwater monitoring program

Nassau County in New York State is home to 1.3 million people and relies on groundwater as a source for 100% of the drinking water delivered to its residents. Commissioned by the Nassau County Department of Public Works (DPW) their groundwater monitoring objective is clear; “to ascertain the overall condition of the groundwater resource and behavior of the aquifer system on a countywide scale through an extensive network of monitoring wells”. In doing so, information is measured to study the system trends in water use, quality, levels and any relationships they may have with weather patterns. Although all work pertaining to sample collection, measurements, data interpretation and reporting is done by the DPW, a cooperative working partnership with the USGS has existed for over 65 years. The data and reports generated are protected under the freedom of information act and distributed to any person or business who may be interested.

Monitoring components consist of 620 wells spread over ~1000 km^2 county with screen depths targeting different aquifers depending on the well locations. Located at (and surrounding) a groundwater dived, multiple wells were placed and are visited monthly to record the water levels at this site. Because of this location’s high natural groundwater level and its susceptibility to fluctuations in response to climate conditions, these wells act as a drought indicator for the rest of the county. Piezometric levels are also recorded and when evaluated against historical information, trends with respect to the behavior of the hydraulic system may be interpreted.

3.3 USGS Groundwater Watch – Groundwater monitoring on a National and State level

The United States Geological Survey (USGS) provides an active network of over 17,000 wells across the country that are measured at least once a year (1,744 are monitored in real time and another 1,280 at a daily timestep). Additionally, a national database of 850,000 wells is kept, maintained and is searchable through the waterdata.usgs.gov website. These networks are used for state and local monitoring projects and hydrologic research. Each state is searchable and from there, each country and individual wells. Site statistics, groundwater level data and site description are all available in downloadable format

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NEW:

https://www.usgs.gov/science-explorer-results?es=Groundwater+Monitoring&classification=map

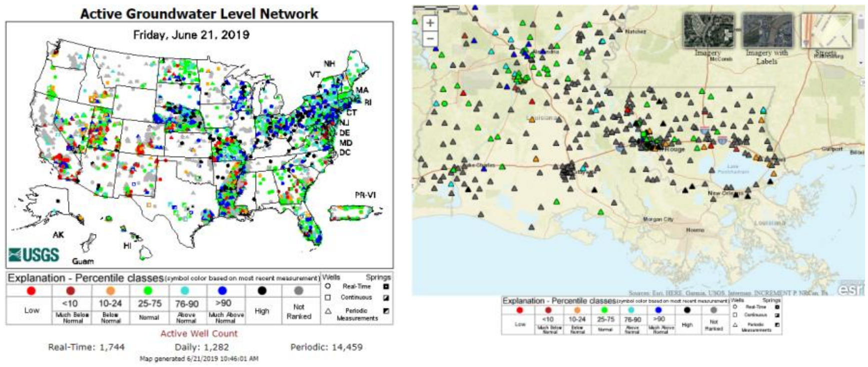

Figure 3.1 (left) United States Active groundwater level network map and (right) Louisiana groundwater well monitoring locations. From (https://groundwaterwatch.usgs.gov/default.asp)

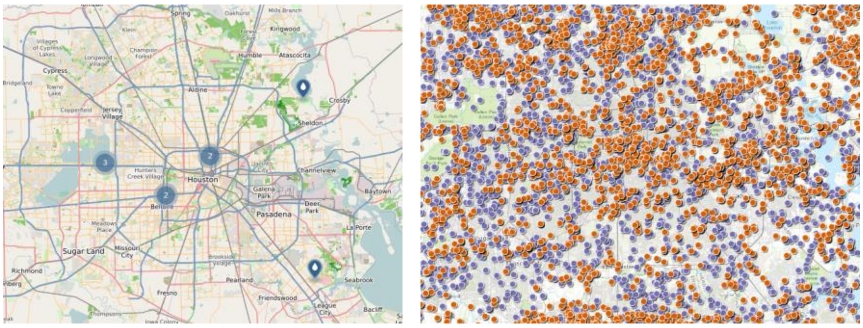

Figure 3.2 (left) locations of automatic recording devices activly monitoring the groundwater levels within the aquifer of interest. (right) All well locations listed as "water supply wells / pumping (purple)" or "monitoring wells (orange)" over the city of Houston. (from: https://www2.twdb.texas.gov/apps/WaterDataInteractive/GroundWaterDataViewer)

States wide water agencies, such as the "Water Data for Texas" group (a subproject of the Texas Water Development Board) also provide publicly available information on the current levels of reservoirs and groundwater, as well as drought, evaporation and rainfall data. The groundwater level measuring projects is a cooperative effort between 50 groundwater conservation districts with the intent to have at least 1 well per 25 sq/miles within minor aquifers and 1 well per 125 sq/miles for major aquifers (left). Figure 3.2 (right) shows the well density over the same area, orange wells are labelled in the well report as "Proposed use – monitoring" whereas wells highlighted in purple are intended for the "withdraw of water". Only wells from the left image provide hydrograph data and well information. Locations from the right image from the interactive water data site only provides information pulled from the submitted drillers well report.

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https://www2.twdb.texas.gov/apps/WaterDataInteractive/GroundWaterDataViewer

Figure 3.2 (left) shows wells that are transmitting real time groundwater levels and can also be found in the active National/State monitoring network provided by the USGS (Figure 3.1). The locations from (Figure 3.2) however, do not include locations where data is recovered and charted periodically. provides a good example of the network density that may be present and may have the potential to use if "re-worked" into a denser monitoring network.

3.4 Concluding observations

With the exceptions of the examples provided earlier, the public distribution of urban groundwater monitoring information was difficult to find at a local level. This is contradictory to the thought that water supply companies, water districts, utility companies or governmental organizations would provide such information freely to show their compliance to state and local laws as well as to build their corporate reputation. Information relating to water quality was generally present in the form of an annual water quality report, but supporting information was not found. If the information is present and being used to guide water related decisions, then a natural step towards a transparent system is presenting the data within a public domain. If however, groundwater related decisions are taking place by a group that does not have the proper tools and knowledge at their disposal, they are putting the environment, infrastructure and the local population at undue risk.

4 A vision on monitoring water and the urban environment

4.1 An INTEGRATED monitoring network

Groundwater is only a single component within a complex system of interrelated parts. Figure 3.4.1 provides an abstracted, generalized example of how groundwater levels interact with other natural and anthropogenic systems. This figure is provided to help raise awareness of the complicated and interrelated process at play as well as inspire discussions about leveraging current (and emerging) technologies to monitor interrelated urban water systems.

> "an INTEGRATED monitoring network for the region
> would ensure that water management strategies
> could be targeted precisely when and where needed"
>
> *- Greater New Orleans Water Plan – Urban Design*

The merging of currently independent (if available) parts such as surface and groundwater levels, water chemistry, subsidence, precipitation, and storm system information could help to provide insights into inter-related parts of the system. In doing so, the potential to better understand water related risks would increase.

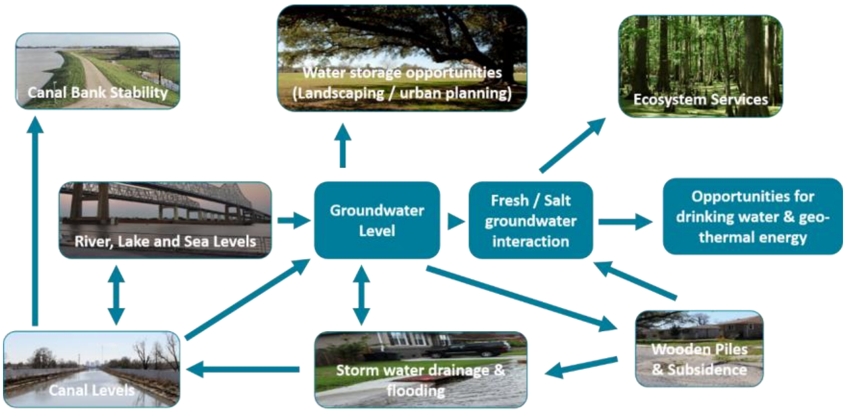


Figure 3.4.1 An example of how groundwater levels may interact with natural and anthropogenic systems.

4.2 The monitoring cycle

Figure 4.2 presents a possible approach towards an iterative integrated water resource management (monitoring) plan and helps to visualize the cyclical nature of the process itself. Building from an understanding of the project objective, defining the information to be collected is an important second step.

A monitoring strategy follows and includes a conceptualization of the “what”, “where” and “how”. The network design advances and materializes the monitoring strategy, installing hardware solutions and creating or implementing software solutions where needed. Processing the data and data analytics can be an automated process, either built into the system or as a standalone repository that stores raw data that can then be made available to whoever is granted access. Decisions on how the data is then reported on, distributed and utilized should be outlined in the vision and decided upon through communications with stakeholders at the start of the project.

Integrated water management strategies are no different than other process that need to evolve with changing technologies, methods and thought processes. Hence the cyclical nature of the process itself. An evaluation of if the process is providing decision makers with information they require and in a more general sense, if the program is satisfying the objectives and scope set during the conceptualization phase.

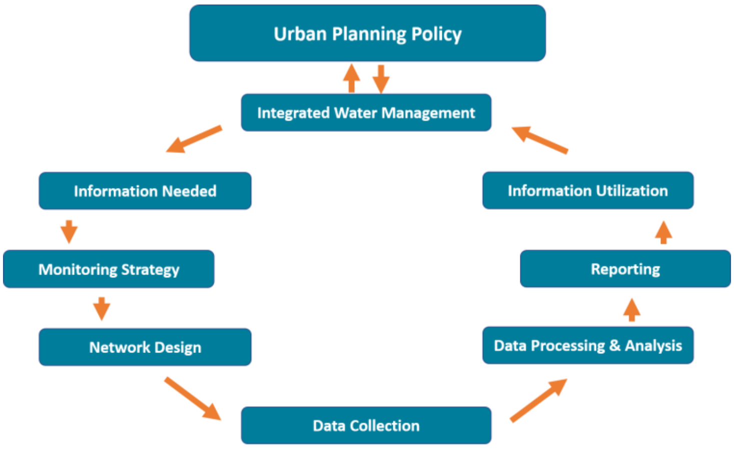


Figure 4.2 Integrated water management monitoring cycle steps and its relationship with urban planning policy decision makers.

To complete the cycle, a re-evaluation of the entire process and its deliverables should be undertaken at regularly scheduled intervals or as needs change. Are there new tools or processes that should be changed or adapted to? Do stakeholders / decision makers require new or different forms of information? Is there information being created that is no longer relevant, out of date or redundant? These are all examples of relevant questions that may be asked to help better understand if a review of the project cycle is needed.

Section 4.3 breaks down the integrated water management monitoring cycle into its parts and couples each action with parts of the figure from section 4.1. These images can be found in Annex 1.

4.3 From design to implementation – Examples of possible solutions

	**Gw Level // River, Lake & Sea levels, Water storage opportunities** (Figure 10.1**)**	**Gw level // water storage opportunities // storm drainage and flooding // wooden piles & subsidence** **(**Figure 10.2**)**	**Canal bank stability // canal levels // gw level // fresh and salt groundwater interaction // wooden piles & subsidence/** **(**Figure 10.3**)**	**Gw levels // fresh & salt gw interaction, ecosystem, opportunities for drinking water // subsidence** **(**Figure 10.4**)**
Integrated Water Management	Rain water infiltration to reduce pluvial flooding & damage	Optimize strategy to reduce pluvial flooding and subsidence	Mid / long term management strategy of outfall canals	Mid / long term management strategy of deep groundwater
Information Needed	How do rivers and lakes influence infiltration opportunities?	Where is removing pavement / infiltration recommended, and where should repairs to storm water drainage take place?	What are the risks of infiltration from? Is subsidence occurring below the canals?	Opportunities and risk of deeps groundwater for wetland ecology, freshwater supply, energy storage and groundwater logging
Monitoring Strategy	Determine influence of river and lake on; (1) surface elevation / lithology and (2) on deep, then shallow groundwater levels (hourly)	Determine interaction between groundwater, storm water drainage, subsidence and land use	Determine interaction between canals, subsurface and groundwater	Determine interaction between deep and shallow groundwater, fresh / salt distribution and subsidence
Network Design	Lithological profiles, well transects, surface water gauges, rainfall	Lithological profiles, well transects, sewer inspections, land use types (paving), rainfall, surface elevation	Lithological profiles, well transects, canal water levels, salinity in canals, groundwater salinity, wetland ecology	Lithological profiles, well transects (shallow / deep), groundwater salinity, wetland ecology, surface elevation
Data Collection	Data Collection	Data Collection	Data Collection	Data collection
Data Processing & Analysis	Graphs / Statistical analysis	Graphs / Statistical analysis	Statistical analysis, groundwater modelling	Statistical analysis, groundwater modelling
Reporting	Zonation map Groundwater depth x lithology = Infiltration potential	Zonation maps: causes and impacts of low groundwater & pluvial flooding	Risk zonation maps: seepage / waterlogging, salinization, subsidence	Zonation maps: opportunities and risks of deep groundwater
Information Utilization	Prioritization of infiltration Measures	Prioritization: un-paving vs storm water repair	Management strategy: maintain or reduce infiltration from canals	Management strategy: enhance freshwater buildup, no drill zones, masterplan for deep groundwater

5 Design of an integrated water monitoring for greater New Orleans

5.1 Introduction – “You can’t manage what you don’t know”

To help combat frequently flooded streets, subsidence, salt water intrusion and other potential effects linked to more frequently occuring, high intensity weather events (i.e. sea level rise and high intensity precipitation events ect.) the City of New Orleans could look toward initiating a integrated water resource monitoring plan combining subsurface, surface and weather related measurement types to help determine a baseline dataset and work towards understanding the relationship between different variables. This section of the report focuses on defining information that is needed, monitoring strategies (objectives) and network design.

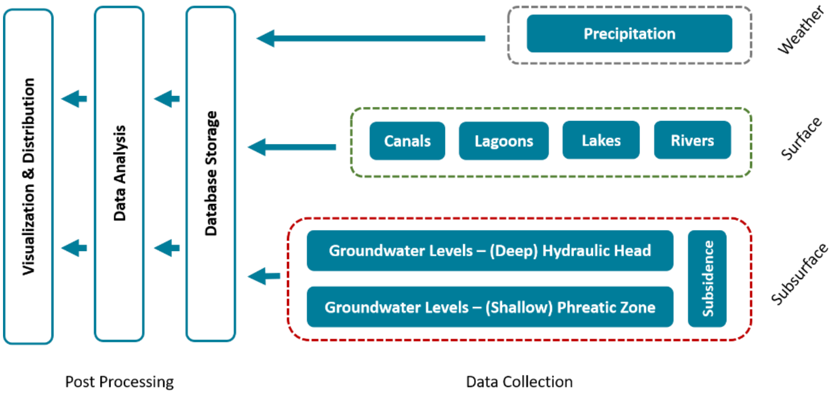


Figure 5.1 An example of different data sources that may be combined in coming up with an urban water monitoring program for New Orleans.

5.2 Monitoring objectives

Setting actionable, attainable, and quantifiable monitoring objective(s) that include manual and technology enabled recording devices distributed over the area of interest is a key step prior to moving into the monitoring cycle. The defined monitoring objectives & resulting action plan is achievable in a cost-effective manor while providing enough data so valid relationships may be seen.

Figure 5.2. One objective could be to safeguard the Heritage Life oak trees. Rising and sustained groundwater levels may drown and suffocate the root system.

The preceding description of groundwater impacts and processes in Greater New Orleans informs the development of the following 12 monitoring objectives:

1. To define which groundwater regimes occur in subsidence-prone clay and peat areas. Can changes be made to groundwater levels to reduce subsidence?
2. To define the extent which wooden foundation piles have emerged above groundwater. Untreated piles are vulnerable to rotting processes.
3. To define the extent at which groundwater levels are influenced by water levels in the canals.
4. To define the extent to which groundwater levels are influenced by subsurface infrastructure. Often the storm drainage and waste water transport pipes are draining groundwater, while the drinking water system is losing water. What will happen with the groundwater situation in future after these systems are renovated?
5. Determine to what extent shallow groundwater levels and deep hydraulic heads interact. Understanding the impact of deep groundwater pumping on shallow groundwater levels.
6. Better understand the relationship between groundwater levels and the influence of the Mississippi River and/or Lake Pontchartrain. Are groundwater levels influenced by Mississippi River or Lake Pontchartrain water levels?
7. Determine the storm water (rain) storage capacity of local soils. When is this capacity exceeded? At what point will ponding and overland flow occur?
8. Determine if there is a salinization risk for freshwater-dependent land use functions.
9. Better understand and define the relationship between sub-regional groundwater flow and Mississippi River / Lake Pontchartrain.
10. Discuss the potential climate change scenarios and the effect on the future groundwater situations. Determine how a monitoring system can help track changes.

