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Horizon 2020

TU1206-WG1-013

Rotterdam

TU1206 COST Sub-Urban WG1 Report

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COST TU1206 Sub-Urban Report
TU1206-WG1-013

Published March 2016

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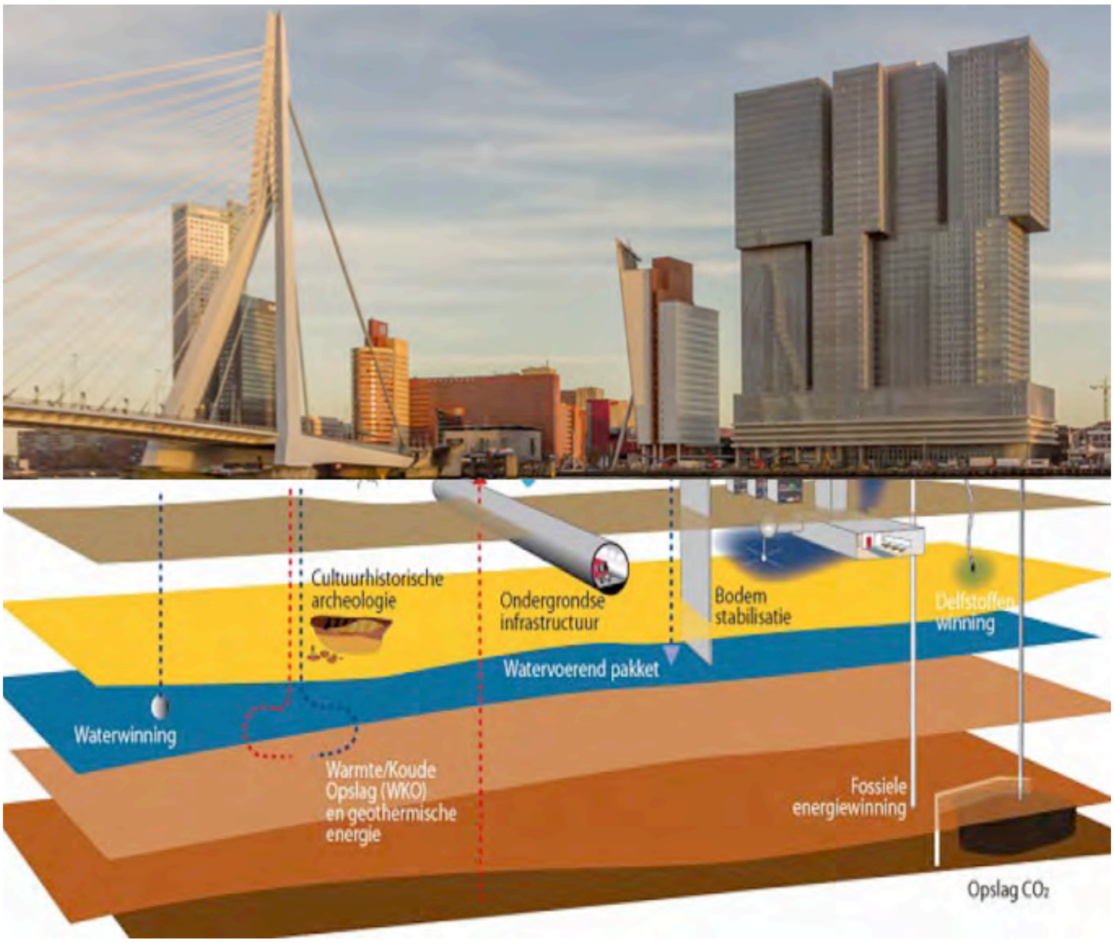
Rotterdam between Cables and Carboniferous

City development and its subsurface



04-07-2016

Gemeente Rotterdam

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1. Introduction

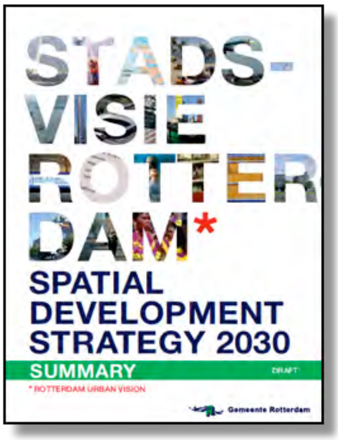
1.1 City and Port

Fig 1.1 View of the City of Rotterdam from the North showing the Erasmus bridge over the Nieuwe Maas river.
Source: Peter Dorsman

Rotterdam is located in the western part of the Netherlands in the province of Zuid-Holland. Most of the country's surface is flat and cultivated, and present-day sedimentation and erosion processes are almost everywhere influenced by man. Rivers are contained within dikes and many streams are canalised; swamps, lakes and large parts of an inland sea have been turned into polders and in many places dikes strengthen the coastline. Without dikes nearly the whole western part of the country would be flooded. To keep the reclaimed polder areas dry and fit for farming, pumping stations – formerly windmills – extract water continuously and transfer it to bordering water bodies. As a drawback, water extraction leads to compaction of soft soils and oxidation of shallow peat layers, resulting in a gradual lowering of the land surface.

Rotterdam is the second-largest city in the Netherlands and the second-largest port in the world. Starting as a dam constructed in 1270 in the Rotte River, Rotterdam has grown into a major international commercial centre. Its strategic location at the Rhine-Meuse-Scheldt delta on the North Sea and at the heart of a massive rail, road, air and inland waterway distribution system extending throughout Europe is the reason that Rotterdam is often called the "Gateway to Europe".

After the successful period of post-World War II reconstruction Rotterdam continued enhancing its status as an international city. Its centre witnessed the appearance of the Erasmus Bridge and the Kop van Zuid: a former harbour area redeveloped into a residential area, see Fig 1.1. Since then, the city has been boasting a skyline unique in the Netherlands. On the edges of the city large residential districts have been built. New entertainment venues, restaurants and festivals have turned Rotterdam into a place with a young, trendsetting image. To keep playing a significant role in the international competition amongst urban regions, Rotterdam will have to employ a strategy that not only aims at the development of the knowledge and services economy but can also guarantee an appealing residential and social climate capable of attracting more graduates and creative workers.



The mission of the city council is formulated in the **spatial development strategy 2030** and focuses on two elements:

- **Strong economy**: Creating a strong economy concentrates on the transition from an industrial economy to a knowledge and services economy, based on the further development of the medical and creative sectors in the port area. Besides the recently concluded construction of Maasvlakte 2, a large new port area, the emphasis will be on innovation in the fields of energy consumption and energy production as well.
- **Attractive residential city with a balanced composition of the population**: Good housing alone is not enough for an attractive residential city: high-standard public space is an important condition for creating attractive and popular residential environments.

ROTTERDAM.**CLIMATE**.INITIATIVE

The **Rotterdam Climate Change Adaptation Strategy** has been developed to make Rotterdam climate-proof by 2025. By climate-proof we mean:

- measures will have been taken to ensure that every specific region is minimally disrupted by and may maximally benefit from climate change both in 2025 and throughout the following decades.
- Structurally taking into account the long-term foreseeable climate change in all spatial development of Rotterdam, while allowing for any associated uncertainties.

Specifically, this means, amongst other measures:

- Linking the strengthening of the flood defences to the urban specifications at the relevant locations. Dike reinforcements are seamlessly incorporated in the city and are multifunctional, serving as recreational trails, natural embankments or are combined with area development. In the outer-dike areas, seeking clever combinations of protection (dikes), spatial planning (e.g. elevating some sections, floating buildings) and damage control (such as evacuation routes, water-resistant design of homes and external spaces, etc.).

- The 'sponge function' of the city is restored with measures, which keep rainwater where it falls, store it and drain it away slowly. These include water squares that relieve the sewage system, infiltration zones along infrastructure and the integration of trees and greenery in outdoor areas (both public and private), which benefits the city environment. By frequently applying these small-scale measures to the 'capillaries of the city', we are able to reduce Rotterdam's vulnerability and at the same time add quality to the environment. This could include, for example, an underground water storage facility linked to car parks or blue-green networks in the city.

- Heat resistance is actively encouraged as part of the design, renovation and maintenance of buildings, outdoor spaces and the road and public utility infrastructure. This could be achieved by, for example, incorporating trees and greenery and creating shade and adequate insulation in homes and offices.

- Maintaining the current robust system, such as dikes, canals and drains, is and will remain the duty and responsibility of the government and local authorities (like the water boards). But climate change adaptation in the city requires more than this. The maintenance of many vital public utilities is in the hands of our urban private partners. It is therefore essential that energy, the supply of (drinking) water and ICT networks do not break down for long periods of time and it is imperative that these remain robust during extreme weather conditions. Most of the buildings and land areas are private property. Implementing adaptation measures in both the public and private urban spaces therefore also requires cooperation with other parties than the government.

Climate change adaptation offers ample opportunities to strengthen the economy of the city and the port, to improve the quality of life in neighbourhoods and districts, to increase biodiversity in the city and to foster committed and active participation by Rotterdam residents. Working together for a climate-proof city pays off. For example, introducing more trees and plants into the city makes the city less vulnerable to extreme rainfall, drought and heat stress. At the same time, this 'green adaptation' will make the living environment more attractive, become the motor for other investments and will inspire the residents of Rotterdam to play an active role.