11. Create groundwater and subsidence awareness (*Figure 5.3*).
12. Set up temporary monitoring networks in vulnerable areas to observe the local effects of dewatering (e.g. subsidence, dry fall of untreated wooden foundation piles). To mitigate damage caused by dewatering, a monitoring protocol is advised. Groundwater level thresholds should be determined (at what groundwater level is risk deemed to be unacceptable to the local infrastructure or environment). If these thresholds are reached, projects plans should continue (or stop) accordingly.

Figure 5.3. Raising public awareness of groundwater monitoring: a floater on top of groundwater allows groundwater levels and fluctuations to be visible above ground. The transparent tube delineates the ranges where groundwater levels are too low (red) and fair (green).

5.3 Water system analysis overview

5.3.1 Shallow groundwater flow

Figure 5.4 depicts an image of the shallow flow system model completed by Deltares/Tulane in 2019 (Van Asselen et all, 2019) over New Orleans. Groundwater flows from levels of higher elevation (green) to areas of lower elevation (blue/purple) and in doing so allows for the mixing of the older subsurface waters with newer waters from the surface, canals, lakes, lagoons or river. Freshwater in drawn into the underground system from the Mississippi (blue arrows) and more saline water can be seen flowing from the canals in the direction of the red arrows.

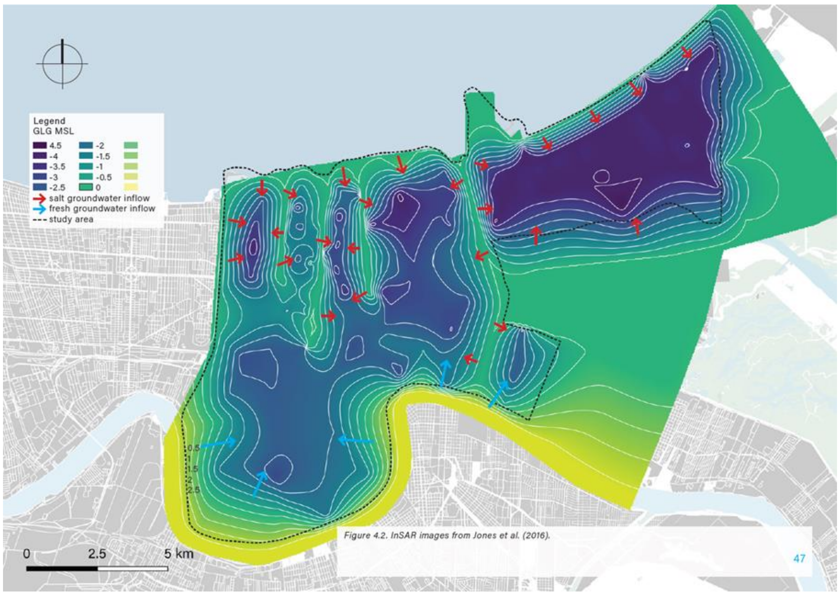


Figure 5.4 Groundwater head level map over New Orleans. Groundwater flows from areas of higher levels (yellow / green) to areas of lower levels (blue / purple) and water type is dependant on the source. Freshwater is fed to the system from the Mississippi river (blue arrows) whereas the canals and water sourced from Lake Pontchartrain is more saline (red arrows).

A conceptual cross section profile trending East to West in the NE quadrant of the city can be seen below in Figure 5.5. This image provides an example of the way the groundwater system interacts with the canals, pipes, parks and subsurface lithology. Hand drawn water level estimates from the sketch can be compared with the modelled results from Figure 5.4.

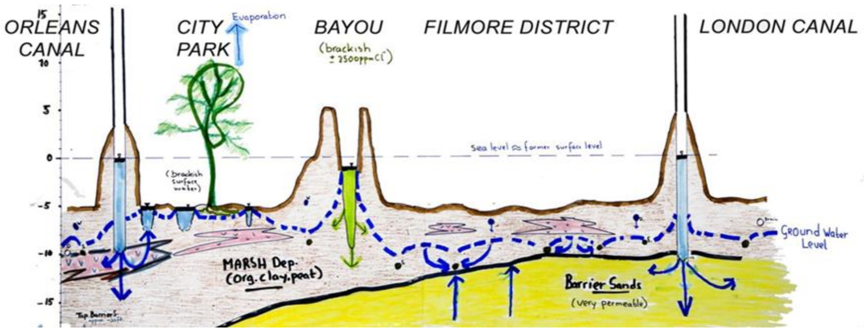


Figure 5.5 A conceptual sketch representing a cross section trending approximatly E-W through the Orleans Canal, City Park, Bayou canal / river, the Filmore District and London Canal. Lithology (organic deposits and Sand layers are represented in brown and yellow, respectivally) and the theoretical flow flines and groundwater levels are represented as solid and dashed blue lines.

Groundwater flow lines, show in the sketch of Figure 5.5 are represented as solid blue arrows and flow from the canals into lithologic layers of higher hydraulic conductivity (sands and lenses within the clay/peat), leaking underground pipes can both add water to the system as well as remove it depending on pipe pressure and permeability.

Like the sketch presented in *Figure 5.5*, the image below (*Figure 5.6*) provides a conceptual sketch of the flow systems between the Mississippi river and Lake Pontchartrain and trends in a North – South direction. Flow fines can be seen moving away from areas of higher piezometric head (the lake, river and higher zones of elevation) towards lower lying discharge areas. The infiltration from these two sources would provide freshwater infiltration from the Mississippi and saline water from lake Prontchartrain as described above and represented in *Figure 5.4* by the blue and red arrows.

Groundwater abstractions and depletion of the deeper confined aquifer has lowered the hydraulic head (aquifer water pressure) over time. This change increases subsidence risk by reducing the counteracting force acting on the downwards overburden from above. The red arrows below also highlight a current lack of understanding with respect to the amount of water that is leaving the system as recharge.

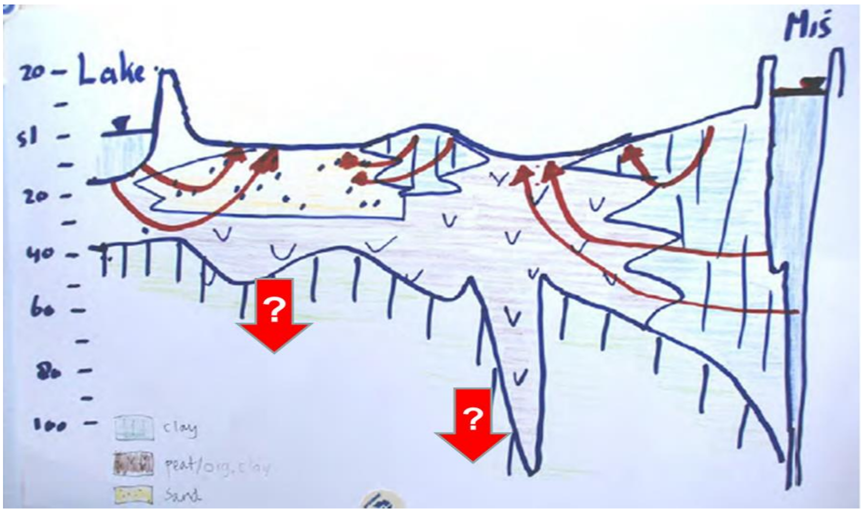


Figure 5.6 A conceptual sketch trending approximatly North – South between Lake Pontchartrain and the Mississippi River in the eastern section of New Orleans. Groundwater flow lines are show as solid red (hand drawn) arrows and lithologies such as sand, peat and clays are represented by blue, purple and yellow colors respectivally.

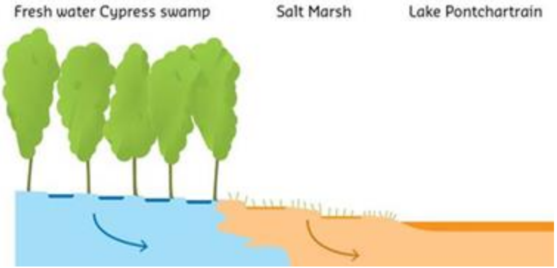
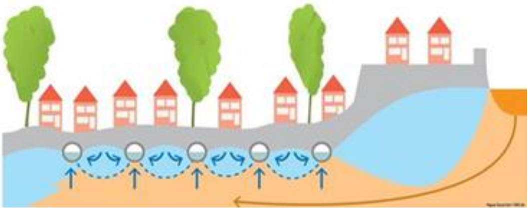


Figure 5.7 (a) Stage 1 - Original ecosystem dynamic between the fresswater cypress swamp (now New Orleans) and Lake Pontchartrain. Fresh water flows from the South to the north (from swamp to lake), following the elevation and pressure gradients through the salt marsh system.

Figure 5.8 (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 5.9 (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 5.10 (c) 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.



5.3.2 Unintentional and intentional groundwater drainage

Until recently, no information existed about the behaviour of shallow groundwater in New Orleans. To fill this gap 73 soil bore holes were drilled with depths up to XXXX meters (see

New Orleans Subsidence Vulnerability report, Van Asselen et all, 2019) and a few high frequency groundwater monitoring well were installed. Both systems delivered valuable new information about the fluctuation of the shallow groundwater system and led to the conclusion that groundwater level is strongly controlled by the civil works infrastructure (pipes) below the roads and sidewalks, as well as by the low surface water levels found in North East New Orleans.

As can be seen in the (conceptual) image of Figure 5.11 (top), the solid blue line representing the mean lowest groundwater level corresponds to the base of wastewater drainage infrastructure during normal weather conditions. During storm events however, groundwater levels can increase with a range between several decimetres (2 feet) up to nearly 2 meters (6 feet) as can be seen in the groundwater hydrograph shown in the bottom left image of Figure 5.11. The groundwater level rises rapidly during the precipitation event but returns to the pre shower groundwater level at a slower rate.

Figure 5.11 also presents a conceptualization of how the stormwater and sewer systems are aligned within the New Orleans subsurface, helping to explain the groundwater drainage processes. Storm drainage pipes and sewage pipes are placed in a subsurface trench filled with gravel and sand (silt), this helps to protect the pipes against the negative effects of subsidence or other ground movements. Additionally, the pipes are connected with geo textile slabs allowing for a flexible joint at the pipe connection. These slabs protect against the inflow of sand into the system but are permeable to groundwater. The permeability or this connection, its degradation over time, and cracked or broken pipes allows for groundwater to enter the drainage system and be removed from the area. The permeable infill materials used during the construction process also creates a preferred flow network for the groundwater to follow. If the groundwater level rises and water pressure from the groundwater is higher than the water pressure within the pipes, groundwater will enter the drainage system and groundwater level be limited to the elevation of drainage network itself. Interestingly, if broken pipes are replaced, a rise in groundwater level should be accounted for in the area where the system had been replaced.

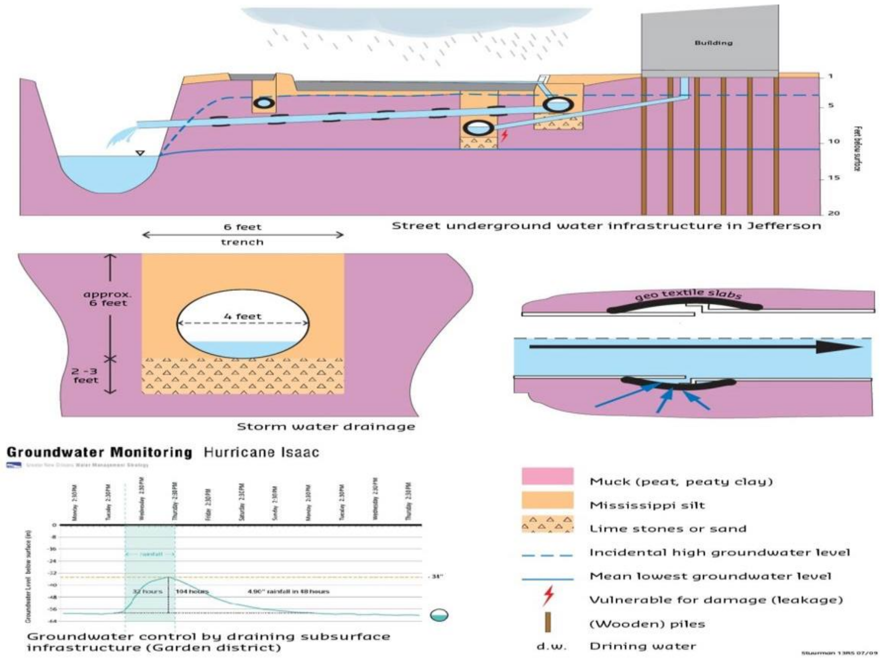


Figure 5.11 A collection of images compiled from XXXXX to describe the influence of underground water infrastructure on the shallow groundwater system. (top) A conceptual schmatic of the depth and placement of storemwater and swer systems and their relationship to the incidental high, and mean lowest groundwater levels. (mid left) a cross sectional view of the pipe and surrounding sediment types. (mid right) A conceptual drawing of the use of geo textiles as joint connectors. (bottom left)a hydrograph showing the relationship between the Hurricane Issac rainfall event and the groundwater level increase.

5.3.3 Deep groundwater flow

Until recent history, the New Orleans deep groundwater aquifer system was only used for industrial purposes and the main groundwater extraction site was located at the Michoud (Entergy) plant (Large purple highlighted area, *Figure 5.12*). The facility used the groundwater for cooling purposes, later discharging it back into the canal system.

The prolonged pumping at rates greater then the rate of recharge (also known as unsafe yield) has lead to the dramatic drop in hydraulic head at the withdraw location and is highlighted by the ‘bulls eye’ pattern in the figure below. The deep aquifers main recharge zone is in the hilled area north of Lake Pontchartrain (*Figure 5.13*) and the deeper aquifers contain both salt and fresh water systems. Due to the length of flow path system, it is suggested that the fresh groundwater body below New Orleans would be thousands or years old.

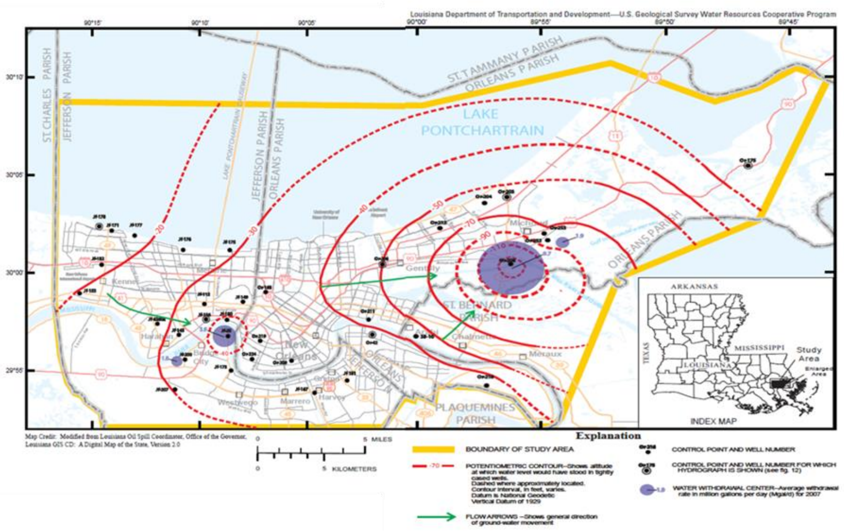


Figure 5.12 Contours of equal hydraulic heads in and around New Orleans (USGS, 19xx). The figure displays the impact of groundwater pumping at the Michoud Entergy plant site on groundwater flow in the deep Gonzales aquifer.