1.2 How can the subsurface contribute to the sustainable development of Rotterdam?

Public space at ground level is scarce in Rotterdam. In order to meet the needs that have been formulated in the Spatial Development Strategy 2030 the city has to take the subsurface into account. The subsurface both offers opportunities and puts constraints on sustainable spatial development.

Fig 1.2 The subsurface as integral part of public space.
Source: VROM 2008

The city has ambitions with the public space: housing, offices, transport, recreational activities, nature, water. City planners translate these aspirations to a model in which public space is designed with features: buildings, parks, roads, pipelines, lakes, etc.
At present the subsurface is already used for foundations and for infrastructure. But the subsurface could also strengthen the identity of an area by showing its archaeology, re-usage of quay walls as storage space, and smart combinations that can improve the exploitation of plans and lead to cost savings like combining thermal storage with groundwater remediation. Sustainable energy like thermal storage (Shallow Geothermal, KWO) and geothermal energy could offer cost savings and these themes fit seamlessly within the objectives of the Rotterdam Climate Initiative. Contributions are delivered in terms of both mitigation and adaptation. Furthermore, the subsurface in the Rotterdam region offers possibilities for CO_2 storage and water retention.

In order to create a high-quality living environment and to facilitate sustainable development of the city it is necessary to adapt a holistic view on the city in which its subsurface plays an important role. The composition and behaviour of the subsurface deposits, as well as the presence of groundwater (both clean and contaminated) make it necessary that all subsurface-related themes are evaluated in relation to each other.

1.3 Issues concerning subsurface usage

There are several reasons why up till now we do not make optimal use of the opportunities the subsurface offers us.

1.3.1 Geological issues

High groundwater level: Dikes along the river Meuse are above mean sea level (msl) but the ground level in the city itself is below mean sea level. The Rotterdam region is therefore subdivided into polders that are actively drained by water pumping stations, see Fig. 1.3.1a, in order to maintain the requested balance between groundwater and surface-water level. On average, groundwater level is only 0.5 -0.7 m below surface level, making it complicated to execute subsurface construction works, see Fig. 1.3.1b.

Fig 1.3.1a Water pumping station in the centre of Rotterdam.
Source: Peter Dorsman

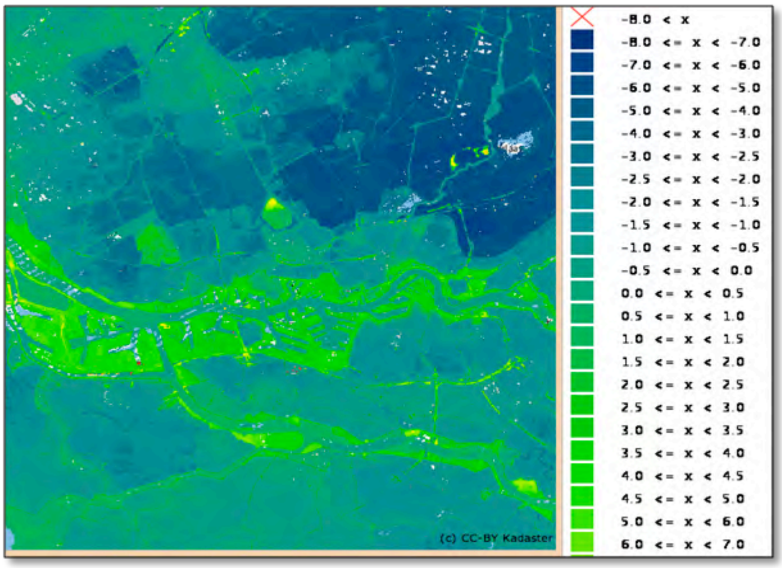


Fig 1.3.1b Groundwater level in Rotterdam
(Colour scale ranges from 8 m below msl to 6 m above msl).
Source: www.pdok.nl

Soft soils and ground water: At 4 m below mean sea level a peat layer of 1-2 m thick is present (so-called ‘Holland peat’), see Fig 1.3.1c. Layers above and below consist of soft clays. This stack of deposits is compacting and oxidising continuously, leading to ground subsidence, see Fig 1.3.1d. This in turn necessitates a lower groundwater level in order to keep Rotterdam dry.

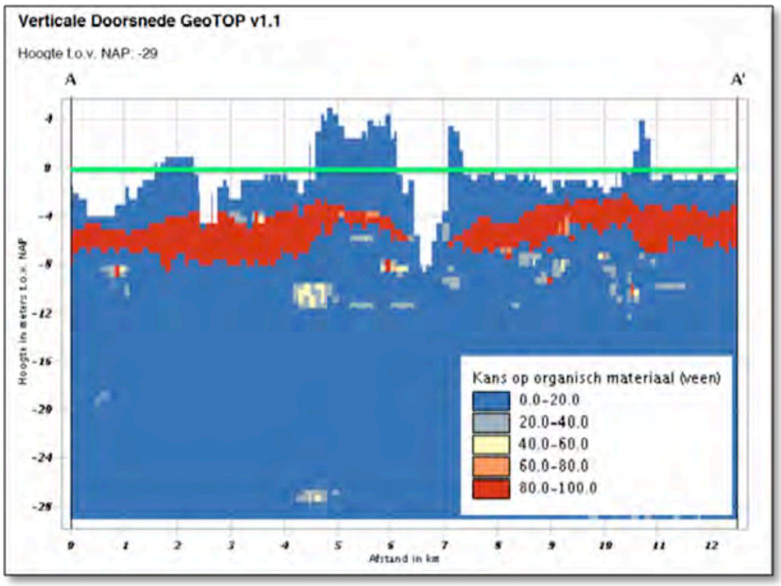


Fig 1.3.1c N-S cross section through Rotterdam:
In green: mean sea level (NAP), in red: 'Holland peat' layer.
Source: www.dinoloket.nl

Fig 1.3.1d Soil settling / Land subsidence in mm/year.
Source: Stadsontwikkeling Rotterdam

Soft soils and foundation: Furthermore, the lowering of the groundwater level exposes wooden piles on which houses in older city districts are founded to oxygen and a rotting process will start, see Fig 1.3.1e.

Most buildings rest on a foundation of piles that have been driven into the uppermost or 'first' sand layer, see Chapter 6.2.1. Average depth of this Pleistocene sand layer is 15 metres below mean sea level, which is 11-14 m below land surface, see Fig 1.3.1f.

Fig 1.3.1e ***Various parallel cracks***
from bottom-right to top-left in wall due to rotting foundation piles.
Source: Peter Dorsman

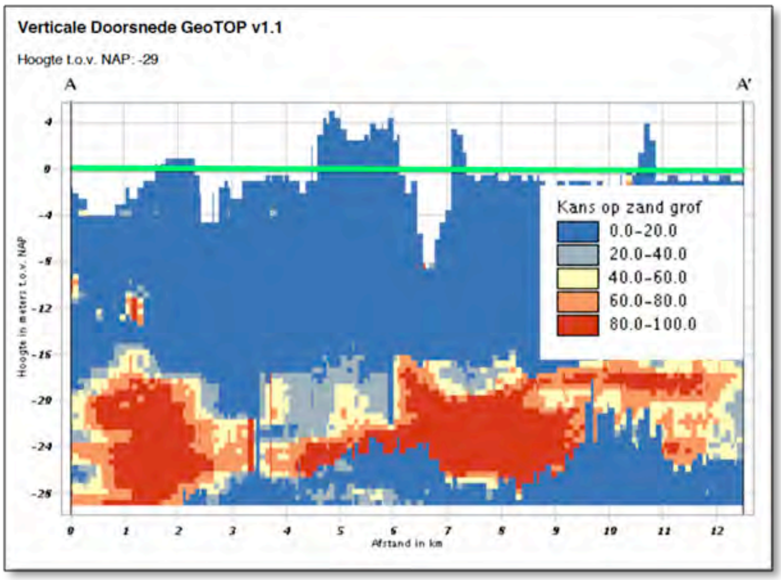


Fig 1.3.1f N-S cross section through Rotterdam:
in green: mean sea level (NAP), in red: 'first' sand layer.
Source: dinoloket.nl

1.3.2 Artificial obstacles

The subsurface contains obstacles such as pipelines, quay walls, unexploded WWII-devices, and archaeological remains, see Chapter 6.1. This may lead to high removal-, reconstruction- and/or preservation costs in connection to new developments and subsurface spatial reservations that may hamper an efficient use of the subsurface.

1.3.3 Planning issues

The subsurface is not very well known amongst the general public, see Fig.1.3.3a. Plans for CO_2 storage in the neighbourhood of Rotterdam in 2008 caused fierce discussions between professionals, residents and environmental organisations, see Fig.1.3.3b. These discussions seemed to be based more on emotions than on facts. Similar discussions occurred during the recent public debate on shale gas exploration elsewhere in the Netherlands and in other parts of Europe. The subsurface is equally unknown amongst city developers. And unknown makes unloved. Result is that the subsurface is too often brought in too late and/or in an unstructured way in the spatial development cycle. This way relevant geotechnical, environmental, and/or physical obstacles are encountered too late in the process, leading to financial complications and delays.