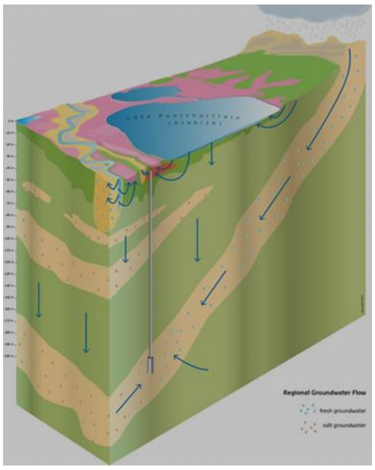


Figure 5.13 Schematization of the regional groundwater system around New Orleans

Monitoring deep groundwater is meaningful in relation to the following:

1. Lowering of the hydraulic head can cause “deep” subsidence that also lower the surface elevation. Lowered hydraulic heads starts 2 processes:
    a. Inelastic (irreversible) drainage of the clay deposits below and above the pumped aquifer;
    b. Elastic (reversible) processes by compaction/concentration of the grains in the sand aquifer. After pumping this will (partly) restore.
2. Knowledge of deep groundwater systems can offer opportunities with respect to future drinking water sources. Deep aquifers could be useful in providing the city of New Orleans with a underground reservoir capable of storing a water bank protected from surface events in case of emergency situations. Additionally, treating the deep brackish water system may prove to be more economic then alternative water sourcing options.
3. Deep aquifers injection and storage could be used as a possible solution for urban storm water management, helping to reduce urban flooding while at the same time helping to restore the lowered hydraulic head.

5.4 Precipitation and evaporation

The use of existing local meteorological information to enhance the understanding of how rain and evaporation influence groundwater levels, storm water runoff and urban surface water levels are key benchmark relationships that are identified as important to better conceptualize the urban hydrologic cycle. It is suggested that between 1 and 3 stations (if available) be fed into the main storage database. Additionally, radar maps or soil moisture maps could also be fed into the database allowing for potential insights into vegetation health to occur.

Currently, there exists a lack of evapotranspiration information over New Orleans. As this is a key water accounting item essential to the successful calculation of a regional water balance, it is suggested that some thought into how and where evapotranspiration information could be built into the system takes place.

5.5 Existing groundwater monitoring sites

There are only a few (recent) operational shallow groundwater observation wells in New Orleans (Mirabeau, St. Anthony Green Streets). A few deep (>200 meter) groundwater monitoring wells are maintained by the USGS.

5.5.1 USGS deep observation wells

There are currently 6 relevant deep observation wells in and around New Orleans (see Table 5.1, Figure 5.14). Nearly all (5 out of 6) are monitoring the hydraulic head (groundwater pressure) in the confined Gonzales New Orleans Aquifer. The monitoring results (*Figure 5.16*) show extreme changes over time. During the Seventies the hydraulic head fluctuated around 120 ft below sea level (Or-42), and 175 ft below sea level (Or-206). This is an extremely unnatural situation as deep groundwater wells drilled here during the 19th Century presented artesian (see *Figure 5.15*). With this observation and due to deep groundwater pumping, the hydraulic head dropped more than 185 feet (> 60 meter).

Well number Or-179, located in Petites Coquilles hosts a deeper observation well within the Abita aquifer (below the Gonzales A.). The time series from this well (*Figure 5.17*) reaches back to 1965 and has recorded a 60-foot drop in hydraulic head between then and 2010. It has since stabilized around 50ft above the NGVD 1929 sea level datum.

Table 5.1 Information of main New Orleans deep groundwater observation wells.

Number	Start	Depth (ft.)	Aquifer
Or – 175	1963	499	Gonzales
Or – 179	1965	2434	Abita
Or – 203	1981	453	Gonzales
Or – 263	1972	647	Gonzales
Or – 42	1948	775	Gonzales
Jf – 156	1974	780	Gonzales

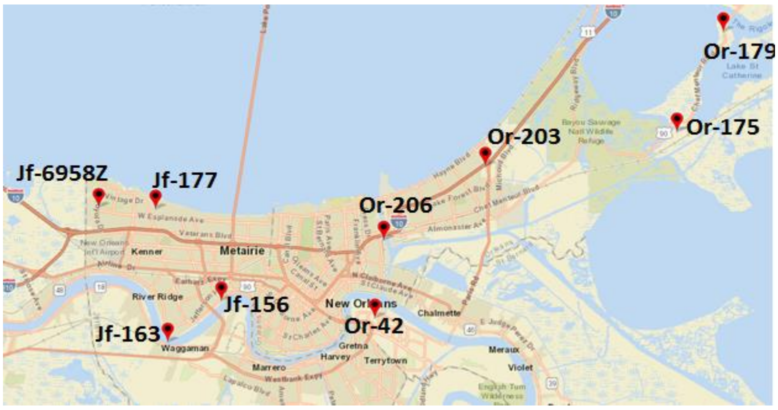


Figure 5.14. The locations of USGS maintained (active) deep groundwater observation wells in and around New Orleans. All sites, accept Or-179 are in the Gonzales New Orleans aquifer. This aquifer is, or was, used for groundwater pumping. The Or-179 is situated in the deeper abita aquifer.

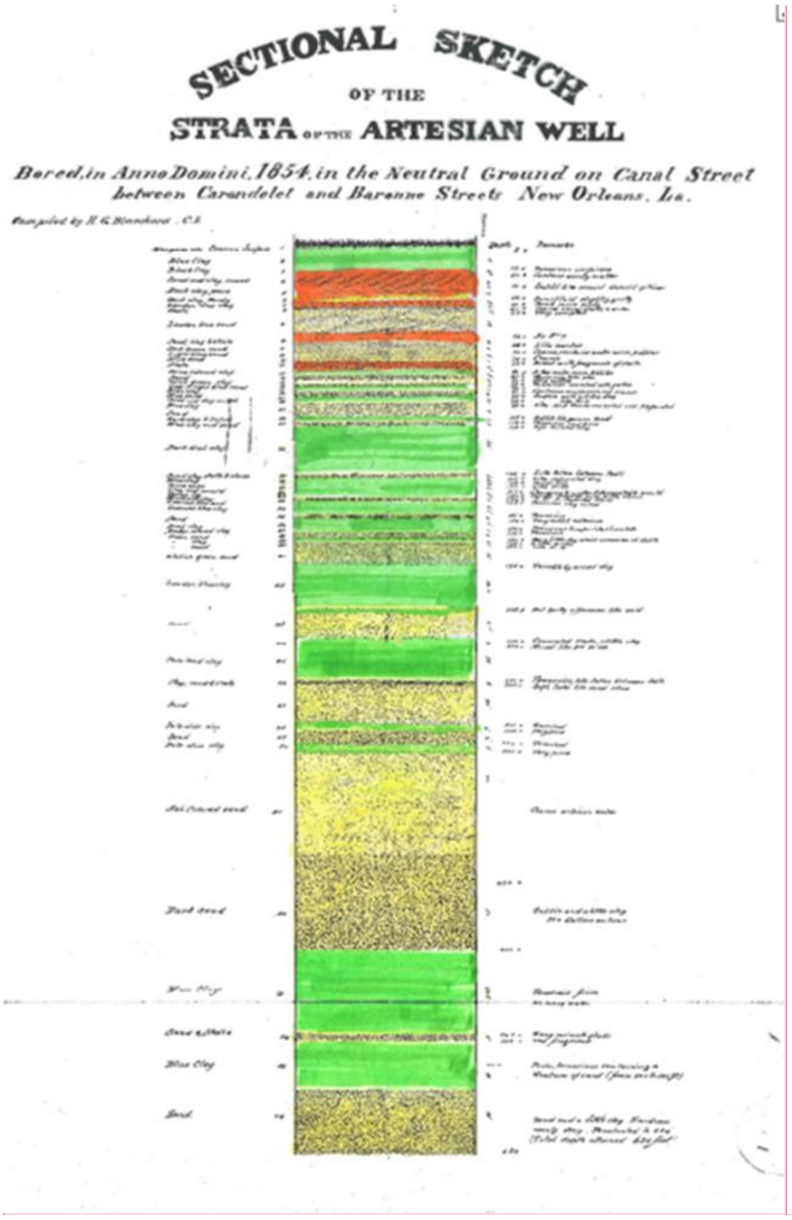


Figure 5.15 This old borehole description showed an artesian hydraulic head in 1854 in the French Quarter.

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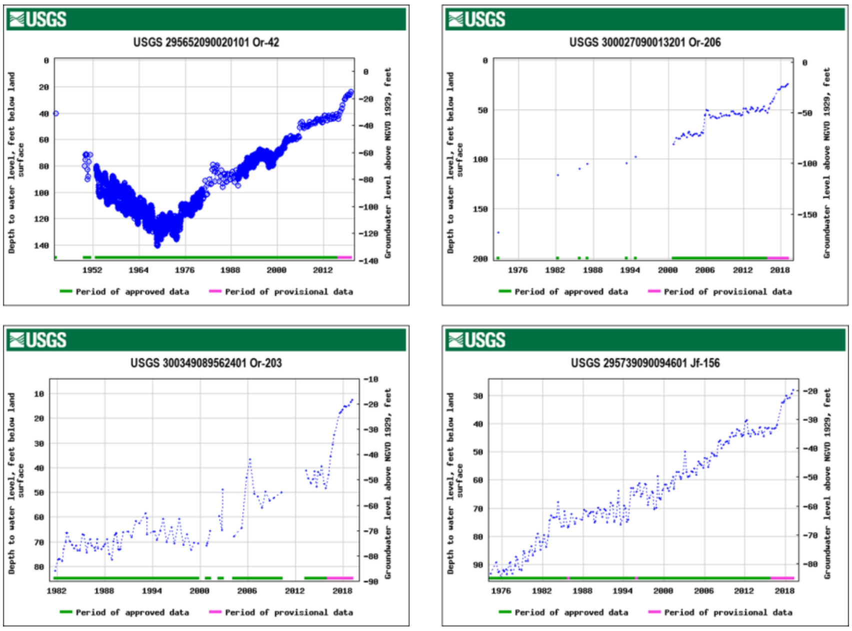


Figure 5.16 Long year time series of deep hydraulic heads (Gonzales aquifer) in and around New Orleans. The hydraulic heads dropped dramatically low in the last century. Since 1970 the hydraulic head restored slowly. The last 3 years the restoration accelerated due to the extraction stop at Michoud.

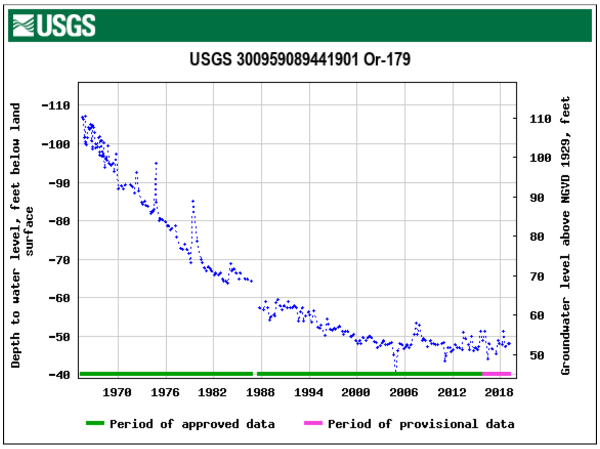


Figure 5.17 The hydraulic head in the Abita aquifer (approx. 2500 feet below surface) dropped approx. 60 feet between 1965-2006. The cause is not clear, but one possible explination could link the decline in hydraulic head to the groundwater

pumping north of Lake Pontchartrain.

5.5.2 Existing shallow monitoring wells

There are few active shallow observation wells in New Orleans. Currently, only 4 sites in the Lafitte Greenway project are active. *Figure 5.18* presents the recent measuring results, showing steep rises (often 2 feet) during rainfall events and dropping over a longer period towards a relatively stable (mean lowest) groundwater level. These lowest groundwater levels are between minus 7.5 and minus 9 feet below sea level.

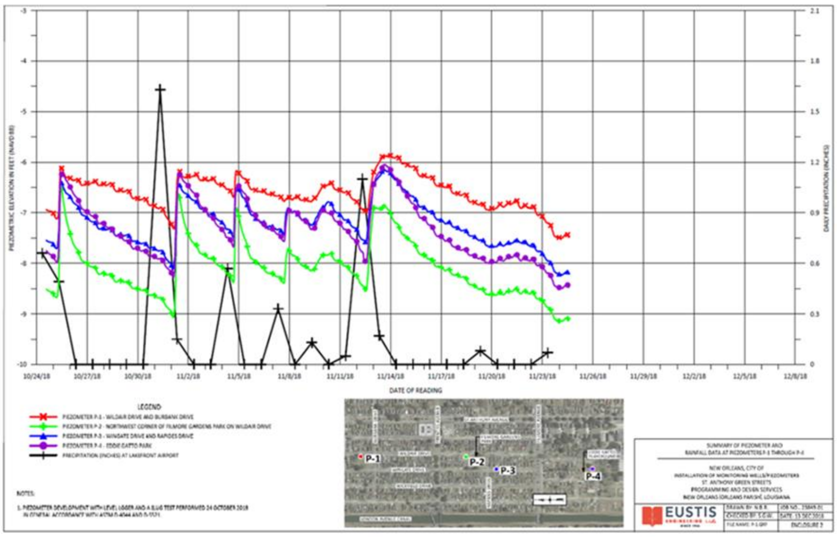
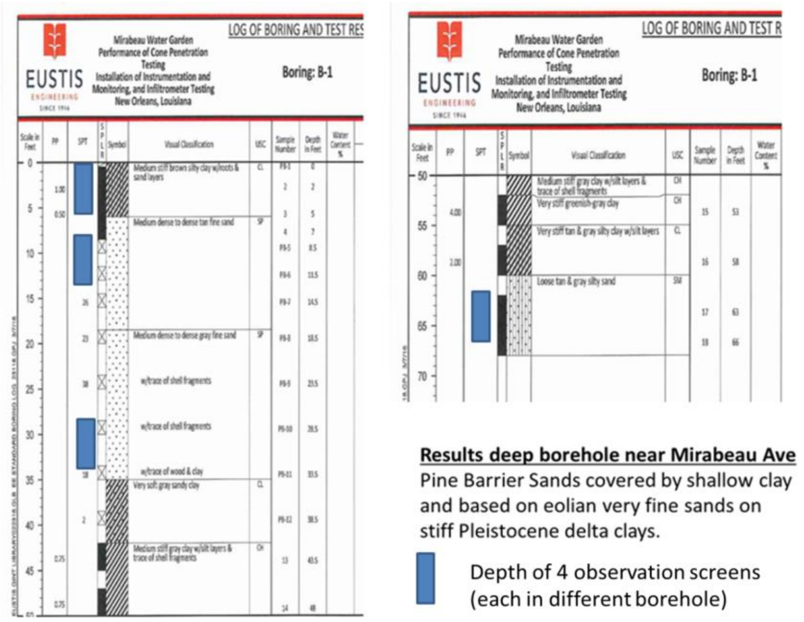


Figure 5.18 Hydrograph lines from 4 operational borehole locations in the Gentilly District. Precipitation is included as the black line. Notice the responce in recorded shallow groundwater levels to precipitation events.

In recent years, shallow groundwater has been monitored at the Mirabeau Avenue site. At the north side of Mirabeau, 4 observation wells are installed near each other at different depths (*Figure 5.19*): (1) in the top of the Pleistocene (90 ft), (2) at the basis of the Pine Barrier sands, (3) at the top of the Pine Barrie sands and (4) in the covering clay layer. The measurements in the deepest filter showed a constant (linear) hydraulic head (approx. equal to surface level). The measurements in the filters in the Pine Barrier sands (2 and 3) were equal and show a fast response to rainfall events.

Figure 5.20 shows a times series recorded from the observation well in the centre of the Mirabeau park area. The filter is approximately 7 feet deep and is placed in the Pine Barrie sands. The graph also shows the surface elevation and the depth of the top of the sands. The high frequency measurements show a very fast reaction (rise) during rain storms, often nearly to surface level. In the following hours/days after a precipitation event, the groundwater level drops in an exponential manner back to the mean lowest groundwater level. This indicated groundwater drainage is like caused by a system at approximately 1.4 m below surface level, and could likely be attributed to the leaking/permeable storm drainage and waste water sewer system in the adjacent streets.



Results deep borehole near Mirabeau Ave

Pine Barrier Sands covered by shallow clay and based on eolian very fine sands on stiff Pleistocene delta clays.

▮ Depth of 4 observation screens (each in different borehole)

Figure 5.19 Borehole description and groundwater observation screens at the Mirabeau multi-screen monitoring site (near Mirabeau Ave).

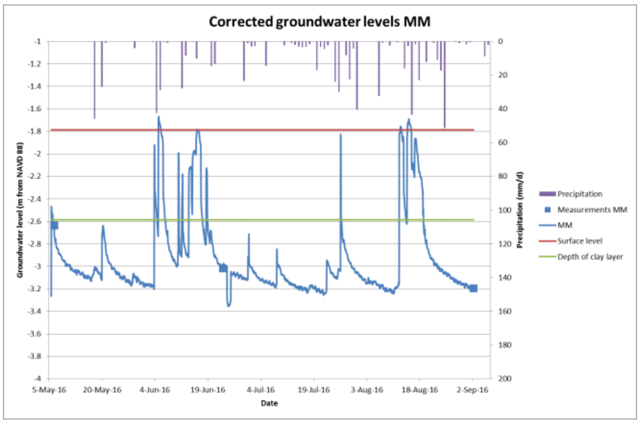


Figure 5.20 Groundwater fluctuation in an observation well in the center of Mirabeau.