Fig 1.3.3a The subsurface: a "black box for both public and non-subsurface specialists".
Source: Peter Dorsman

Additionally, this way also the opportunities the subsurface offers us (e.g. offering additional public space and possibilities for sustainable energy usage) are overlooked and cannot be fully exploited.

Fig 1.3.3b Newspaper article about social resistance concerning CO_2 storage in Barendrecht, 10 km south of Rotterdam
Source: www.ad.nl

1.4 Responsibility of subsurface specialists

The City of Rotterdam has a wealth of information and knowledge about the subsurface of Rotterdam. It is the responsibility of its subsurface specialists to make this information and knowledge available to decision makers, urban planners and city developers, as well as to the general public. The subsurface specialists should provide insight into the underground with attractive **visualisations** of the right information, presented at the right time and geared to demonstrate the possibilities and impossibilities of the subsurface in order to seduce decision makers to sustainably exploit the underground. Rotterdam participated (together with the cities of Utrecht, Arnhem and Enschede) in the national programme on spatial planning of the subsurface (Ruimtelijke Ordening Ondergrond) that was initiated in 2008 by the Ministry of Housing, Spatial Planning and the Environment (VROM). This was the first time that a holistic view was applied to subsurface usage. Since then Rotterdam has continued to invest in answering questions like "what are the possibilities in the subsurface" and when taking a profit of these possibilities, what are the effects, (influences on the subsurface, environmental effects, contribution to climate objectives), what is the urgency, what are the costs and how to weigh and prioritise one possibility versus another, see Chapter 7.

2. City description

2.1 Key city data

Rotterdam, in size the second city in the Netherlands, is most famous for its port: the largest port and industrial complex in Europe. See Fig 2.1. Currently Rotterdam has a population of 618,467 inhabitants. The areal size of the city is 320 km^2.

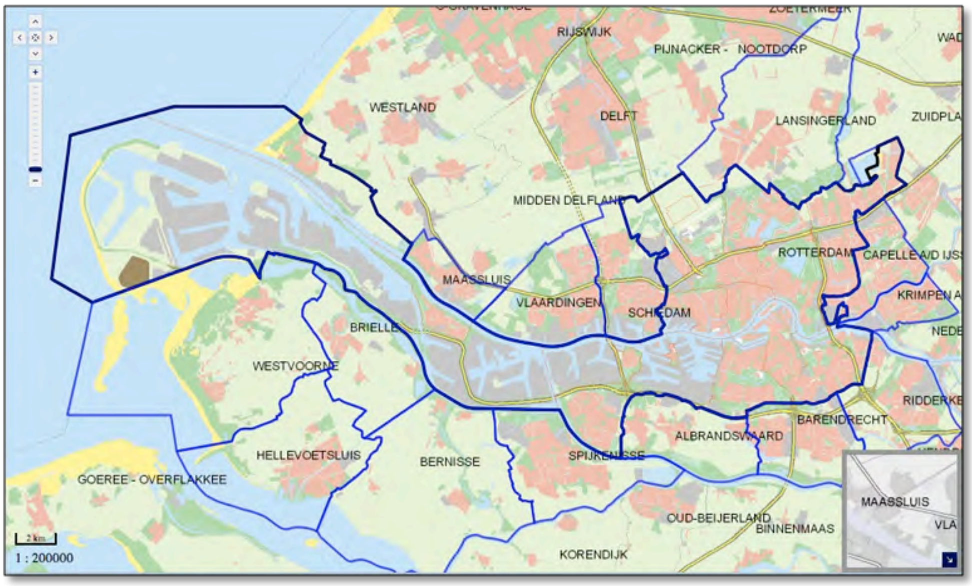


Fig 2.1 Rotterdam and neighbouring cities that make up the Rotterdam-Rijnmond region. Municipal boundaries are shown in dark blue. The Port area is shown in grey, the City area in red.
Source: GisWEB Stadsbeheer Rotterdam

The population of the greater Rotterdam area, called "Rotterdam-Rijnmond" is approximately 1.3 million on an area of 860 km^2. In the Netherlands, Rotterdam has the highest percentage of immigrants; almost 50% of the population is of non-Dutch origin, predominantly from Surinam, Turkey, Morocco, Serbia and the Dutch Antilles.

2.2 Port

Rotterdam's commercial and strategic importance is based on its location near the mouth of the Nieuwe Maas, one of the fluvial channels of the Rhine-Meuse delta embroucing into the southern North Sea. Rotterdam is the largest port in Europe and one of the busiest ports in the world. The port's main activities are petrochemical industries and general cargo handling and transhipment. The port is the gateway to the European market of more than 350 million consumers. The annual throughput is about 450 million tons (2012).

In 1872, the Nieuwe Waterweg ('New Waterway') was completed, a ship canal constructed to keep the city and port of Rotterdam accessible to seafaring vessels. It was necessary to dig the Nieuwe Waterweg, because the natural Rhine-Meuse fluvial channels were in the process of silting up.

In the first half of the twentieth century, the port's centre of gravity shifted westward towards the North Sea. Covering 105 square kilometres (41 sq mi), the port of Rotterdam now stretches over a distance of 40 kilometres (25 mi). It consists of the city centre's historic harbour area, including Delfshaven, the Lloydkwartier, the Maashaven/Rijnhaven/Feijenoord complex, the harbours around Nieuw-Mathenesse, Waalhaven, Vondelingenplaat, Eemhaven, Botlek, Europoort, situated along the Calandkanaal, Nieuwe Waterweg and Scheur (the latter two being continuations of the Nieuwe Maas) and the reclaimed Maasvlakte area, which projects into the North Sea. The construction of a second Maasvlakte received started in 2008 and this new port area was ready for the first ship to anchor in 2013.

Fig 2.2 The Rotterdam harbour.
Source: Stadsontwikkeling Rotterdam

2.3 Infrastructure

Rhine and Meuse rivers provide excellent access to the centre of Europe, including the industrial Ruhr region in Germany. Rotterdam is well connected to the Dutch railway network and has several international connections. In 2007, the Betuweroute, a new fast freight railway from Rotterdam to Germany, was completed. Highway links to the hinterland are excellent but the Rotterdam region is infamous for its traffic density. Rotterdam-The Hague Airport is the third largest airport in the country. Located north of the city, it has shown a very strong growth over the past five years, mostly caused by the growth of the low-cost carrier market. The airport is connected to the City centre with a bus service.

2.4 Housing

If a favourable work and residential climate is considered an indispensable premise for a strong(er) city, the realisation of it within the existing urban area will offer maximum benefits and will lead to the efficient use of the scarce space. Furthermore, in this way optimal advantage will be taken of the existing facilities and the green outskirts will be spared.
Good housing alone is not enough for an attractive residential city. Therefore, Rotterdam wagers on fully-fledged, quality residential environments by devoting a great deal of attention to public space and the indispensable facilities (education, child care, medical/social, sports and games, et cetera). In order to attract more families with children and high and medium income groups, the residential environments of strong districts like Kralingen and Hillegersberg will be extended. Top priorities in weaker districts are the restructuring and the tackling of the existing housing stock. In practice, building within the perimetre of the existing city means that Rotterdam has set a target for itself to increase the density of housing stock by 56,000 dwellings at inner urban sites.

3. Geology and physical-geographical setting

3.1 Geological evolution from Carboniferous to Cenozoic

The geological evolution of the Netherlands resulted in a highly structured and surprisingly varied subsurface geology below a deceivingly flat topography. In much of the Netherlands, more than 10 km of predominantly siliciclastic sediments overlie the metamorphic basement. These sediments comprise several major unconformities, but on the whole the geological record is almost continuous from the Late Paleozoic to the recent Holocene and present Anthropocene (see Fig 3.1a and Fig 3.1b).
Several tectonic events affected the area during its geological history. The Rotterdam area is situated on the southern edge of the West Netherlands Basin just north of the London-Brabant High. Faulting in the basin has a SE-NW orientation and these faults have been reactivated multiple times during the geological history that followed, see Fig 3.1c and Fig 3.1d. In the following sections the most important geological events and associated deposits in the Rotterdam area will be discussed in more detail.

Carboniferous
The deepest-lying rocks of interest in the area are found at a depth of around 4000 m and belong to the Late-Carboniferous Limburg Group (see Fig 3.1a) .

Permian
During the beginning of the Permian the region experienced a period of non-deposition and erosion Therefore sandstones of the Boven-Rotliegend Group so abundantly developed in the Groningen area, (where they contain the gas of the Groningen gas field) only have a limited thickness of less than 25 m in the Province of Zuid Holland. At the end of the Permian the area subsided and thin layers of clay and limestone layers were deposited.

Triassic
Subsidence of the area continued during the Triassic. Lacustrine shallow-water conditions led to deposition of fine-grained Lower Buntsandstein Formation. Later during the Early Triassic highs like the Dutch Swelling developed and along their sides several grabens were formed. The research area is located in the SE-NW oriented West Netherlands Basin. Due to strong influx from erosion material transported from the SE-hinterland sandstone layers were deposited. These now form the formations of the Main Buntsandstein Sub-group.
In the province of Zuid Holland rocks of the Triassic have been exploited for oil and gas and are currently being exploited for geothermal energy.