5.5.3 Surface water – a ground water measuring device?

In East New Orleans, there are several man-made lagoons remaining from sand mining operations that were developed in the 1960s' during highway construction. The lagoons are not connected with the local canal system although some lagoons have overflow constructions built in, discharging water into the urban storm drainage system when a critical threshold is reached. Water within these systems is brackish or salt and these lagoons act (more or less) as an open-air groundwater monitoring site.

Normally, the lagoons are recharged by rain and seepage, and loose water by (open water) evaporation. Monitoring these sites could also produce more insight in New Orleans evaporation as well as groundwater level measurements and salinity information. We propose monitoring 2-3 lagoons for the indicators mentioned above.

Figure 5.21 An example of isolated lagoons in New Orleans North-East.

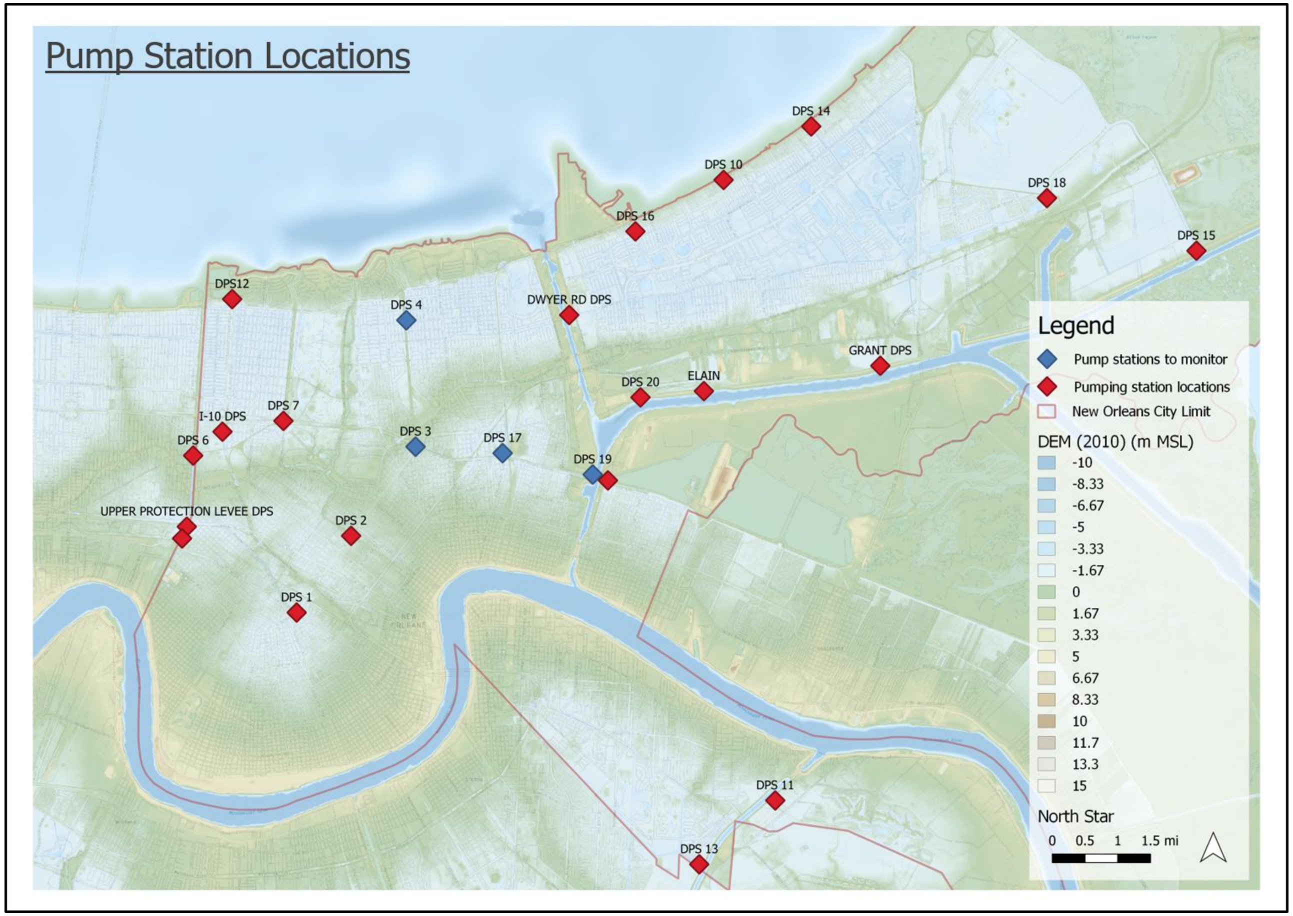


Figure 5.22. New Orleans pump station locations and proposed monitoring sties.

5.6 Active surface water monitoring around the City

The water levels of the Mississippi, Lake Pontchartrain, canals and Wetland Triangle are important constraints for groundwater flow. With exception of the drainage canals and ponds in New Orleans NE all the surface water levels are much higher than the groundwater levels in the urban area. Understanding this relation between water levels (and water quality) of the surrounding waters and urban groundwater (now and in the future) is important for: (1) understanding seepage (groundwater discharge) in the urban area, (2) understanding salinization of urban groundwater, (3) understanding heave risks.

There are several relevant and active monitoring sites maintained by USGS, USACE and NOAA (figure xx).

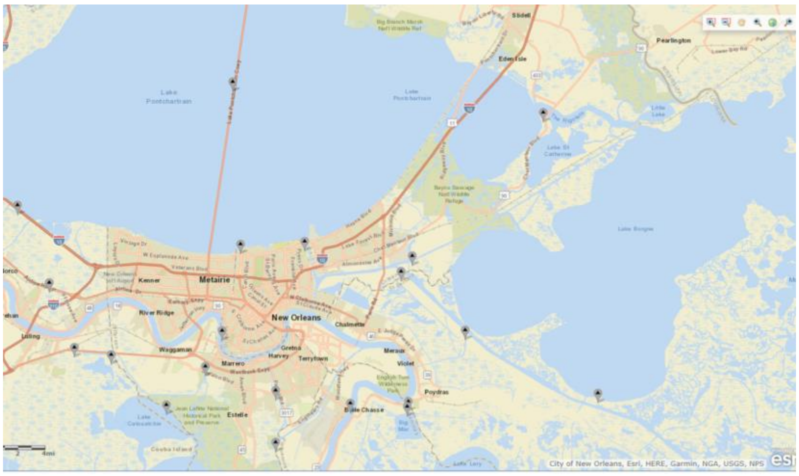
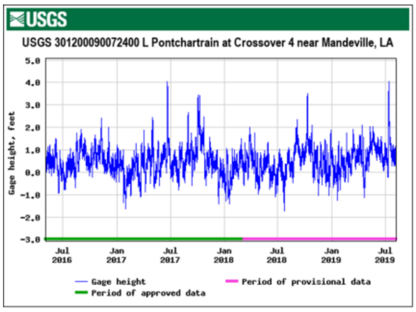
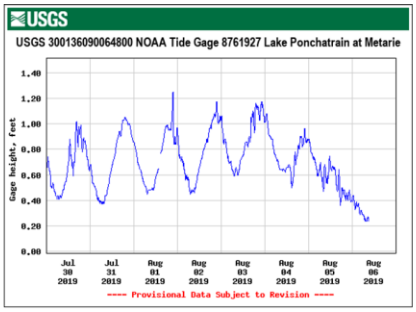
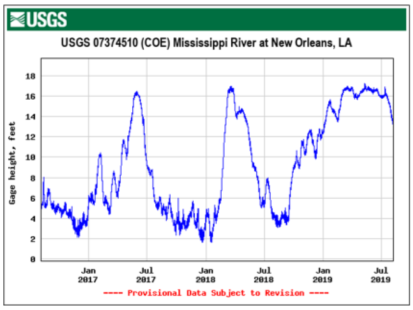


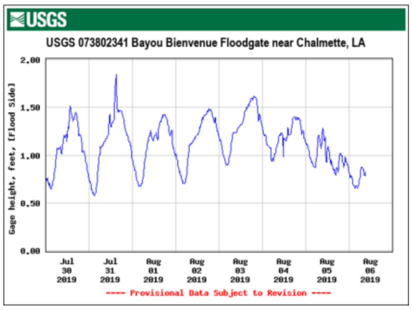
Figure xx: Active surface water monitoring sites around the city.

The results for the most relevant sites (Mississippi, Lake Pontchartrain and Bayou Bienvenue) are presented in figure xx. The last years, water levels of the Mississippi fluctuated between 2-17 feet, while the water level at the other side of the city (Lake Pontchartrain) in general fluctuates between -1 and 2 feet, with incidental extremes of 4 feet.









5.7 Mississippi salt water intrusion

To better understand the salt content of the Mississippi is important to guarantee the fresh water intakes for drinking water supply. But, can also become relevant because the river is an infiltrating body. During low water discharges a salt water wedge will “travel” stream upwards (figure xx). This process is monitored by the USACE during low discharge periods. A sand sill constructed to the proper height above the river bottom can reduce saltwater flow and artificially arrest the wedge. In order to mitigate for the increased duration and extent of saltwater intrusion above Mile 64 AHP, an underwater sill will be constructed when necessary. Conservative estimates show that the sill would need to be constructed an average of about once every five years. Since completion of the 45-ft. channel, a sill has been constructed three times: in 1988, in 1999, and in 2012.

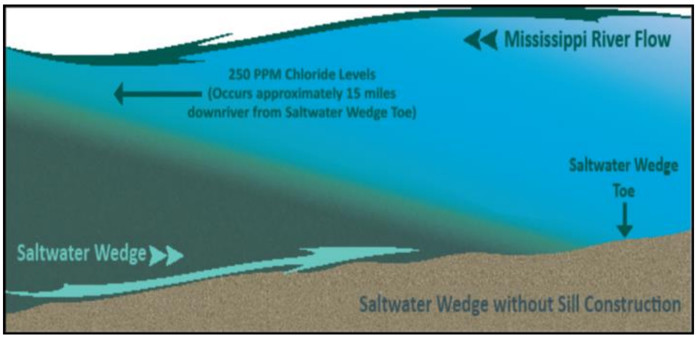
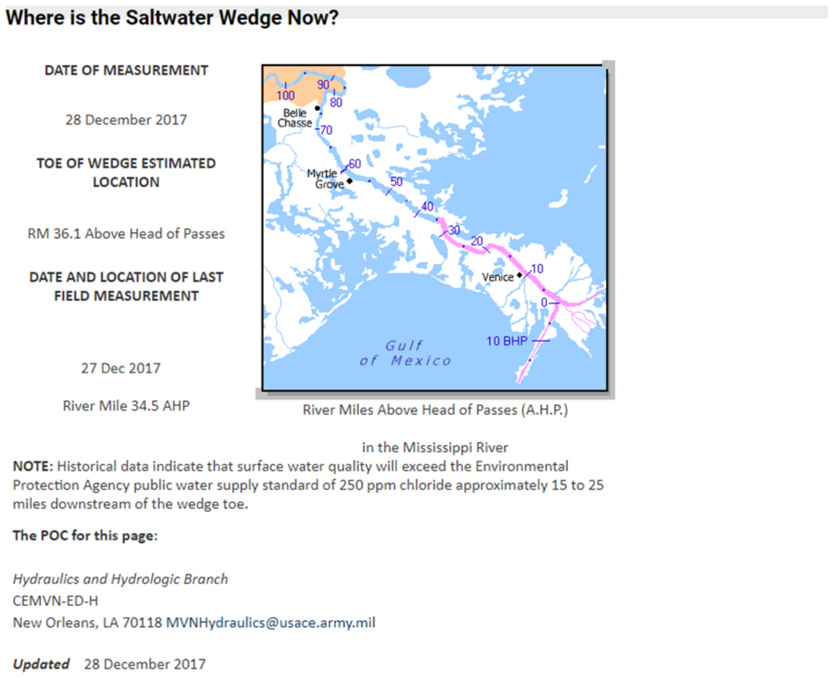


Figure xx presents the monitoring results for the salt water wedge during low flow in December 2017.



Where is the Saltwater Wedge Now?

DATE OF MEASUREMENT

28 December 2017

TOE OF WEDGE ESTIMATED LOCATION

RM 36.1 Above Head of Passes

DATE AND LOCATION OF LAST FIELD MEASUREMENT

27 Dec 2017

River Mile 34.5 AHP

River Miles Above Head of Passes (A.H.P.)

in the Mississippi River

NOTE: Historical data indicate that surface water quality will exceed the Environmental Protection Agency public water supply standard of 250 ppm chloride approximately 15 to 25 miles downstream of the wedge toe.

The POC for this page:

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Updated 28 December 2017

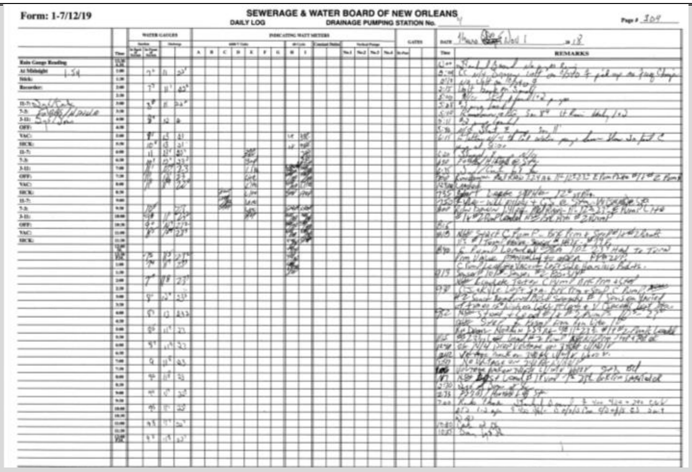
Figure xx presents an example of the salt wedge monitoring results.

5.8 Storm Drainage

New Orleans began to develop its two-part drainage system over 100 years ago and consists of (1) a waste water system and (2) a storm water system. Increased levels of storm water drainage during precipitation events is one of the Cities major problems. If the climate change predictions of more frequent, high intensity rainfall events are assumed to be correct then obtaining a better understanding of the current storm drainage transport system and identifying the right information to improve this system is of great importance.

To do so, it is suggested that a better understanding and analyse of pumping data through the use of time series analysis and system modelling. In addition, spatial information will improve understanding in three ways: (1) provide the operational status of the main system, (2) provide the operational status of the catch basins, and (3) present the locations of regular urban flooding.

The storm drainage system is an unintended but important factor in groundwater management as the system drains groundwater at many locations. The pumping stations are also operational during ‘dry-weather’ flow periods or periods without rainfall (using constant-duty pumps). A modernization of the current system (Figure 5.23) could help with the optimization of the system itself, lead towards a better understanding of how the drainage system is linked with precipitation events and groundwater / surface water levels, and in turn, providing a reduced risk to the citizens and potential cost saving measures to the operators.



Form: 1-7/12/19

SEWERAGE & WATER BOARD OF NEW ORLEANS

DAILY LOG DRAINAGE PUMPING STATION No. 4

Page # 309

Figure 5.23. An example of the current system the Sewerage & water board of New Orleans uses to monitor drainage of their systems. Digitization of this process could unlock potential cost saving measures through optimization and unlocking trends in the data.

5.8.1 Advice for monitoring drainage pumping stations

The main monitoring objectives for the drainage pumping stations is to better understand the relationship between station pumping activity and precipitation events. In doing so, information on salinity, quality, quantity and dry / wet weather water transfer will be recorded, over time establishing a baseline for the system. Figure 5.22 highlights the names and locations of major pumping stations within New Orleans. Although it would be advantageous to monitor every pumping station, at the beginning of the project we recommend starting with the four locations represented by blue symbols in central New Orleans (DPS 3, DPS 4, DPS 17, DPS 19). At these four locations we suggest the measurement of discharge, electrical conductivity and periodically, a “complete” hydro chemical analysis.