Jurassic
During the transgression from the end of the Triassic to the beginning of the late Jurassic, the study area was part of an extensive open marine area. Here thick packages of silt, clay and marl of the Altena Group were deposited. At the end of the Middle Jurassic Kimmerian tectonics caused further subsidence in the West Netherlands Basin. The various fault-bounded blocks experienced their own degree of subsidence resulting in differences in deposition. Rocks of the Schieland Group were deposited in the area from the middle of the Late Jurassic and during the earliest Cretaceous. These rocks contain massive sandstone series with thicknesses ranging from 30 to 75 m. This package is well developed in the central and northern part of the West Netherlands Basin to the north of the Rotterdam region. In the province of Zuid Holland this package has been exploited for oil and gas and is currently explored and exploited for warm water (geothermal heat).

Cretaceous
During the Early Cretaceous the sea gradually expanded towards the SE. In this shallow-marine sedimentary environment the sandstone, siltstones, claystone and marls of the Rijnland Group were deposited up to several hundreds of metres thick in the province of Zuid Holland where they were exploited for oil and gas and are currently exploited for warm water (geothermal heat). At the end of the Early Cretaceous the sea level was worldwide at a high level and throughout the late Cretaceous a thick sequence of limestones of the Chalk Group formed. During the beginning of the Late Cretaceous compressional forces of the N-S-oriented Subhercynic tectonic phase caused reversal of the direction of motion along fractures in a number of Mesozoic basins. The inversions are responsible for initial, sedimentary thickness differences of the Chalk Group and also for significant erosion of older rock series.

Palaeogene and Neogene
At the end of the Cretaceous, the West Netherlands Basin disappeared as a structural element. In the course of the Palaeogene (Eocene) a new subsiding basin was formed further south: the Voorne Trough. In the period of tectonic calm that followed, widespread subsidence created space for thick Palaeogene and Neogene deposits. In the Rotterdam region, marine conditions prevailed during this period. Deposits are found everywhere in the region and exist mainly of unconsolidated alternating sand and clay layers. The thickness of these deposits ranges from 400 up to 1200 m.

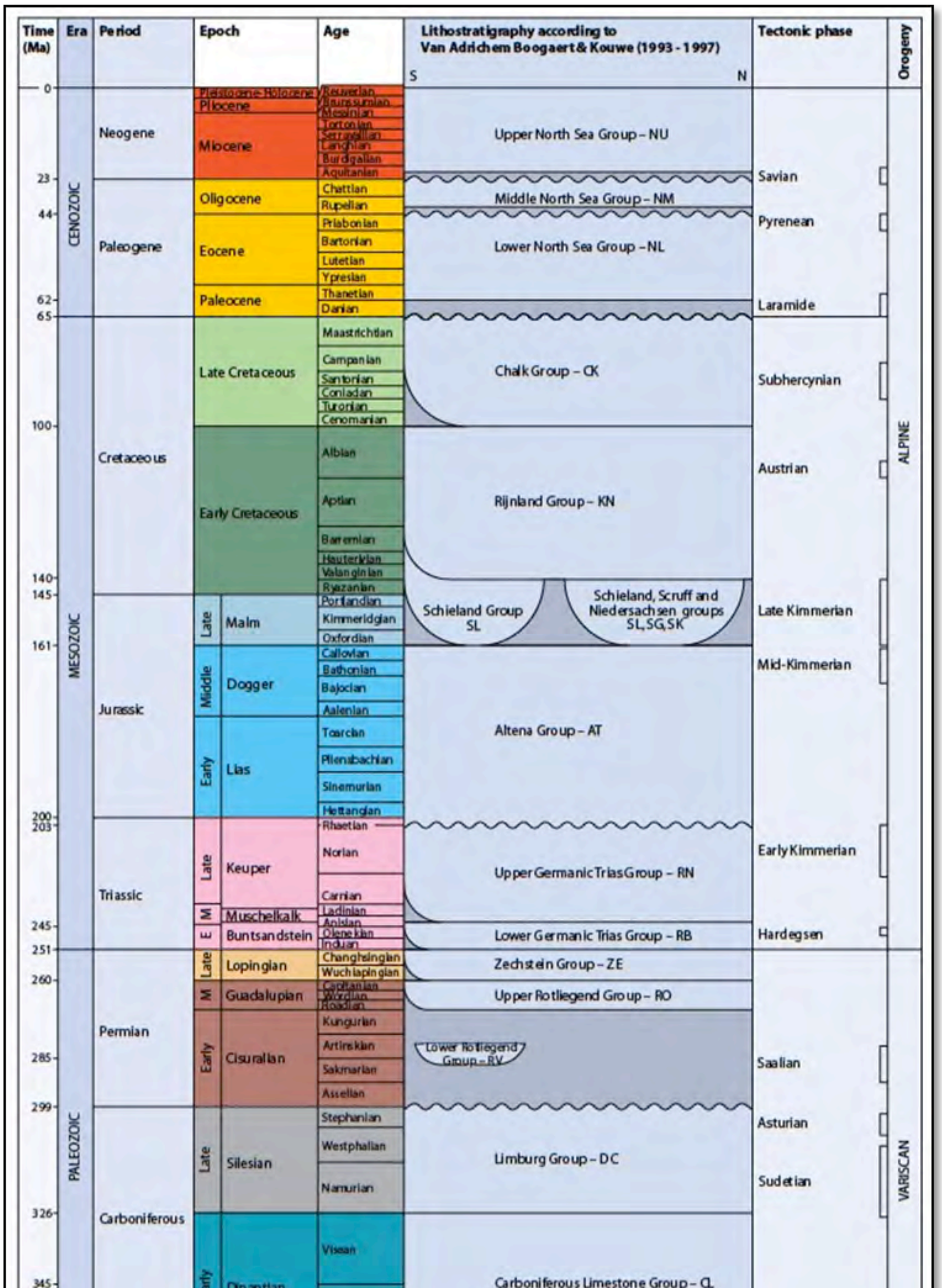


Fig 3.1a Geological time scale (after Gradsein et al. 2004) and lithostratigraphic column (after van Adrichem Boogaert & Kouwe 1993)
Source: Duin et al 2006

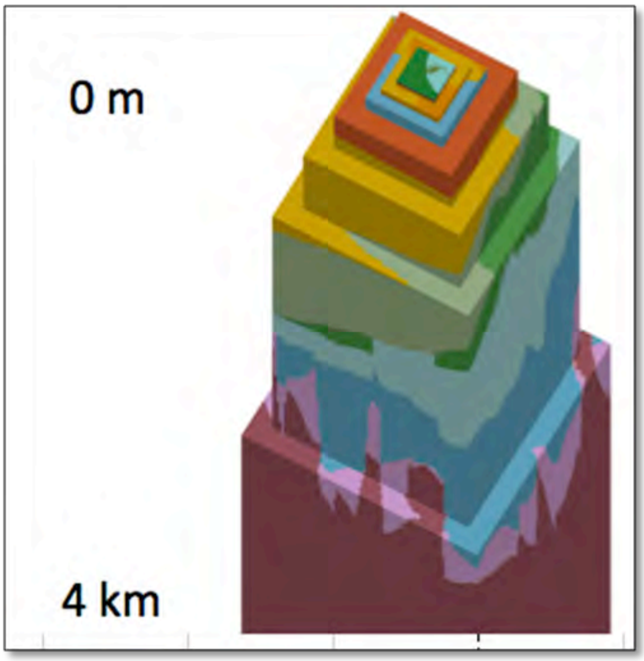


Fig 3.1b 3D Model of the subsurface of Rotterdam (up to 4km deep) showing the lithostrati-graphic section of rocks encountered by oil and gas wells in the vicinity of Rotterdam*.*
Source: TNO/Geological Survey (NLOG, REGIS and Geotop data;
3D model by TNO/Geological Survey and Stadsontwikkeling Rotterdam)
Colour coding of lithostratigraphic units corresponds to Fig 3.1a and Fig 3.1d.