- Make available daily (hourly) pumping quantities for every pumping station, including daily local rainfall,
- Add sensors at the pumping station to monitor water level, temperature and salinity
- Make available daily pumping quantities of constant duty pumps
- Organize monitoring of urban flooding (where and when water on the streets) during different rainfall intensities

Commented [GZ4]: I dont know what is going on here? The

1. In general we advise to monitor every SWBNO pumping station:
    a. Discharge per hour or per day,
    b. Continuous electrical conductivity (EC/salinity, temperature, water level)
    c. Periodic “complete” hydro chemical (sample) analysis (nutrients, pollutants, but also standard parameters, e.g. as a start 6 samples/year → 3 during dry and 3 during wet periods.
2. During our project we advise to start with the four Gentilly related pumping stations (3, 4, 17, 19)

Commented [GZ5]: This is already said above?

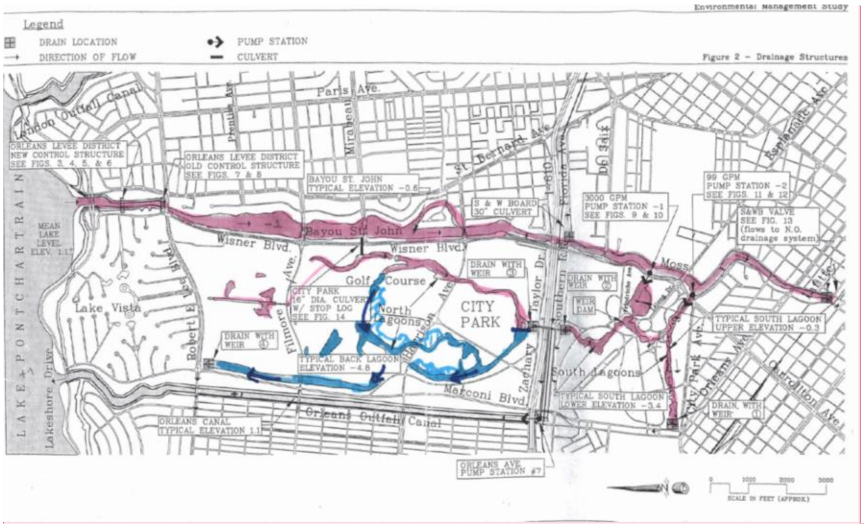
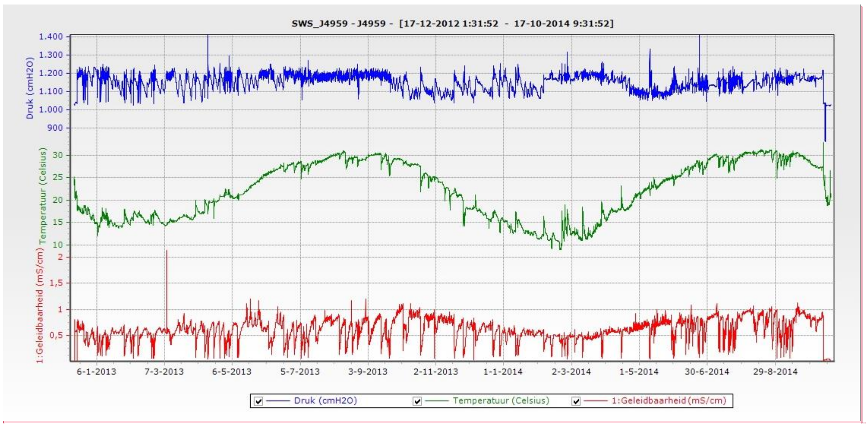
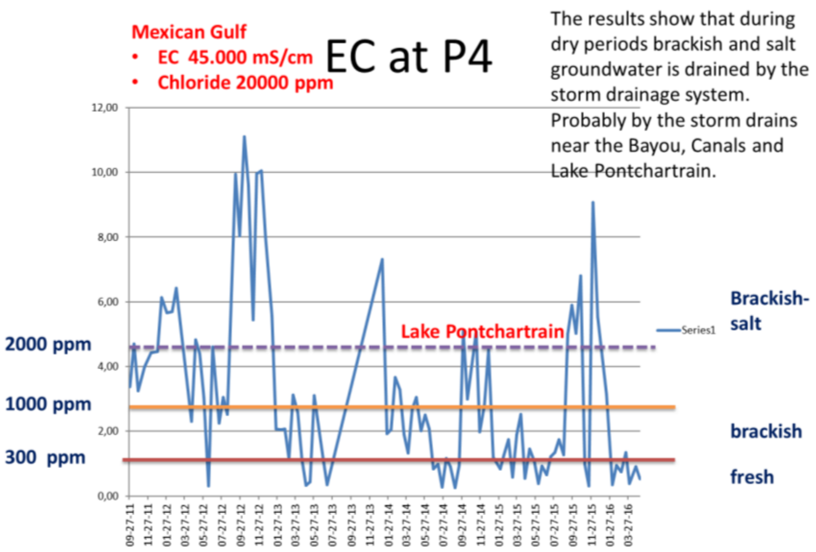


Figure 5.24



Commented [GZ6]: This is not referenced? What it's purpose?
Freshwater vs saltwater?

Commented [GZ7]: Is this an example of what the system could look like? Why is it here?



The results show that during dry periods brackish and salt groundwater is drained by the storm drainage system. Probably by the storm drains near the Bayou, Canals and Lake Pontchartrain.

Figure 5.25

	Chloride mg/L	Salinity %	Salinity ‰	Electrical Conductivity µS/cm	TDS ppm	*remarks*
Oligohaline-fresh	<30	< 0.04	< 0.4	<500	<400	Rainwater (EC = 40-60 µS/cm) or water with high rainwater percentage
Fresh	30 -300	0.04 – 0.1	0.4 – 1.0	500 – 1,100	400 – 1,000	Mississippi river water, tap water New Orleans.
Brackish	300 – 1,000	0.1 – 0.2	1.0 – 2.0	1,100 – 2,750	1,000 – 2,000	Higher than 300 ppm chloride becomes tasted. Often useful for irrigation.
Brackish-salt	1,000 – 10,000	0,2 – 1.8	2.0 - 18	2,750 – 24,000	2,000 – 18,000	Range of Lake Pontchartrain, Bayou St. John (EC 4500 µS/cm,= approx. 2,000 mg/l chloride)
Saline	10,000 – 20,000	1.8 – 3.6	18 - 36	24,000 - 47,500	18,000 – 36,000	Coastal sea water (Mexican Gulf) has salinity of 32 ‰, open sea 36-36.5 ‰
Hypersaline	> 20,000	> 3.6	>36	> 47,500	>36,000	Groundwater in contact with salt formations, or marshlands with local high evaporation rates.
Brine	>45,000	>10	>100	106,000	>100,000	Groundwater in contact with salt formations

Commented [GZ8]: I this needed?

Table: Estimated conversion of different salinity indicators. Note that TDS is in mg/kg water (ppm) and Cl in mg/L. Conversion of mg/L to mg/kg is by multiplication with solute density^{-1}. Brine definition via TDS, according to Davis & De Wiest 1966. EC at 20^{o}C. (Based on Stuyfzand (2012) regarding chlorinity classes and equations to convert Cl into EC and EC into TDS. EC and most TDS values have been rounded off).

5.9 Waste Water

An understanding of the waste water system is important as all water balance items should be accounted for within the system. This in turn leads to a more accurate model and better risk estimations. As described earlier in this chapter, New Orleans has separated storm drainage and waste water systems. In its simplest form, the amount of treated waste water should be less than produced drinking (minus real losses) but the reality for New Orleans shows more water is treated then put into the system. This highlights that groundwater being drained by the wastewater system through broken pipes, permeable geotextile joints, and also sometimes by design.

This drainage system provided by the wastewater network helps to artificially control the groundwater level, lowering it (in theory) to the height of the buried pipes, over time an equilibrium is reached and fluctuates in relation to the rate of water entering the system, and water being removed. At locations where pipes are being replaced, an increase in groundwater level is cautioned as the drainage network is removed.

5.9.1 Wastewater system monitoring advice

- Daily monitoring of water quantities at wastewater treatment plants (arrived, treated)
- Daily monitoring of the quantity of pumped water at the local pumping stations.
- Continuous water quality monitoring of waste water selected parameters to better understand the water origins (e.g. salt-water parameters like chloride and sodium)
- A temporal project monitoring project using (natural) tracers to better understand the origins of waters.

Commented [GZ9]: Same as in the storm drainage or different?

5.10 Drinking Water

The Mississippi river has been providing residents of New Orleans with its drinking water more than a hundred years. Normally, under these circumstances there exits little to no relationship between the drinking water and groundwater systems as long as safe yield practices are followed. As the urban environment is built up over time and the installation of drinking water pipe networks occur, the local groundwater system may be altered as an anthropogenic preferential drainage network is formed in the coarse grained, high transmissivity trench infill material of which the pipe network is constructed (as described earlier in the storm and waste water networks). This altered flow system may cause lower groundwater levels in the shallow system.

Commented [GZ10]: What is “ these” referring to? The fact that N.O. is using the river as a drink water source?

A second and opposite relationship that should be noted is the effect of groundwater recharge from losses in the drinking water distribution network. These losses are most often negligible but depending on the severity and distribution, leakage may produce a localized effect. In the Netherlands the total loss of produced drinking water is ~ 5% and one of the lowest rates in the world. This loss is including illegal tapping (e.g. grow houses) and deliberately flushing to clean the pipe system. In the Dutch system, loss into the subsurface (artificial recharge) is approximately 50% (~ 2.5 % of produced drinking water).

Commented [GZ11]: What is this 50 % refering to?

6/4/2019 More than half of New Orleans S&WB's water lost to leaks, costing millions, audit reveals | News | theadvocate.com

https://www.theadvocate.com/new_orleans/news/article_4061017a-477e-11e9-9c4d-871c1c63ec95.html

More than half of New Orleans S&WB's water lost to leaks, costing millions, audit reveals

BY JEFF ADELSON | JADELSON@THEADVOCATE.COM MAR 15, 2019 - 6:58 PM

Advocate photo by Matthew Hinton -- The Sewerage & Water Board's Carrollton water treatment plant.

Buy Now

Figure 5.26

In comparison, New Orleans drinking water losses are estimated at more than 50%, most of which infiltrates into the subsurface. To address water loss attributed to leaking pipelines, S&WB has undertaken a strategic water loss control program including flow monitoring and a leak detection program to accurately and reliably identify water leaks (August et all, 2009).

Table 5.2 TITLE

FY	Total	-	Apparent Losses	=	Real Losses	/	Uarl	ILI*
2008	31072.71	-	393.09	=	30679.62	/	1.83	46
2009	32891.34	-	405.12	=	32486.22	/	1.91	46.6
2010	28642.8	-	450.45	=	28192.35	/	1.84	41.9
2011	31892.56	-	438.87	=	31453.69	/	1.93	44.7
2010	31786.54	-	428.01	=	31358.53	/	1.99	43.2
2013	28844.17	-	450	=	28394.17	/	2.11	36.8
2014	29373.89	-	437	=	28936.89	/	2.13	37.1
2015	27848.6	-	459	=	27389.6	/	2.16	34.7
2016	30977.8	-	383.16	=	30594.64	/	2.22	37.5
2017	30633.7	-	462.24	=	30171.46	/	2.23	36.9

Recently, the SWBNO conducted a water audit update (Nora Freeman, 2019). The real water losses in 2017 amounted to 30171 million gallon per year (83 million gallon/day, see Table 5.2). Based on this information and divided by the land surface of New Orleans (Wikipedia: 439 km2), we calculate a mean groundwater recharge by leaking pipes of approx. 0,7 mm/day. This is nearly equal to the natural recharge (rain minus evaporation) of the Netherlands, and even more than the natural recharge in New Orleans. In New Orleans, mean daily rainfall is ~ 4 mm/day, but daily (open-pan) evaporation is ~ 4.5 mm/day. So, the drinking water loss at this moment is a very significant factor in N.O.'s groundwater recharge, and renovation of the infrastructure will impact the groundwater situation and vegetation situation.

It’s still unclear how drinking water loss is divided spatially. This knowledge could improve our modelling of the urban groundwater situation, including the understanding of groundwater impact of water mains renovation. Figure 5.27 (SWBNO, 2019) presents the age of water mains in New Orleans. It’s conceivable that loss is related to age, but it can also be argued that younger mains are constructed in softer soil areas and are therefore more vulnerable.

We believe that the existing seasonal shrink-swell processes should be considered during new renovation activities.

5.10.1 Recommendations for monitoring

- Continue the yearly water audit to determine real losses,
- Try to better understand the impact of drinking water loss on groundwater levels and soil and ground water quality
- Design a salinity risk monitoring network in the Mississippi to understand in-time possible salinization of the drinking water intake location.

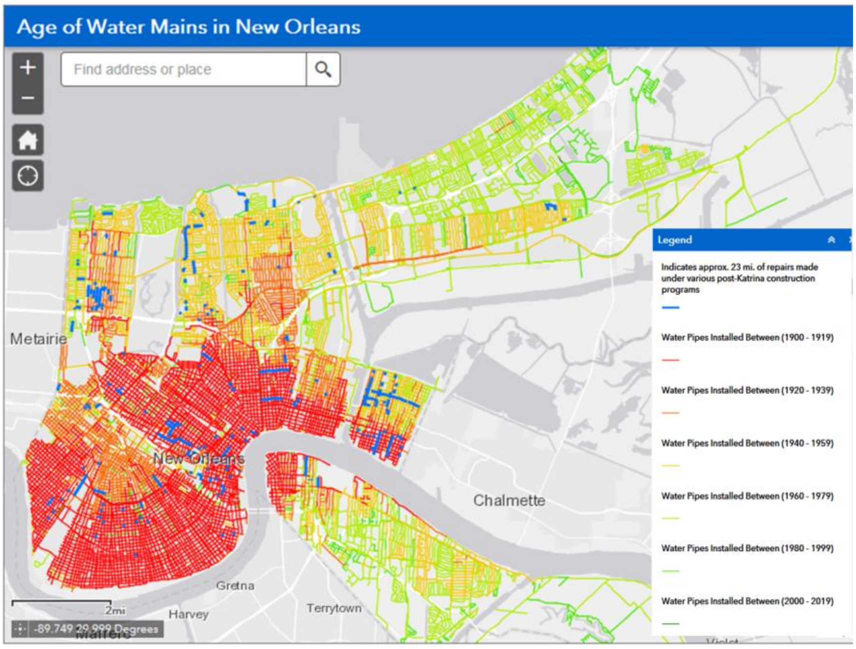


Figure 5.27 Age and distribution of the New Orleans water main network.

5.11 Ecology

Ecological monitoring infrastructure in GNO is currently not aligned with groundwater and subsidence monitoring locations. The structure and species composition of vegetation in metro New Orleans is highly variable. Lewis et al. (2017) demonstrated that management policies, land abandonment, and elevation are useful predictors of this variation. Less understood is how soil properties, nutrient flows, drainage efficiency, and surface and ground water interact with the urban ecosystem and produce or respond to this variability. Much of the extant relevant data is collected and managed by different municipal and parish entities, requiring data gathering and synthesis to ascertain hydrological and potential pan-GNO ecological linkages. A more integrated and comprehensive understanding of the role of vegetation and urban ecosystems in hydrology and soil properties would empower land managers to manage the urban ecosystem strategically in line with other regional and proposed project goals for mitigating subsidence, flooding risk, and coastal land loss.

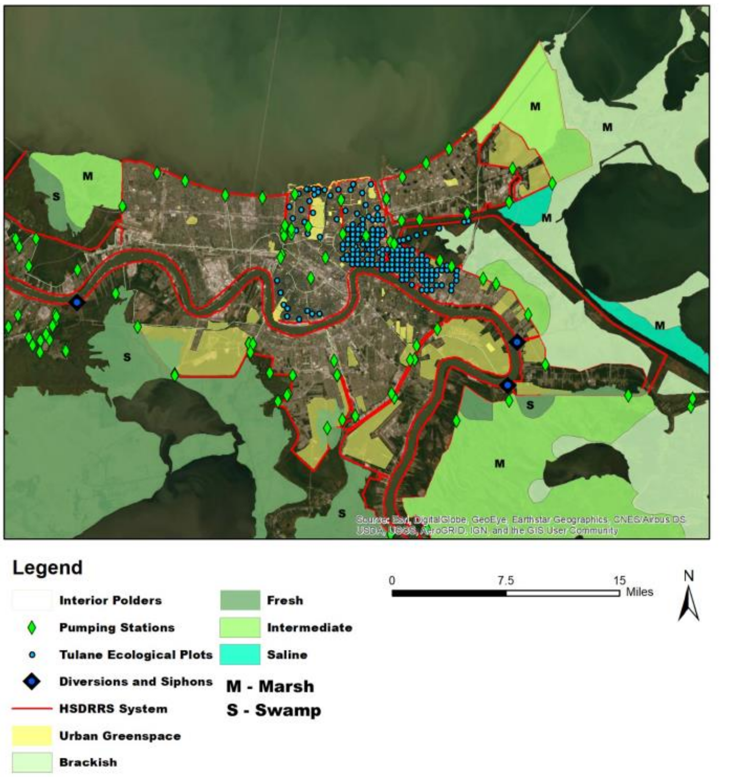


Figure 4. Ecosystem information map for the Greater New Orleans region (satellite image as background). In addition to the locations of HSDRRS, thin white lines indicate the boundaries of poldered areas of distinct drainage. Filled areas represent natural, predominately wetland areas newly encompassed by HSDRRS or immediately outside the protection system, with marsh wetlands indicated by an "M" and cypress swamp by an "S". Colors also distinguish fresh, brackish or urban (managed green space). The existing Tulane (Lewis et al., 2017) grid of ecological monitoring stations is plotted (blue dots). This network will be expanded to encompass the entire HSDRSS region in the proposed project with locations (50) coinciding wherever possible with the grid of stations shown in Figures 3 and 4 for coring sites (50), groundwater monitoring sites (20), and CRMS/CORS sites (10 CRMS).

5.12 Subsidence and shrink swell

Subsidence occurs most often in response to one of two situations. 1) through the decrease in pore pressure and resulting collapse in matrix space due to overburden pressure (ie. as a result of over abstracting groundwater from a confined aquifer), and 2) From the oxidization of peat as a result of lowering the shallow groundwater table. Both result in damages to local infrastructure and both are situations where knowledge of the local soil and subsurface groundwater system helps aid in risk reduction.

Commented [GZ12]: Roelof, can you check for correctness?

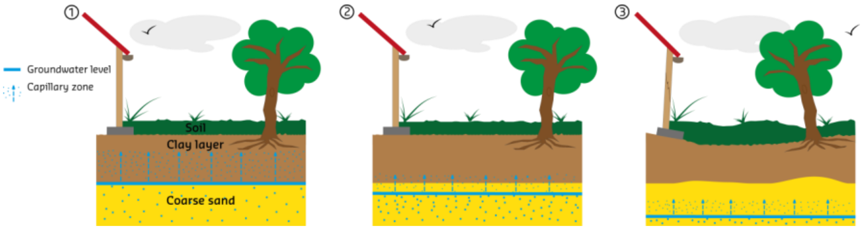


Figure 5.28 A conceptual demonstration of the relationship between groundwater level, capillary rise, evapotranspiration and their effect on the shrink / swell property of clays.

The sequence of images shown above highlights the increase in capillary rise through clay sediments and its subsequent reduction and the water level drops into the sandy zone. It's effect is that water can no longer be distributed through the clay zone. The sediment will dry over time if recharge does not occur in the form of rainfall (surface recharge) or groundwater level rise. Over time, water is continuously removed from the system by the vegetation through the process of evapotranspiration. The combination of a lower water level, lack of rainfall and continuous evapotranspiration leads to the contraction (shrinking) of the clay sediments. When this reaction happens in reverse, the clay particles adsorb water and swell in size.

Figure 5.29 shows a map view of the subsidence risk and was drawn after the borehole work undertaken in YEAR. Describe how they map was created

Commented [GZ13]: What year did the boreholes get drilled?

Is this map based on risk to subsidence? Built off the borehole information recovered from the drilling work?

Figure 5.29 ADD LEGEND? Where is this image from?

Technology and computing power are enabling satellite-based earth observation techniques to help define where subsidence is taking place in near real time. Interferometric Synthetic – Aperture Radar, more commonly referred to as InSAR is the process of decoding and comparing active radar images that are sent and received from satellites to show relative changes in ground, or structure level over time. *Figure 5.31* is a processed InSAR image using a standard definition Sentinal-1 dataset between January 2016 and April 2019. This image is provocative in a number of ways. Green areas represent a stable environment and poses no risk or concerns, red and blue areas represent subsidence and uplift at a magnitude of greater than 5mm/year. These areas should be of concern.

The blue area in NW New Orleans was a initially surprising result until the data was cross referenced with a ground based gps station that is operated by the US government confirmed the trend. Groundwater level measurement from the National groundwater monitoring network give an indication of *why* this is occurring. Deep groundwater monitoring sites Or-206 and Or-203 (Figure 5.14, Figure 5.16) show a rise in the deep groundwater level of the Gonzales Aquifer where the epicenter of the surficial rebound lies at the location of the Michoud Entergy plant abstraction site (Figure 5.30). The reduction in abstraction at this location changes the steady state situation that had occurred during the time of pumping, this is a very similar situation that the City of Delft automated groundwater monitoring program was designed to observe, and the gradual, stepwise reduction in pumping rate was intended to prevent (See section 2.1.2).

Sites subsiding at a rate of over 5mm/year are highlighted by the red locations and occur most prominently along the dike systems at the edge of the Lake Pontchartrain Causeway, as well as the dike along the canal near Lake Borgne. A third site in the Warehouse District and the French Quarter District are most likely caused by dewatering operations that are taking place at numerous construction projects within this area.

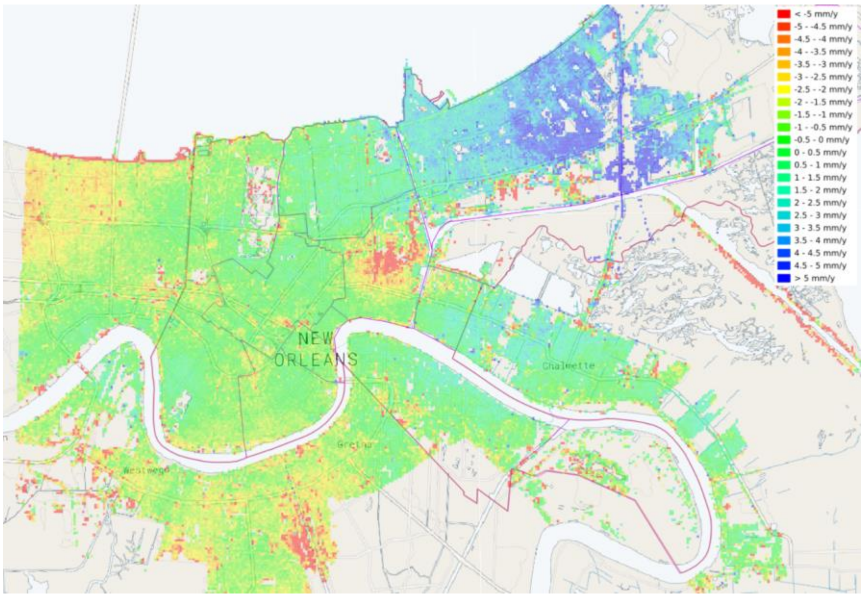


Figure 5.31 Standard resolution InSAR results over New Orleans at a -5 to +5mm/year deformation rate scale. Blue areas signal uplift, red areas signal subsidence.

Proposed subsidence monitoring objectives include:

1. Classification of vulnerable “at risk” areas with respect to subsidence and uplift
2. Locate and Quantify the amount of subsidence or uplift occurring within New Orleans. (Historic and current)
3. Research the potential causes subsidence and uplift
4. Define a monitoring program and action strategy during dewatering periods of civil works projects.
5. Define a monitoring program and action strategy after time the completion of pipe network upgrades.
6. Work with the city water and road departments to design a maintenance program based on a weighted, multi – criteria analysis including (subsidence, soil type, pipe age, construction type, pipe material, ect.).
7. Continuation of InSAR monitoring with 2 year intervals.

6 Monitoring network design: Surface and Groundwater water locations

In total, 29 measurement locations are suggested to satisfy four major program objectives (Figure 6.1):

1) To study groundwater levels in relation to subsidence vulnerability (especially at locations with organic layers just below the know lowest groundwater level);
2) To understand the risk of groundwater flooding during precipitation events;
3) To study groundwater levels in relation to high lake and river levels;
4) To understand the relation between (leaking) street infrastructure and groundwater levels.

Of the 29 recommended sites, 15 locations measure information from a single point below surface level (1 screen) and 8 locations were selected as sites where 2 measurement depths (2 screens) are recommended. Placing multiple measurement devices at a single location is done to recover information pertaining to the shallow phreatic zone and deep hydraulic heads from the Pine Barrier sands (or deep regional aquifer system). Symbols labelled “P” indicate that the depth of the screen is to be set directly below the overlaying peat layer to help build an understanding of the relationship between water levels and subsidence.

Placement of wells parallel to Lake Pontchartrain were recommended to grow the understanding of the relationship between lake and groundwater, salinity and geo-technical risks (i.e. heave, bursting clay layers due to overpressure of deeper aquifers). Observation well locations were also selected parallel to the Mississippi river to help develop a better understanding of water level gradient and geotechnical risks to the south of the city.

The scope of this project includes integrating and building on the knowledge that others have gained through previous work in the area. Five locations (represented by blue triangles) show the locations of operational projects to be added to the database. More information on monitoring objectives at each location can be found in the Tabel 6.1.

Frequency and method of observation is a combination of high frequency telemetric devices and manual measurements. For the latter, public engagement opportunities within schools and neighbourhoods can be built into the system allowing for educational and social integration within the project. Manual measurements can be taken using a measuring tape / plunger or electronic water level tape. Pressure sensors from van Essen Instruments would allow for water level measurements to take place at hourly or daily intervals dependant on location and can be coupled with cellular data transmission units.

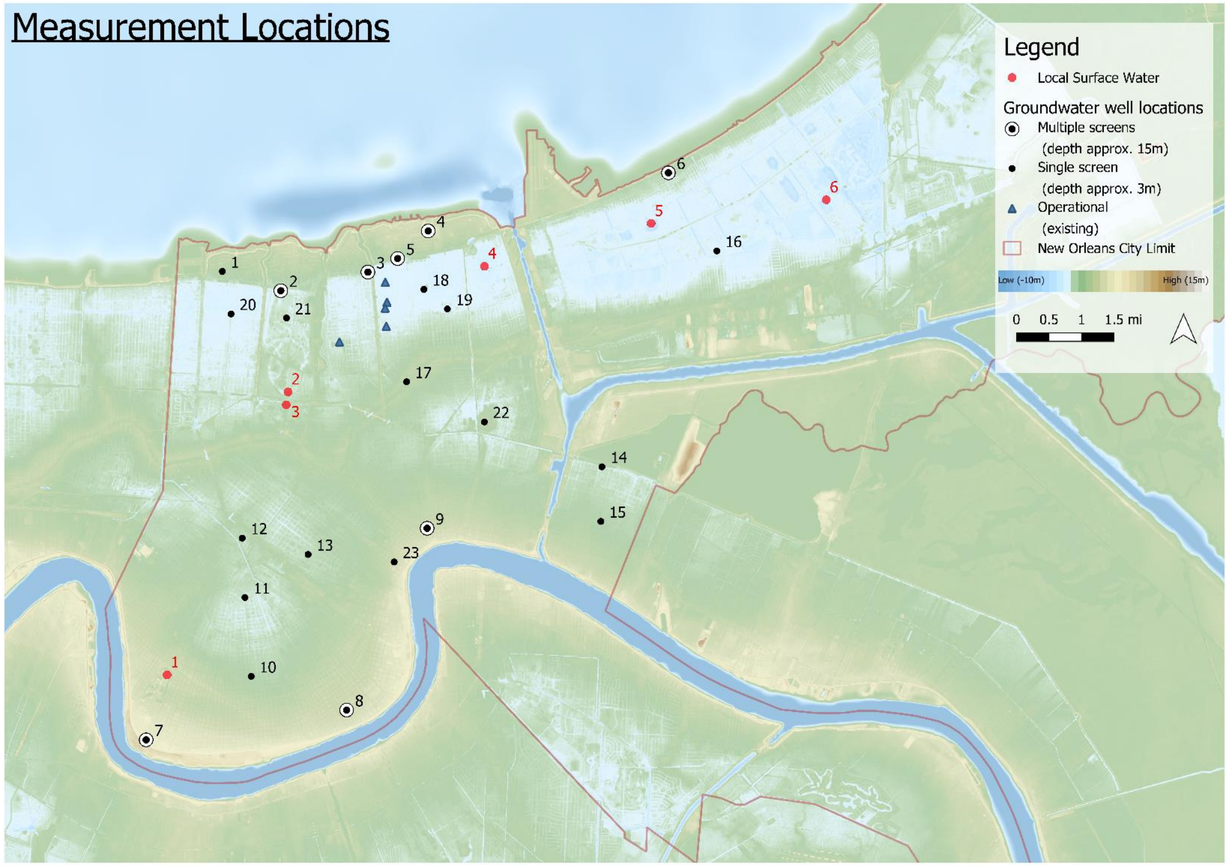


Figure 6.1 Locations of recommended surface and groundwater monitoring locations within New Orleans. Wellbore 20 & 22 represent the approximate installation location of the monitoring device. Wells labelled with "approx.." indicates an approximate well location, where as wells labelled with a "P" indicate wells drilled into peat.

Tabel 6.1

Well ID	Location Name	Observation well objectives (at new locations)
1	Harlequin Park (North Shore)	(1) Phreatic groundwater level and hydraulic head change in relation to Lake Pontchartrain water level fluctuations, including sea level rise, (2) salinity with depth
2	Gen. Lee - City Park	(1) Hydraulic head change in relation to Lake Pontchartrain water level fluctuations, including sea level rise, (2) salinity with depth
3	Robert Lee - Pratt (P)	(1) Phreatic groundwater level fluctuation. First peat level just below Mean Lowest Groundwater level, (2) hydraulic head, (3) salinity with depth
4	Live Oaks Park	(1) Phreatic groundwater level and hydraulic head change in relation to Lake Pontchartrain water level fluctuations, including sea level rise, (2) salinity with depth
5	New Orleans Mosquito, Termite and Rodent Control Board	(1) Phreatic groundwater level and hydraulic head change in relation to Lake Pontchartrain water level fluctuations, including sea level rise, (2) salinity with depth
6	Hayne Blv - Burke Ave	(1) Hydraulic head change in relation to Lake Pontchartrain water level fluctuations, including sea level rise, (2) salinity with depth
7	East Dr. Audbuon Park	(1) Phreatic groundwater level and hydraulic head change in relation to Mississippi water level fluctuations, including sea level rise, (2) salinity with depth
8	Clay Square Park	(1) Phreatic groundwater level and hydraulic head change in relation to Mississippi water level fluctuations, including sea level rise, (2) salinity with depth
9	Park Washington Square	(1) Phreatic groundwater level and hydraulic head change in relation to Mississippi water level fluctuations, including sea level rise, (2) salinity with depth
10	Samuel Square Park	(1) Phreatic groundwater level, (2) salinity with depth, at this location we measured salt groundwater (remarkable).
11	Gen. Pershing - Dupre	(1) Phreatic groundwater level in relation to peat at 30 cm below MLG
12	Telemachus - Palmetto	(1) Phreatic groundwater level in relation to peat at 10 cm below MLG
13	Gravier - Tonti	(1) Phreatic groundwater level in relation to peat at 40 cm below MLG → could be moved in NW direction (lowest elevation)
14	Florida Ave.	(1) Phreatic groundwater level fluctuation. First peat level just below Mean Lowest Groundwater level.
15	Caliborne Ave.	(1) Phreatic groundwater level fluctuation in relation to subsidence risk, (2) groundwater flooding risk & main (municipal) infrastructure
16	Tillford Rd. - Edenboro Rd.	(1) Phreatic groundwater level fluctuation in relation to subsidence risk, (2) groundwater flooding risk & main (municipal) infrastructure
17	Mount Olivet Mausoleum	(1) Phreatic groundwater level at water divide
18	Buddy Deuterive Park	(1) Phreatic groundwater level and hydraulic head change in relation to Lake Pontchartrain, underground infrastructure and precipitation/evaporation.
19	Milne	(1) Phreatic groundwater level and hydraulic head change in relation to Lake Pontchartrain, underground infrastructure and precipitation/evaporation.
20	Lake View (approx)	(1) Phreatic groundwater level in relation to subsidence vulnerability, underground infrastructure and precipitation/evaporation.
21	Filmore City Park	(1) Subsidence control (peat just below lowest groundwater level)
22	St. Claude	
23	French Quarter (Seignouret - Brulatour House)	(1) Understand phreatic groundwater level in relation to street underground infrastructure and top of wooden piles. (perhaps also in relation to Mississippi water levels).
1	Audubon Park	(1) to determine discharge into St. Charles urban drainage system, (2) quantity, quality and salinity, (3) determine river level impact
2	City Park	(1) to determine water quality in Park (salinity, nutrients), (2) to estimate discharge from park into storm drainage system.
3	City Park	(1) to determine water quality in Park (salinity, nutrients), (2) to estimate discharge from park into storm drainage system.
4	Lagoon Pantchartrain Park	(1) isolated lake acts partly as groundwater observation well, (2) evaporation information, (3) salinity in time ? , (4) relation with Lake Pontchartrain levels
5	Lake Willow	(1) isolated lake acts partly as groundwater observation well, (2) evaporation information, (3) salinity, (4) relation with Lake Pontchartrain levels
6	Lake Bullard Ave	(1) isolated lake acts partly as groundwater observation well, (2) evaporation information, (3) salinity, (4) relation with Lake Pontchartrain levels

6.1 Temporary (project) groundwater monitoring networks

During building activities and installation of subsurface infrastructure, temporary groundwater extractions are often needed to dewater the construction site. These extractions create decreased groundwater levels, accelerate local subsidence, and may cause structural damage to build up infrastructure nearby. To mitigate this damage, a monitoring protocol is advised:

- In vulnerable areas, temporary monitoring networks should be installed
- Groundwater thresholds should be determined for projects in vulnerable areas. If these thresholds are reached, projects should be stopped immediately, and mitigation measures taken.