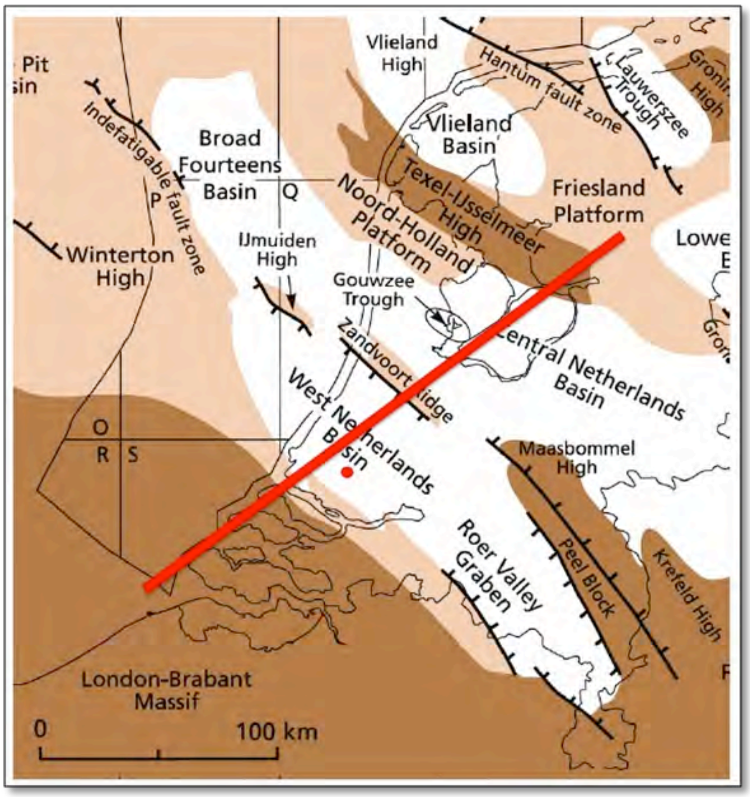


Fig 3.1c Jurassic/Cretaceous structural elements. A SW-NE geological cross section (Fig 3.d) is indicated with a red line, Rotterdam is indicated with a red dot.
Source: TNO/Geological Survey

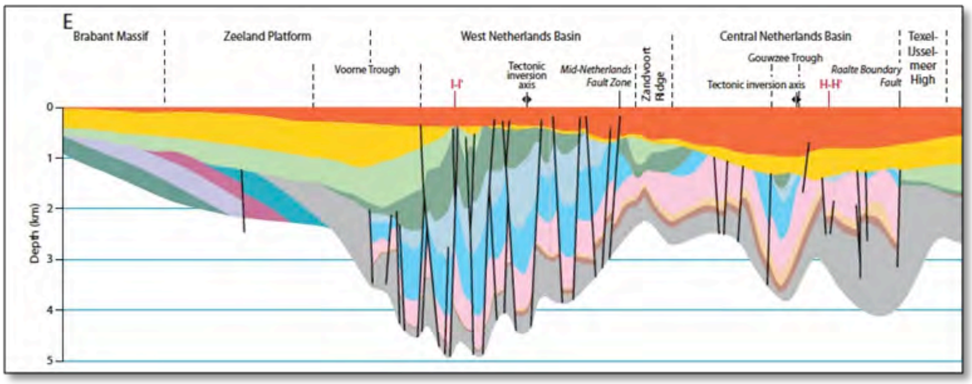


Fig 3.1d From 0-5 km depth: SW-NE cross section (location indicated in red in Fig 3.1c).
Source: Duin et al 2006

Quaternary deposits make up the upper part of the sedimentary sequence below Rotterdam. Due to ongoing tectonic subsidence of the North Sea Basin, Quaternary sediments reach a thickness of ca 300 m. The Quaternary period is characterised by fierce climatic shifts from cold glacial conditions to warm interglacial conditions. During glacial conditions, sea level was much lower than today. The coastline was situated hundreds of kms to the SW and N of the present-day coastline. In those times, Rotterdam was far inland and humans and animals could walk from Rotterdam to London. The cyclic climatic changes have caused cyclic changes in sedimentary environment and a diverse stack of associated deposits, ranging from clayey and sandy coastal deposits to gravelly river deposits, and from fine-grained windblown sand to lagoonal peat. In general, in the vicinity of Rotterdam glacial periods are characterised by sandy and gravelly fluvial deposits, whereas interglacial periods are characterised by fine-grained coastal and deltaic deposits and peat. The uppermost coarse-grained deposits, dating from the last ice age, are also known as the 'first sand layer' and serve as the main foundation level for nearly every building in the city of Rotterdam.

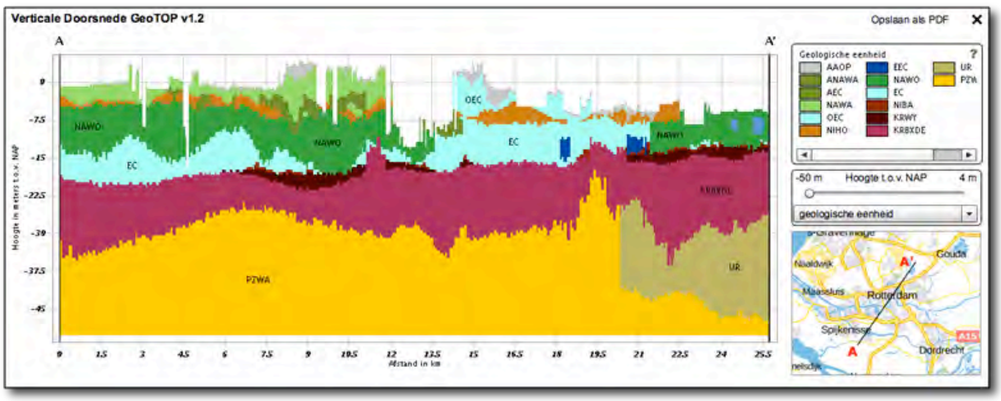


Fig 3.1e From 0-50 m depth: SW-NE cross section (location indicated in box).
Source: TNO/ Dino loket.

The upper 10-15 m of the subsurface consists of coastal and fluvial Holocene deposits. Rapid sea-level rise at the start of the Holocene caused drowning of the landscape and the formation of peat, followed by the deposition of clayey shallow marine deposits to the west and fluvial sandy channel and clayey flood basin deposits to the east. The current-day landscape is characterised by a sandy coastal barrier system, interrupted by estuaries and tidal inlets. Behind the coastal barrier, a coastal plain is present that consists of clayey tidal deposits and peat. Due to continued drainage by man, the surface level in most of this area today is below mean sea level. Further east, fluvial deposits are dominant. These comprise sandy channel deposits near present-day and former river channels and clayey deposits and peat in the flood basins in between.

3.2 Wells and Seismic data

Most of the knowledge of the deeper part of the subsurface has been obtained from wells drilled by oil companies in their hunt for oil and gas and more recently by companies exploring for geothermal heat, see Fig 3.2a. Another important source of information of the subsurface is provided by seismic data: physical characteristics of rocks in the deep surface are collected in a non-destructive way and this data is continuously recorded along a vertical profile through the earth. After calibrating the seismic data with the real data obtained from wells, seismic data can be used to interpolate between wells and to construct geological sections as in Fig 3.1d. An example of a seismic line is displayed in Fig 3.2b and Fig 3.2c.

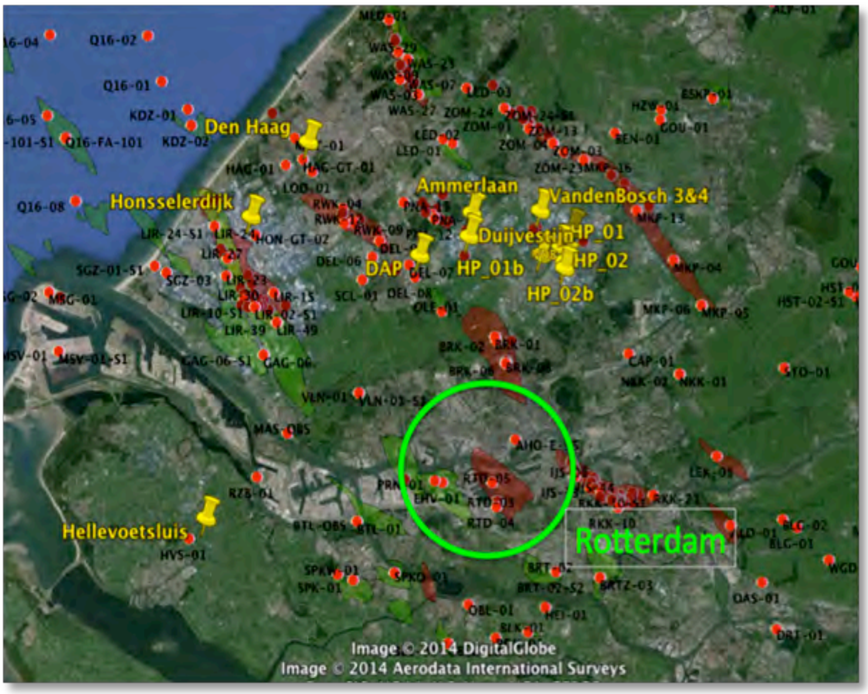


Fig 3.2a Oil and gas wells (red dots) and geothermal wells (yellow markers) in the province of Zuid Holland
Source: Stadsontwikkeling Rotterdam