7 Practical considerations

7.1 Determination of the detailed field location

The choice for the exact field location is completely related to the monitoring objectives, but also often troubled by practical considerations. In our monitoring study (this report) we would like to collect more general water system information like, groundwater fluctuation during the year in different soil areas and groundwater – rainfall relationships. Therefore we prefer as little as possible influence of draining pipes or infiltrating or draining canals. So, preferable the observation wells are installed in the middle between 2 streets and with distance to canals. Of course, also local land use needs to be considered. Comparison of data will become more difficult (with relative few monitoring locations) when land use is strongly variable.

7.2 Ten Commandments for the placement of groundwater observation wells

1. A level tube consists of a perforated part (the filter screen) and a blind riser tube. The larger the tube diameter, the better: 36 millimetres is common. The top of the filter screen must correspond to the average highest groundwater level. The bottom side is at least half a metre (2 feet) below the average lowest groundwater position;
2. The average highest and lowest groundwater levels can often be determined on the basis of soil characteristics. The zone below the average lowest groundwater position is always grey, at peat brown (oxidized peat above the lowest groundwater level is black). Between the highest and lowest water levels, rust stains are often discernible. Unfortunately, these characteristics are not documented by standard in drilling;
3. Placement of level tubes during the dry period (season) reduces the likelihood of dry falling;
4. In case of clay or peat layers, consider well where the measurement is most meaningful: below or above the disturbing layer or both. In the latter case, make two separate drill holes;
5. Recover perforations of penetrated clay or peat layers with swell clay (bentonite). Add a filter stocking and coarse filter sand around the filter screen;
6. Avoid inflow of rain water along the tube by choosing favourable locations (not local depressions), by using a impermeable well cover and by adding swell clay around the tube at ground level;
7. The top of the tube should be sealed with a perforated CAP and a robust protective sleeve;
8. Work the measuring point preferably above ground level, but make sure it is not too much visible (to reduce change of molest);
9. Place the observation well not next to a tree or close to surface water, unless the specific measuring objective this demands;
10. Has the contractor installed the well according to the design? A moving of some meters (or decimetres in depth) can already seriously frustrate the achievement of the measuring purpose.

7.3 Installation of monitoring wells

It must be ensured that the monitoring well is correctly recording the water table or the hydraulic head at the specified depth. Therefore, the well will have to be properly installed and developed. Checks include the tightness of its casing (e.g. the positions and tightness of

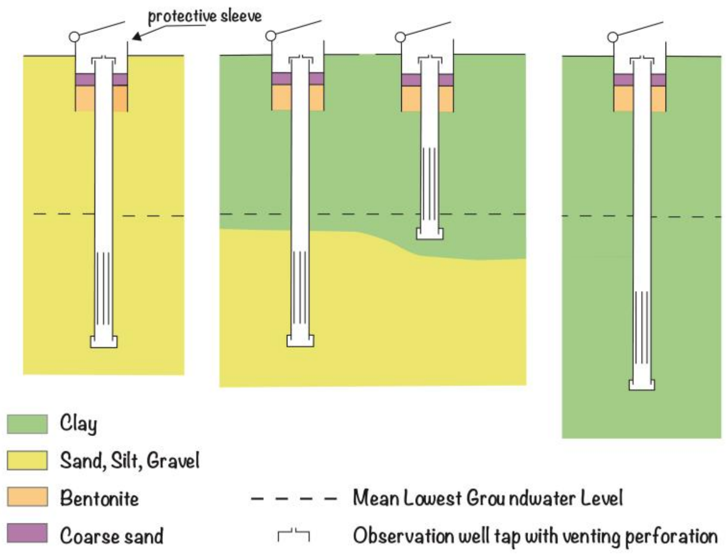
the annular sealants). Rehabilitation of monitoring well may be required after a certain time. Therefore, the functionality of the monitoring well should be checked at regular intervals.
The well casing and screen material should meet the specified requirements. Requirements listed by EPA may be used as reference (EPA, 1994):

- The materials should maintain their structural integrity and durability in the environment in which they are used over the entire operating lifetime;
- They should be resistant to chemical and microbiological corrosion and degradation in contaminated and uncontaminated waters;
- They should be able to withstand the physical forces acting upon them during and following their installation, and during their use;
- They should not chemically alter groundwater samples;
- They should be easy to install during the construction of a monitoring well and the material itself or its stability (tensile strength, compressive strength, and collapse strength) should not alter after installation.

Filter packs need to be put in place in such a way that there is no segregation of materials and that the projected top and bottom depths are maintained. At greater depths the use of prepacked filters is recommended, because only this way it is sufficiently ensured that the filter pack is properly located.

The used filter pack material must be bacteriologically safe and during installation any bacteriological or other contamination must be avoided. The chosen gravel pack size depends on the aquifer material (sieve analysis results) and influences the screen slot size.

Top and bottom formation seals must be properly installed in order to avoid water reaching the casing through leaking annular sealants. Centralizers should be installed at proper distances so that the proper functioning of seals and gravel packs is guaranteed.



7.4 Well completion

This section contains some practical suggestions to complete the well installation.

- Make sure that the outside surface of the piezometer tube, including the joints, is as smooth as possible to ease its installation;
- Use centralizers to keep (non-prepacked) screens in the centre of the borehole.
- Make sure that the inside surface of the piezometer tube is as smooth as possible to avoid that measuring equipment may get stuck.
- In case of several piezometers in one borehole, the top of the piezometers above surface level should be indicative for the depth of their screen (the deeper a piezometer, the lower its top). The tubes of piezometers may be cut at heights differing by 5 cm, for instance.
- Do not use a screw-top to close a tube.
- Give each tube a unique number and place a unique identification label on the monitoring well.
- Construct a cement surface seal above surface level for stability and to prevent from surface water entering the well directly.
- A steel casing will protect from vandalism and water entering the well.
- Fix a lock to prevent unauthorized access to the well, if necessary in combination with a fence around the monitoring well.

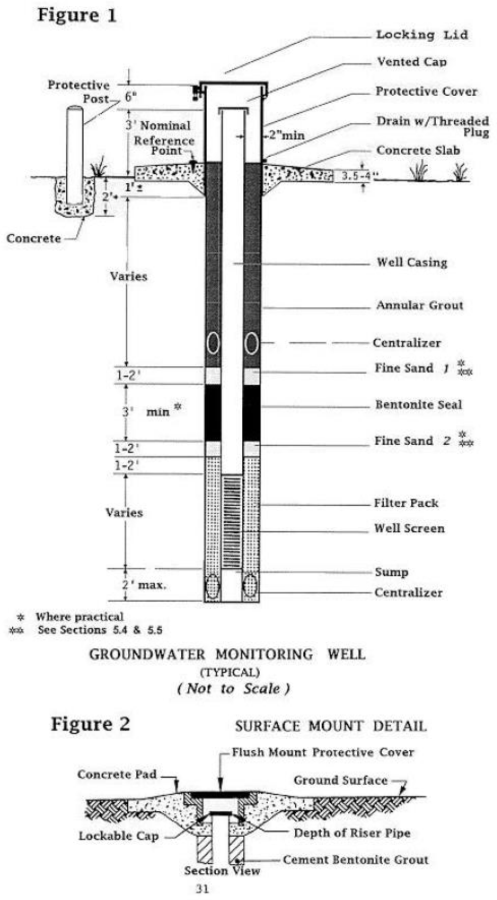


Figure 1
Locking Lid
Vented Cap
Protective Post
6"
Protective Cover
3' Nominal
Reference Point
2"min
Drain w/Threaded Plug
Concrete Slab
3.5-4"
1' ±
2'+
Concrete
Well Casing
Varies
Annular Grout
Centralizer
1-2'
Fine Sand 1 ✲ ✲✲
3' min ✲
Bentonite Seal
1-2'
Fine Sand 2 ✲ ✲✲
1-2'
Varies
Filter Pack
Well Screen
Sump
2' max.
Centralizer
✲ Where practical
✲✲ See Sections 5.4 & 5.5
GROUNDWATER MONITORING WELL
(TYPICAL)
(Not to Scale)
Figure 2
SURFACE MOUNT DETAIL
Flush Mount Protective Cover
Concrete Pad
Ground Surface
Lockable Cap
Depth of Riser Pipe
Cement Bentonite Grout
Section View
31

Figure 7.1

7.5 Maintenance

Add information here?

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7.6 Measurement Methods & Frequencies

A conceptual understanding of the groundwater system, its periodic fluctuations and defining the purpose of the system itself is an important first step in selecting an appropriate sampling method and frequency. The sampling frequency should be sufficiently high enough to capture the periodic fluctuations within the natural system or the effects caused by human activities. Manual data collection like in the Amsterdam case provides a low cost, time intensive solution to measuring gradual seasonal changes but would not be able to capture the rise in groundwater associated with rainfall events. It should be mentioned however, that the knowledge of canal water levels in Amsterdam provides sufficient control of groundwater elevation understanding, so the long-term trend of the phreatic system is of main importance.

Reason for Measurement	Frequency Requirement
Storage capacity	Hourly
Groundwater subsidence	Daily
Surface water – groundwater	Hourly
River water – Groundwater	Hourly to Daily
Street Infrastructure – Groundwater	Hourly
Wooden piles – Groundwater	Twice a month

Manual measurements occur less frequently and are prone to recording, record keeping, or calculation errors. Automation solves for these problems and can be implemented in a cost-effective manner. Additionally, technology driven solutions will provide a sampling frequency that is high enough for monitoring networks covering large areas and where abrupt changes to the environmental conditions are present (i.e. the effect of precipitation, tidal influence or water pipe ruptures). As seen in the Dresden case from section XXXX, internet connected devices allow the collection frequency to be altered (or set) to the operators’ preference or based on environmental conditions.

Dataloggers or “abandoned” measurement devices are an in between solution that provide the accuracy and frequency of an automated device but requiring an operator to download the data. These groundwater level recording devices have built storage capabilities but not the ability to transmit the information that is stored within the unit itself. Integrated and third-party hardware providers convert data loggers into telemetry devices, providing cellular and satellite capable data streams depending on cellular coverage within the area of interest.

Technology is enabling more frequent measurements to occur while cellular or satellite-based transmission services and offsite data storage provides safe, secure and cost-effective ways of recording the dataset. Ultimately, understanding and defining the reason for the monitoring network and conceptualizing the speed at which the system is moving are important aspects to consider when selecting a network that is appropriate for the city. Often, a mixed system made up of multiple measurement types (telemetry, hand measurements, interested citizen scientists and dataloggers) may produce the best results.

7.6.1 Real-time sensor IoT connected devices

7.6.2 Robust awareness monitoring sites

7.7 Post processing & ‘Data basing’

Data storage and visualization has been advancing rapidly over the past 5 years. Cloud storage solutions provides an added layer safety against data losses that could occur on a local system but if a locally storage solution is preferred, there are many options in this space as well. Distributed systems, where data is stored among a network of computers or computer nodes is another data storage solution design. Although not the purpose of this document, database storage structure should be considered during the initial phases of a project to incorporate current information and future growth of the network. A smart system should be fully digital and compiled in an effective, smart, searchable way.

From a visualization perspective, dashboard software packages with mapping capabilities are becoming more and more prevalent as companies like Microsoft, Tableau and ESRI are all competing for market share. Dashboards allow data to take on a new life as interactive graphs, charts, slicers, maps and other custom visuals provide creators with ample creative license and viewers to see the data in a more friendly way. Figure 7.2 presents an example of a dashboard created in Microsoft PowerBI where borehole, groundwater and chemical timeseries information is presented in an online, interactive method.

Figure 7.2 A screen capture of DiscoverEI’s interactive “Synthetic water quality” Dashboard.

8 Recommendations for the use of monitoring results in urban planning

Good start but missing additional info with the direct link to urban planning.

Urban planning requires a unique mixture of technical and political skills, both of which require fact-based inputs so informed decisions can be made with a mindset backed by a current and appropriate dataset. An urban water monitoring plan that includes, groundwater, surface water, soil information, pumping rates, precipitation and subsidence rates could also be termed an integrated water monitoring program and will help to provide clarity to answers relating to water resources. Programs of this nature are iterative, non-static, require a large amount of foresight, optimization, expert local knowledge as an inputs and direction from stakeholders.

The use of the monitoring results is as wide ranging as the creativity of the user. Urban planners could use the dataset to look at current events and future modelled scenarios to understand how risk associated with natural events may change of time, and how the implementation of risk reduction measures may protect the people and infrastructure within the areas of interest. Departments linked to sewage, water and transportation may also be able to use the data from this system to implement cost savings through program optimization of their maintenance schedules or the operation of mechanical stations themselves. Emergency services could the system information to help strategically allocate resources and provided data to first responders in relation to flood risk (ground or surface) or in case of mechanical failure of a key piece of equipment. By providing this system to the public, operators be able to provide useful pieces of information to concerned or inquisitive citizens and aid in their own understanding of the city's water network.

Overview / summary of the suggested activities:

- Groundwater monitoring network (shallow and deep systems)
- Surface water monitoring network (Lakes, lagoons, rivers, canals)
- Water quality of the above systems
- Subsidence monitoring (Satellite based)
- Pumping stations
- Subsurface water distribution systems (Sewage, wastewater and drinkwater systems)

We suggest starting small with a well-designed, optimized system that is capable of being properly maintained and provides learning opportunities for the community. This system should be cost conscience, include only what is required by the goals set at the start of the project and be scalable to a larger system.

9 Literature

August, Rudy, David W. Kurtz, Griff Machinski, 2009: Sewerage and Water Board of New Orleans: Water Loss Control Program. **Pipelines Specialty Conference 2009**

Nora Freeman, Freeman LLC, 2019: Water audit update. Sewerage and Water Board of New Orleans, **Fiscal Years 2008 – 2017**

IGRAC, 2008: Guideline on: Groundwater monitoring for general reference purposes.

CONSTRUCTION OF GEOTECHNICAL BOREHOLES AND GROUNDWATER MONITORING SYSTEMS HANDBOOK. PREPARED BY THE LOUISIANA DEPARTMENT OF ENVIRONMENTAL QUALITY AND LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT, DECEMBER 2000

Stuyfzand, P.J. 2012. Hydrogeochemcal (HGC 2.1), for storage, management, control, correction and interpretation of water quality data in Excel (R) spread sheet. KWR Watercycle Research Institute, KWR-report BTO.2012.244(s), updated in Feb.2015, 82p.

STOWA, 2012: Report 50. HANDBOEK METEN VAN GRONDWATERSTANDEN IN PEILBUIZEN (Handbook measurements groundwater levels in observation well: STOWA is the knowledge centre of the Dutch water boards)

R. Taugs, L. Moosmann, N. Classen & P. Meyer (March, 2016) Hamburg TU1206 COST Sub-Urban WG1 report.

Nguyen01 (April 5, 2017). Peilbuizen Waternet V1.0. Retrieved May, 2019, from https://maps.waternet.nl/kaarten/peilbuizen.html

Gemeente Delft and Munisense (Unknown). Munisense open data portal. Retrieved May, 2019, from https://opendata.munisense.net/

City of Dresden (Unknown) Dresden Themenstadtplan. Retrieved May, 2019 from, http://stadtplan2.dresden.de

City of Antwerp (Unknown) Stand Antwerpen. Retrieved May, 2019 from, http://stadantwerpen.maps.arcgis.com/home

Geological Survey of Norway, NGU (Unknown) The national groundwater database GRANDA, Retrieved May, 2019 from, http://geo.ngu.no/kart/granada/.

The San Francisco Public Utilities omission (April, 2016) 2015 Urban Water Management Plan for the City and County of San Francisco. Retrieved May 2019 from, https://www.sfwater.org/Modules/ShowDocument.aspx?documentID=8839

Suozzi, T. (2005) Nassau County Groundwater monitoring program (2000 – 2003).

Groundwater Watch, Office of Groundwater (May 2019) Active groundwater level network, U.S. Department of the interior. Retrieved May, 2019, from https://groundwaterwatch.usgs.gov/default.asp

10 Annex 1

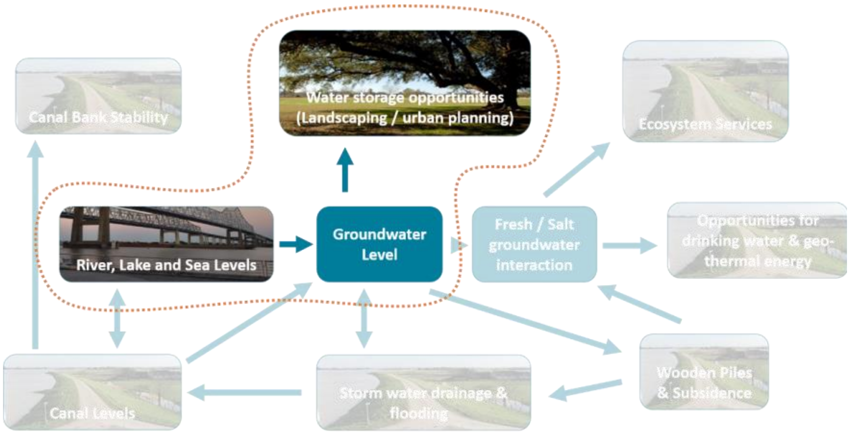


Figure 10.1 – Highlighted interactions between groundwater levels, groundwater level and natural surface water systems within the context of the integrated monitoring system vision as presented in Figure 3.4.1.

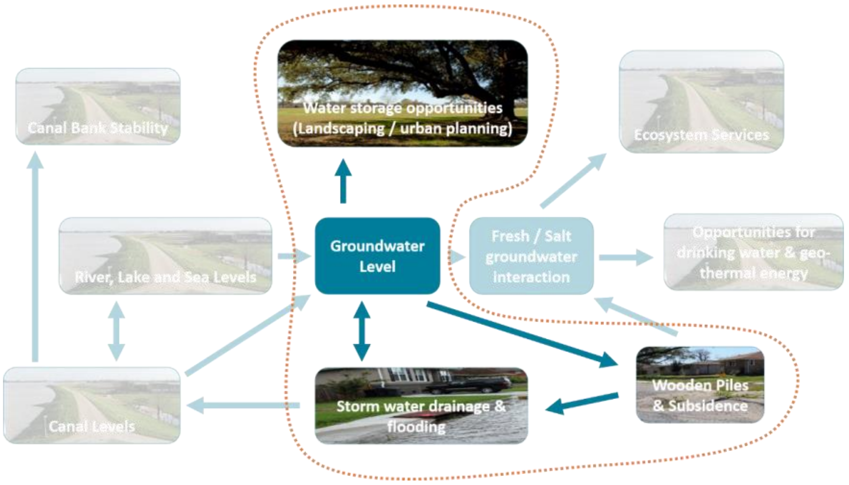


Figure 10.2 - Highlighted interactions between groundwater levels, water storage opportunities, storm water drainage and flooding, and wooden piles and subsidence within the context of the integrated monitoring system vision as presented in Figure 3.4.1.

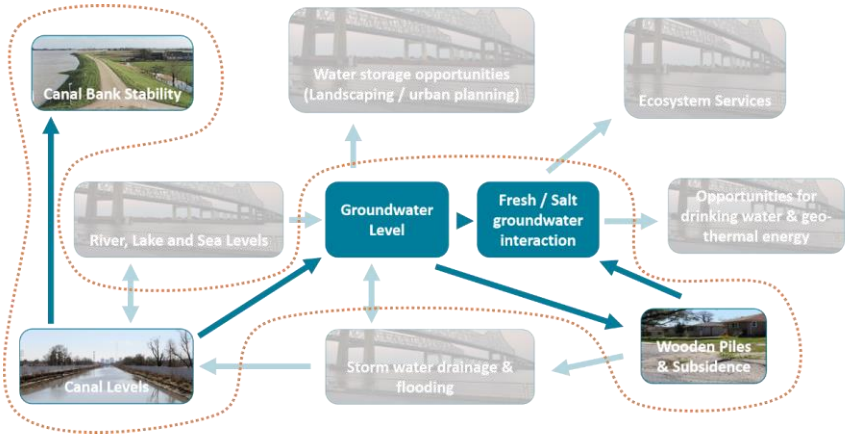


*Figure 10.3 - Highlighted interactions between groundwater levels, canal bank stability, canal levels, fresh / salt water (groundwater) interactions and wooden piles and subsidence systems within the context of the integrated monitoring system vision as presented in Figure 3.**4.1**.*

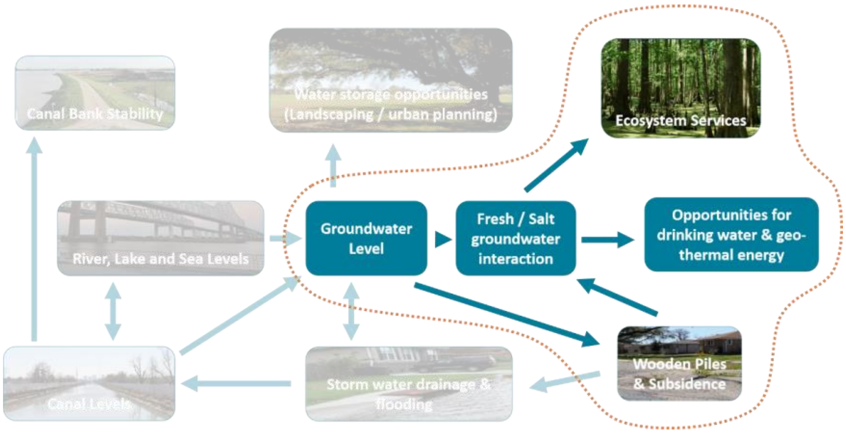


Figure 10.4 - Highlighted interactions between groundwater levels, fresh / salt water (groundwater) interaction, ecosystems, opportunities for drinking water & geothermal energy and wooden piles and subsidence systems within the context of the integrated monitoring system vision as presented in Figure 3.4.1

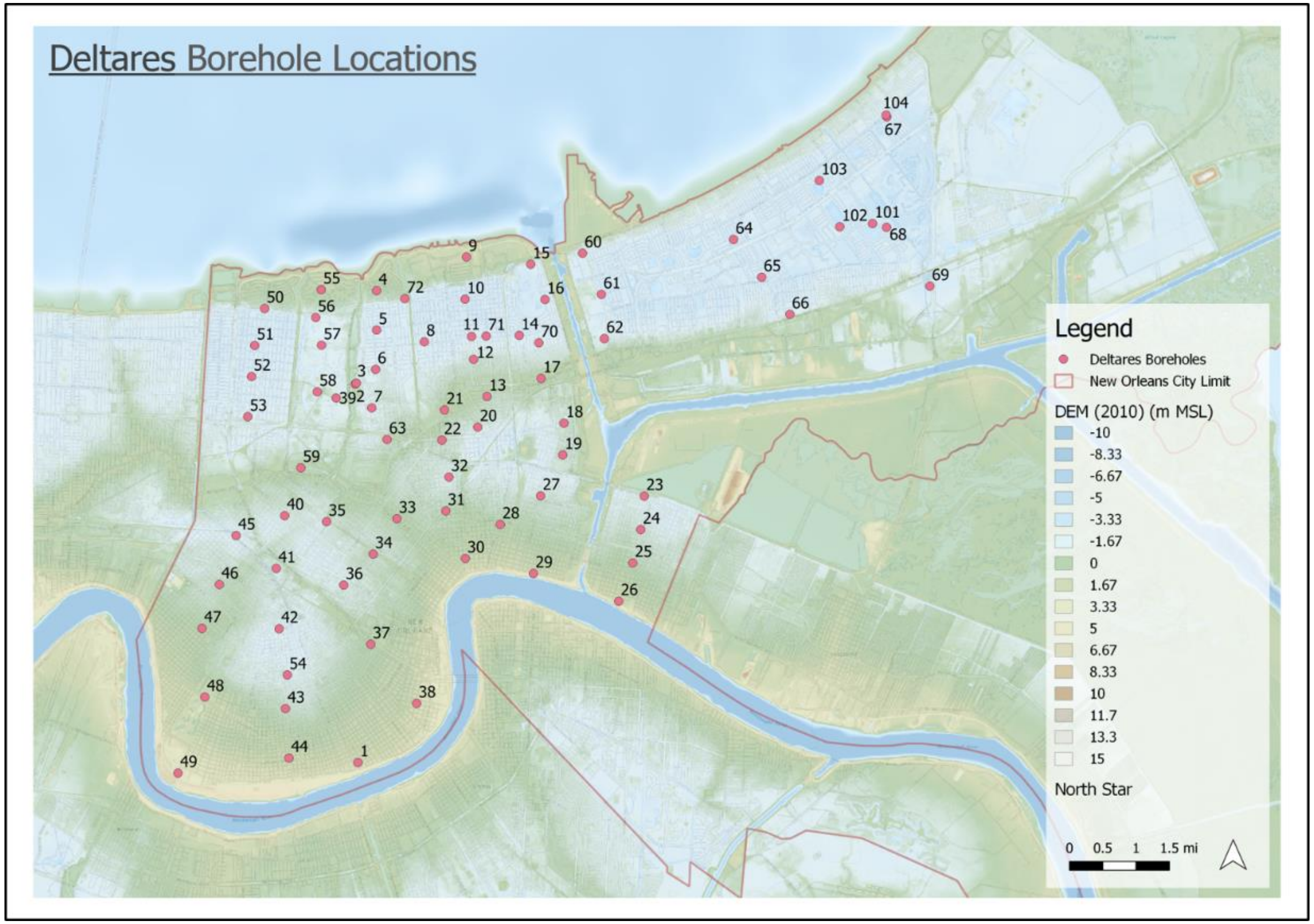
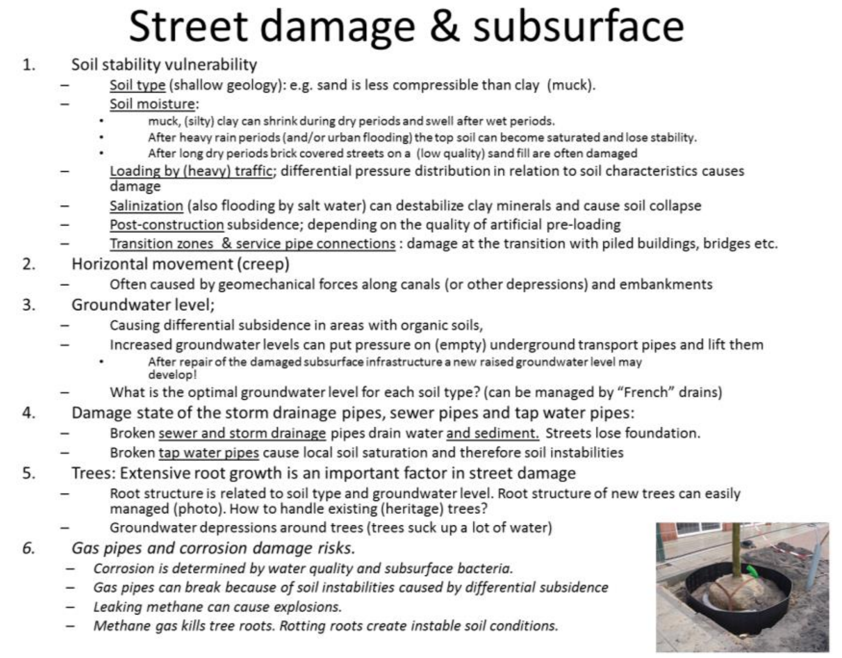


Figure 10.5 Deltares borehole locations located within the Greater New Orleans boundary.



Street damage & subsurface

1. Soil stability vulnerability
   - Soil type (shallow geology): e.g. sand is less compressible than clay (muck).
   - Soil moisture:
     - muck, (silty) clay can shrink during dry periods and swell after wet periods.
     - After heavy rain periods (and/or urban flooding) the top soil can become saturated and lose stability.
     - After long dry periods brick covered streets on a (low quality) sand fill are often damaged
   - Loading by (heavy) traffic; differential pressure distribution in relation to soil characteristics causes damage
   - Salinization (also flooding by salt water) can destabilize clay minerals and cause soil collapse
   - Post-construction subsidence; depending on the quality of artificial pre-loading
   - Transition zones & service pipe connections : damage at the transition with piled buildings, bridges etc.
2. Horizontal movement (creep)
   - Often caused by geomechanical forces along canals (or other depressions) and embankments
3. Groundwater level;
   - Causing differential subsidence in areas with organic soils,
   - Increased groundwater levels can put pressure on (empty) underground transport pipes and lift them
     - After repair of the damaged subsurface infrastructure a new raised groundwater level may develop!
   - What is the optimal groundwater level for each soil type? (can be managed by "French" drains)
4. Damage state of the storm drainage pipes, sewer pipes and tap water pipes:
   - Broken sewer and storm drainage pipes drain water and sediment. Streets lose foundation.
   - Broken tap water pipes cause local soil saturation and therefore soil instabilities
5. Trees: Extensive root growth is an important factor in street damage
   - Root structure is related to soil type and groundwater level. Root structure of new trees can easily managed (photo). How to handle existing (heritage) trees?
   - Groundwater depressions around trees (trees suck up a lot of water)
6. *Gas pipes and corrosion damage risks.*
   - *Corrosion is determined by water quality and subsurface bacteria.*
   - *Gas pipes can break because of soil instabilities caused by differential subsidence*
   - *Leaking methane can cause explosions.*
   - *Methane gas kills tree roots. Rotting roots create instable soil conditions.*

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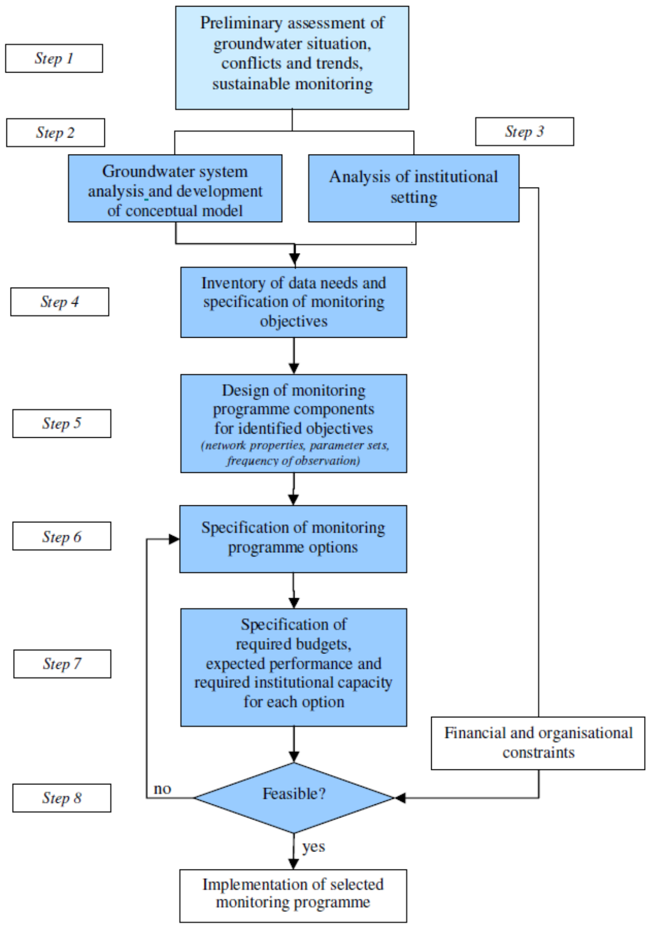

Figure 2.2: Scheme for design of a groundwater monitoring programme

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