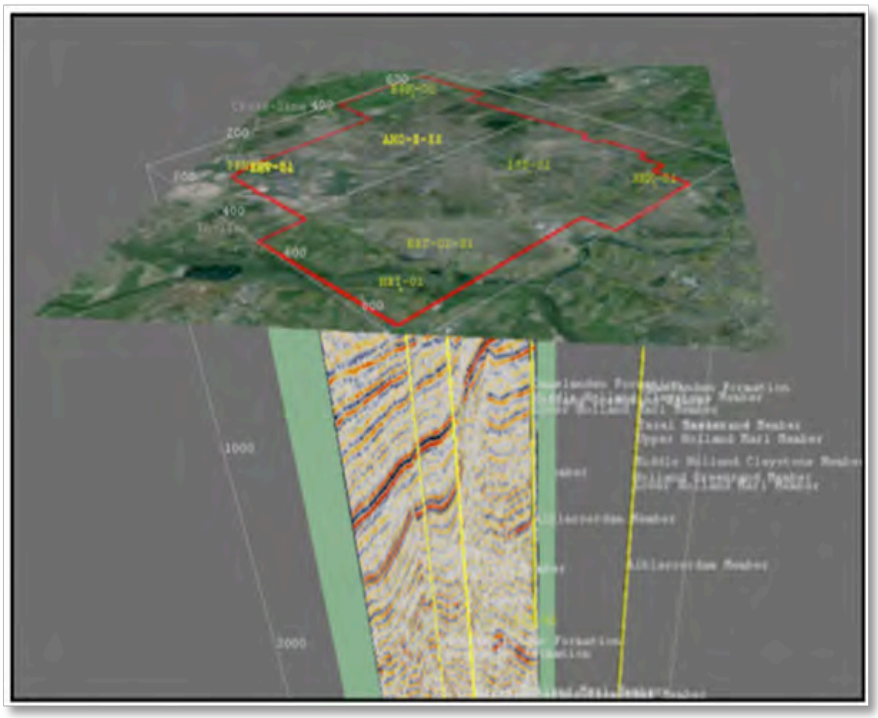


Fig 3.2b Outline of 3D seismic survey L3NAM1985A in Rotterdam area (in red). Oil & gas wells are presented in yellow and below is the outline the profile of the seismic section, also shown in Fig 3.2c.
Source: Stadsontwikkeling Rotterdam / Brabant Water

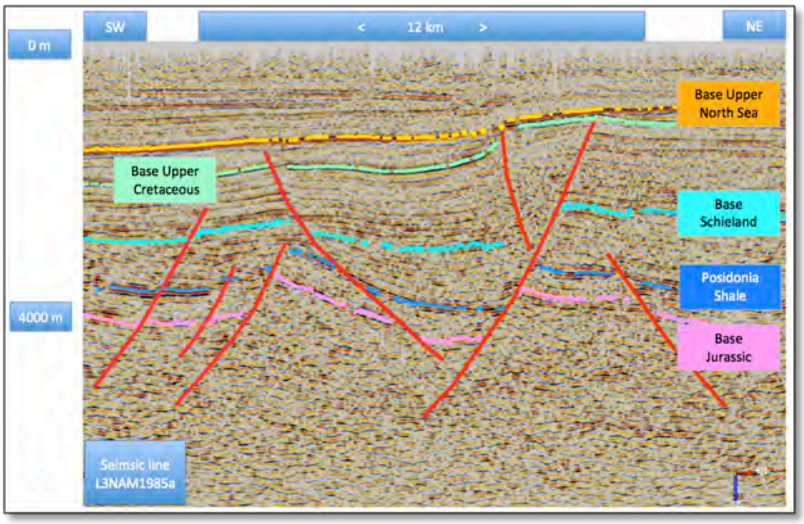


Fig 3.2c Seismic cross-section; interpreted inline 490 of seismic survey 3D L3NAM1985A over Rotterdam. Interpretation of such a seismic profile combined with evaluating oil and gas wells is the base for constructing geological profiles as displayed in Fig 3.1d.
Source: Stadsontwikkeling Rotterdam / Brabant Water

3.3 The Anthropocene: The cultivation of peat lands

In recent times, man has been an important geological agent in this area: rivers and their associated sediments are contained in-between dikes, see Fig 3.3.

Fig 3.3 Primary dikes and embankments in the Rotterdam Region
Source: Stadsontwikkeling Rotterdam

Furthermore, peat has been dug for fuel and clay, sand and gravel have been abstracted as aggregate resource and/or building material. Today, sediment transport by man is more important than sediment transport by natural processes. See chapter 6.1.9 on Trading Soil. The grey layer in Fig 6.2.10 shows the “man made” (=anthropogenic) layer.
The drainage of peat lands gradually induced oxidation of the peat and ultimately led to subsidence. In extensive areas in the west and north of the country several metres of subsidence has occurred since medieval times. The subsidence still continues. In the coastal zone the excavation of peat resulted in lakes. From the 16th century on, part of these lakes were surrounded by dikes, pumped dry and converted into ‘polders’. The Prins Alexander Polder in the northeast of Rotterdam extends 6 metres (20 ft) below sea level, or rather below 'Amsterdam Ordnance Datum' (NAP). The lowest point in the Netherlands (6.76 metres below NAP) is situated just to the east of Rotterdam, in the municipality of Nieuwerkerk aan den IJssel.

3.4 Physical geography

Rotterdam is divided into a northern and a southern part by the river Nieuwe Maas. The city centre is located on the northern bank of the Nieuwe Maas. Built mostly behind dikes, large parts of the Rotterdam are below sea level. To keep the reclaimed polder areas dry and fit for farming, pumping stations, formerly windmills, extract water continuously to transfer into bordering water bodies, see Fig 3.4.

Fig 3.4 Flat polderland west of Rotterdam.
Source: Peter Dorsman

3.5 Seismology

Natural earthquakes are genetically and geographically related to movements along faults in the subsurface. Faults in the Rotterdam region are not active at present times and therefore naturally induced earthquakes do not occur in the wider Rotterdam region. Earthquakes induced by human activities occur in the Netherlands in the northern province of Groningen. These are related to the extraction of gas from the giant Groningen gas field. In the region of Rotterdam gas and oil extraction has taken place in various fields (see Chapters 3.1 and 6.4) but due to the small size of these fields no earthquakes or tremors have been registered in the region, see Fig 3.5.

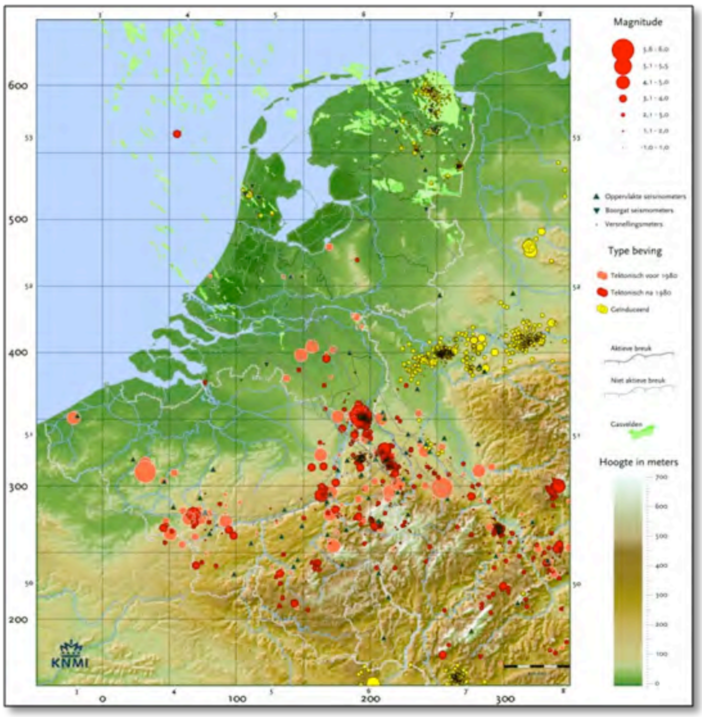


Fig 3.5 Earthquakes in the Netherlands from 1900-2004: red dots indicate naturally induced earthquakes; yellow dots indicate earthquakes resulting from human activity (gas extraction in Groningen and coalmining in Germany). The size of each dot is an indication for its magnitude. Gas fields in light green.
Source: KNMI

4. Historical development of the city

The Rotterdam region was from 9000 to 4500 BC a large bog-swamp where a small river, the Rotte, with several branches flowed. Through archaeological excavations we have come to know that this region was visited on a more or less regular base by groups of hunters. In the so-called new Stone Age, about 4500 to 2000 BC, these groups began to develop agricultural habits. This led to a more or less permanent settling on higher plains and river dunes. Due to regular flooding these settlements could not obtain permanent status.
Permanent agricultural settlements were possible in the Iron Age and the Roman era. During the Roman occupation the first infrastructural systems like roads and channels were constructed. The population in the region grew. The waning Roman influence went parallel with a rising climate. The Maas-Merwede area once again changed in a boggy swamp-area less suitable for habitation. During the Carolingian age many hamlets were built around a parish-church. One of these was Rotta located at the outlet of the Rotte. During the 12e century floods washed this small village away. To cultivate the surrounding marshes the Counts of Holland pawned the badlands to freeman and lower nobility. This was done to meet the growing need of farmland. To drain the marshes and create farmland parallel ditches were dug perpendicular to the existing river. These patterns of ditches are nowadays still visible in the modern urbanised area. The draining of the marshes had less favourable effects: due to consolidation and compaction of the soil the surface lowered often below sea level which increased the chance of flooding. To prevent this, a belt of dykes was built in the Maas Mewed area. The construction of these dykes was realised during the 13e century. To coordinate these works counsels were instigated: the so-called "**Hoogheemraadschappen**" (water boards). Part of this system of dykes was the primary dyke "Schiedamse Hoge Zeedijk" from which in turn the dam in the Rotte was a part of. This dam was built in the year 1270.
To maintain the flooding of excess water from the Rotte, sluices where necessary. These sluices were constructed with lock gates that closed when the water in the Maas was high and opened with an excess of water from the Rotte or Rotta (from rot = 'muddy' and a = 'water', thus 'muddy water'). This dam that gave Rotterdam its name was located at the position of the modern-day Hoogstraat. Behind this dam fishermen and craftsmen build their houses and shops.

Fig 4a Rotterdam in 1299
Source: C.Hoek

Rotterdam was, firstly temporarily in 1299 later on definitely in 1340, granted city-rights. These gave its citizens the right to dig a moat and build a wall around the city. Outside the city parallel to the dam was a

canal, named the Steiger, with the possibility for ships to dock. Outside of the dyke south of the city lay a tidal marsh split in two by the outlet of the river Rotte. The two parts were called West and Oost Nieuwland. A small expansion of the city in 1358 led to the building of the walls and the digging of the moat.
The Westmoat was called the Coolsvest, the East moat was called the Goudsevest and the Southern moat developed in later years into two harbours: the Blaak and the Nieuwe Haven. The humble Rotterdam acquired only as late as the 16e century the means to change the bastion from a wooden fence in a sturdy brick wall. Important for the development as a city of merchants, was the digging of the Schiekanaal, a canal north of the city that disclosed the hinterlands and made trade on a regional scale possible. This channel caused many disputes with the more important city of Delft and led to the construction of a second canal by Delft, de Delftse Schie, next to the village Schoonderloo and to the founding of Delfts own harbour: Delftshaven. Both of these were in later ages swallowed up by the expanding Rotterdam. In the year 1572 during the uprising against the Spanish authorities, the prince of Orange deemed the position of Rotterdam strategic. This led to the beginning of fortification of the city. Rotterdam expanded with the tidal marshes that lay south of the city on which several ship wharfs and carpenter shops were already located. The Coolsvest prolonged with a new moat called the Schiedamschevest. A bastion was erected. But due to a truce between the warring parties the planned fortification of the riverside was never completed. At the end of the 17e century Rotterdam focused on the trade with France, England and Scotland.
The Wijnhaven, Bierhaven and Glashaven were constructed in the former tidal marshes. In less than fifty year Rotterdam surpassed its competition as the most important trading-port in the region. The Prosperity of the city was shown by the construction of several stately Buildings one of which was the Schielandhuis that can still be seen near the most Southern part of the Coolsingel. Outside the city, in the beginning of the 18e century Rotterdam developed the "1e Nieuwe Werk" a project that led to the digging of the Zalmhaven. Around this new harbour the wharfs and shipyards were located. The moving of these activities from the southern part of the walled city to this new location left room for and provided rest for the merchants to build their houses here. At this time building began outside the city walls. Thus three very different areas developed. Within the walls the triangular shaped city was cut in two by the dam in the Rotte. The upper northern part of this triangle was the oldest part. In later years it became increasingly populated. The many waterways were often used as a source of drinking water and at the same time as an open sewer. There was hardly any natural flooding of the water in the old inner city. The living conditions south of the dam were a lot better.

Fig 4b Rotterdam in 1588
Source: Guicciardini

The river caused a regular supply of fresh water due to the tide of the river. The City-Triangle was surrounded by a typical Dutch rural area. The ditches still drained the peat and the buildings were located around the many paths, waterways and walkways that crossed the polder. The wealthy citizens build their mansions here and used the fertile soil for their gardens behind these mansions. But these were not the only inhabitants. Small shops opened their business here. Some of these activities polluted the soil with e.g. white-lead. The defence of the city had lost its urgency. The foundation of one of the old towers was used to support the first water pump station of the Netherlands that was driven by steam. But it could not supply enough power and was replaced by 6 water-mills located at a drainage-canal near the Oostplein. More important for the development of the city was a second project which was completed in

1854 the “Tweede Nieuwe Werk”. This project led to the digging of the Veerhaven and the construction of the Westerkade. Another harbour, the Westerhaven, was established but this harbour only functioned for 48 years and was filled-up. This was the time of the city-architect Rose who managed the building of the quay wall at the Boompjes the most southern leg of the City-triangle. This made the docking and unloading of larger sea ships on this location possible.

Fig 4c Rotterdam in 1623
Source: Huys & Versyden

There was no more room on the northern shore of the Maas for further development. But at the other side of the river lay a world of possibilities. But Rose had a more urgent need to address.
Due to the overpopulation of the inner city and the unhealthy conditions Cholera epidemics presented a continuous challenge. Rose thought he could solve this problem by the construction of a belt of canals around the city-triangle that would flush the inner city. He gave his name to this project: the “Rose singelplan”. This project gave Rotterdam its luscious 19e century canals, among which were the Westersingel and the Noordsingel. We can still visit them on a walk just outside the City-triangle. It was the beginning of the industrial revolution. Railways made the world smaller. Rotterdam was part of this Revolution. The first connection was with Amsterdam. Later Rotterdam was connected to the East by rail. The railway to the South led to the filling-up of the Rotte in the inner city. This was done to make the construction of a railway bridge that split the city possible. In 1899 a canal to the North Sea was dug: the “Nieuwe Waterweg”. These developments gave Rotterdam an enormous boost. This led to an expansion of the population. To house these new inhabitants the urbanisation of the rural parts around the city became a necessity. Parallel to these developments the industrialisation of the Southern bank of the Maas was instigated. The Noorderhaven was constructed and, after a visit by the Dutch Royalty, was renamed the Koningshaven.

Fig 4d The Merwehaven, a harbour constructed in 1930.
Source: City of Rotterdam

The most Northern part of the island Feijenoord became the Noordereiland. Two other harbours were constructed in this period: the Entrepothaven and the Spoorweghaven. Lodewijck Pinchoff initiated this but he went bankrupt and he fled to the USA. The activities of his company were taken over by the Rotterdam municipality. Some years later G.J. De Jongh, the newly appointed municipal surveyor, took over the baton and planned two larger harbours the Maashaven and the Rijnhaven and later on another harbour was constructed: the gigantic Waalhaven.
The annexation of Delfshaven made the development of harbours located near the neighbouring city of Schiedam possible, these where the “Vier Havens” and the “Merwehaven”.
All these works also led to the first annexation of a series of villages that were located on the Southern bank. The areas around these harbours were filled with new neighbourhoods to house the workers of the harbours and factories that opened shop here. The first petrochemical plants were build which gave some of these harbours their function e.g. the 1e en 2e Petroleumhaven, built West of Rotterdam on the Southbank of the river Maas. Then the Second World War came. The City Triangle was destroyed by the bombardment, as were many of the harbours. After the war the torn city of Rotterdam made strength out of weakness. The centre of the city was rebuilt as a modern metropolis. Instead of the integral design of Witteveen, a more organic approach by van Traa was chosen.
The city expanded to the South where modern “garden-cities” arose designed by the architects van Tijen, Stam Beese and van Drimmelen. During the 5th decade of the 20th century the Botlek harbour was constructed. In 1957 the City Council decided to make an artificial peninsula with space for many new harbours. This peninsula is called the Maasvlakte. The trade in petrochemical products made Rotterdam the biggest port of the world. This status was sustained for quite some time. In the Rotterdam harbours steel became an important product to ship. The shipping of containers by the ECT was also a very important factor for the worldwide importance of Rotterdam. Although Rotterdam is not the biggest port in the World anymore, the construction of a second Maasvlakte established in 2013, makes certain that the importance of Rotterdam as world-class port is still unquestioned.

Fig 4e The Waalhaven / Eemhaven areas, constructed in the first half of the twentieth century.
Source: City of Rotterdam

5. Urban planning and management

5.1 Planning over past centuries

In order to explain the relationship between urban planning, management and subsurface, four districts in Rotterdam are shown. These areas represent different stages of the growth of the city and are organised in a different way. Afterwards the current way of planning is described.

1854 Water project

The first big expansion of the city came with the construction of an ingenious water system. Around the city, a waterway was realised, and the space in between was filled with housing. This waterway 'Singel' used the difference in ground water level. Clean, fresh water from the river Maas was directed into the Singel, no manpower needed, it just flowed in. Two steam-driven pumping-stations where used to pump the unclean water out, to the Maas. This Singel was not only used for water management, but it was also a green recreational route. And still is today.
Reason for this big city expansion was the improved infrastructure network, the railway connection to Amsterdam, Utrecht and Antwerp, and the new water connection to the sea. The amount of jobs grew and people moved to the city. At first, the planning and construction of the new housing was done on private initiative. But the municipality took over due to bad living conditions and hygiene.

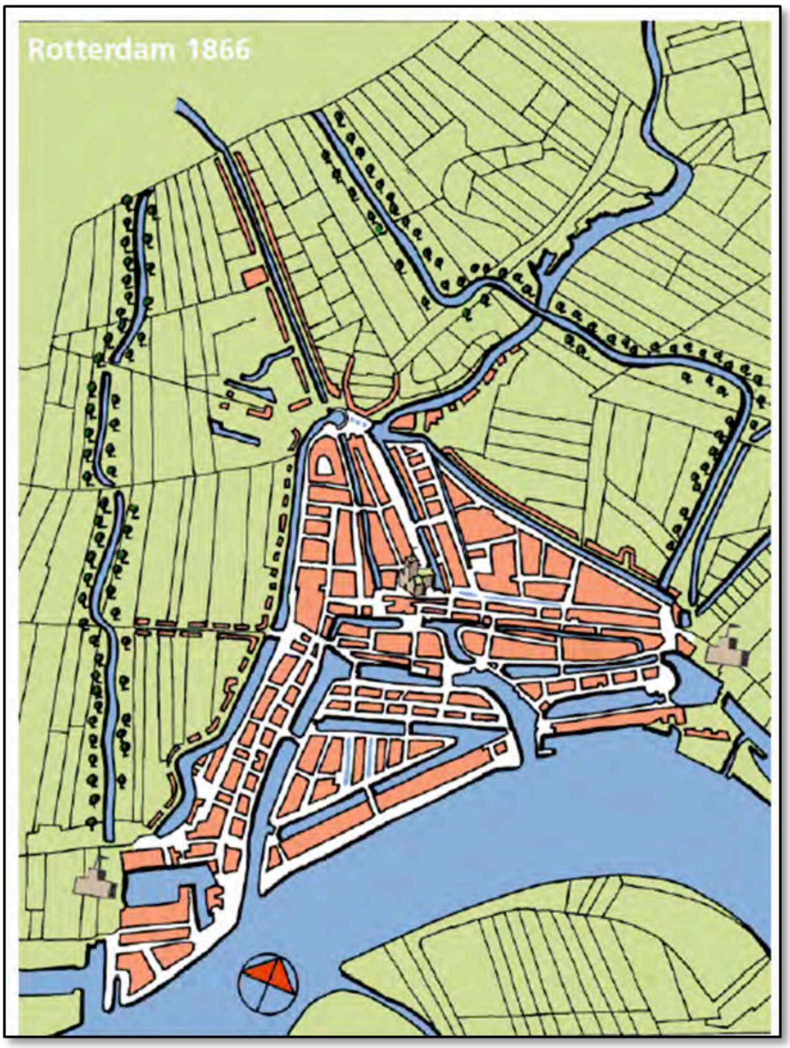


Fig 5.1a The Rotterdam Water Project around 1866, figure shows "Singels" around the city
Source: Lesbrief Monumenten 2002

1890 Kralingen
During the end of the 19th century the city kept growing, Kralingen (on the west of the city centre) is a good example of how this was done. The underlying polder structure (small parcels of land separated by ditches) was left intact and filled with housing; the former water-infrastructure became the infrastructure.

Fig 5.1b The Kralingen area in the eastern part of the city
Source: Areal Photograph of City of Rotterdam

Fig 5.1c The Kralingen area in 1880
Source:City of Rotterdam

1946 City Centre

Rotterdam's city centre was destroyed during the Second World War. In 1941 the first recovery plan was made by Witteveen. He wanted to restore the old city structure but received a lot of criticism. Then, in 1946, Van Traa made a plan, which was based on more modern urban approaches. It had a wider structure, different from the original one, taking the growing amounts of traffic into account.

Fig 5.1d The City Centre in 2014
Source: Areal Photograph of City of Rotterdam

Fig 5.1e The City Centre in 1694
Source: City of Rotterdam

1960 Ommoord

After the Second World War there was a big need for housing, partly because the new plan for the city centre includes less housing than before. The area of this particular expansion is, just as Kralingen, a polder with a clear structure of land and water, but this structure was not implemented in the urban plan.

Fig 5.1f Ommoord in the north eastern part of Rotterdam in 2014
Source: Areal Photograph of City of Rotterdam

Fig 5.1g Ommoord in 1918
Source: City of Rotterdam

1985 Prinsenland

Prinsenland is a more recent expansion of Rotterdam, where they returned to the concept of preserving the original polder structure. This has several advantages, of which efficient water management is the most important. The polder structure helps to drain the area, and it captures rainwater.

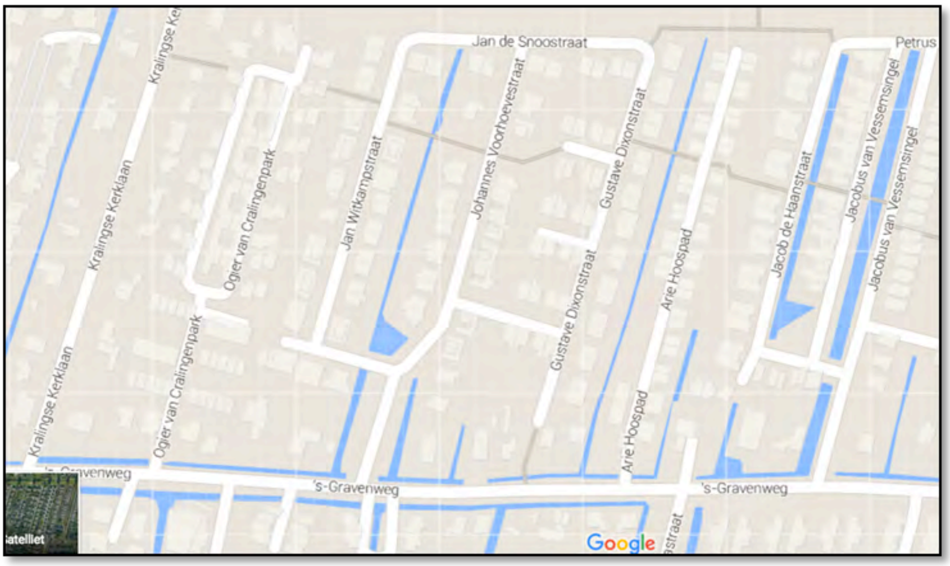


Fig 5.1h Street plan of Prinsenland in the eastern part of Rotterdam in 2015
Source: Google Maps

Fig 5.1i Prinsenland in 1850
Source: Van Veenmoeras tot Polderstad

These examples show how the subsurface played a significant role during the various stages of expansion of the city.

5.2 **Contemporary planning process**

5.2.1 Administration

In The Netherlands there are several governmental layers to be distinguished:

- National government
- Provinces
- Regions in Urban areas; in Rotterdam area: Stadsregio Rotterdam
- Cities / municipalities
- Waterboards (Waterschappen/ Hoogheemraadschappen)

The twelve provinces in the Netherlands make their own ‘structure vision’, based on the national governmental plans. Municipalities create their own vision and determine detailed ‘zoning plans’, both should fit into the national vision. In this way the Netherlands is organised in three levels/scales. Together with surrounding municipalities, Rotterdam is part of the Stadsregio Rotterdam. This is an official independent administrative body working on a regional scale with emphasis on issues like infrastructure and environmental policies. In 2015, the Stadsregio Rotterdam has been merged with Haaglanden, a similar administrative body for the greater The Hague area. Together they form the “The Rotterdam The Hague Metropolitan Area”.

Water boards (Waterschappen and Hoogheemraadschappen) are the authorities responsible for (ground)water management. They are responsible for the water related issues, such as the maintenance of the dikes and dunes, but also the discharge of rain- and wastewater. They are becoming more important in the future due to the rise in sea level. Rotterdam is a ‘water city’, on the banks of the river Maas, and building up some of its un-embanked areas. The part of the city that is protected by dikes consists of very low-lying land. This means that groundwater represents a huge problem as this has to be pumped out to keep the citizens dry. But when too much groundwater is pumped up, the land surface will subside even more and the problem escalates. Groundwater management is a job that requires expertise in hydrology and especially in hydraulics and the flow of water through porous heterogeneous media such as sediments.
The northern part of Rotterdam is managed by the Hoogheemraadschap van Schieland en de Krimpenerwaard. The part of the city south of the river is managed by the Waterschap Hollandse Delta. In recent years we have been swamped by a tidal wave of new policies on water management and spatial planning at regional, national and European level. And it is becoming more and more important to link the water issues to spatial development. Together with the water boards, Rotterdam has composed a Water Plan. This water plan is focussed on implementing spatial measures nowadays, in order to protect the city in the future.

5.2.2 Municipal planning system

Until the 1850’s, most of the city development happened as a result of private initiatives. But due to bad living conditions in the new city developments, the municipality took over. The organisation changed from ***permissive*** to ***strong***. Nowadays the organisation is changing again, to the category of ‘**balanced**’. Instead of leaving the development of new suburbs to the townships themselves, the City of Rotterdam is looking for collaboration with the private and commercial market in order to create a shorter period from planning to construction. This private orientation is caused by a shortage of capital for investment.
The City of Rotterdam wants to find private commercial partners that show a long time commitment to the city. These parties are supported by the municipality and combined in ‘networks’, for example a cooperative association or a foundation in which the municipality can participate. Together the parties can make arrangements for projects and for analysing the projects together. Then the mutual interests are identified and business cooperation is established. The parties become ‘shareholder’ of the city. In this balanced organisation is also more space for public participation. One example is ‘Stadsinitiatief’ (city initiative), this is a kind of competition where citizens could present ideas of which one will be launched.

Rotterdam harbour area

Rotterdam and its harbour are often mentioned together, as if they are part of the same organisation. This used to be the case; as the Rotterdam harbour was part of the municipality that made all the decisions. This changed 12 years ago: a new company was founded, the ‘Havenbedrijf Rotterdam’ (Port of Rotterdam), that became a private company. The government and municipality are the sole stakeholders (50-50). In this way a *balanced* cooperation is established.

In Rotterdam ownership of the land is divided by the City- and Harbour authorites, the Dutch State (mainly the waterways), private companies and citizens, see Fig. 5.2.2.

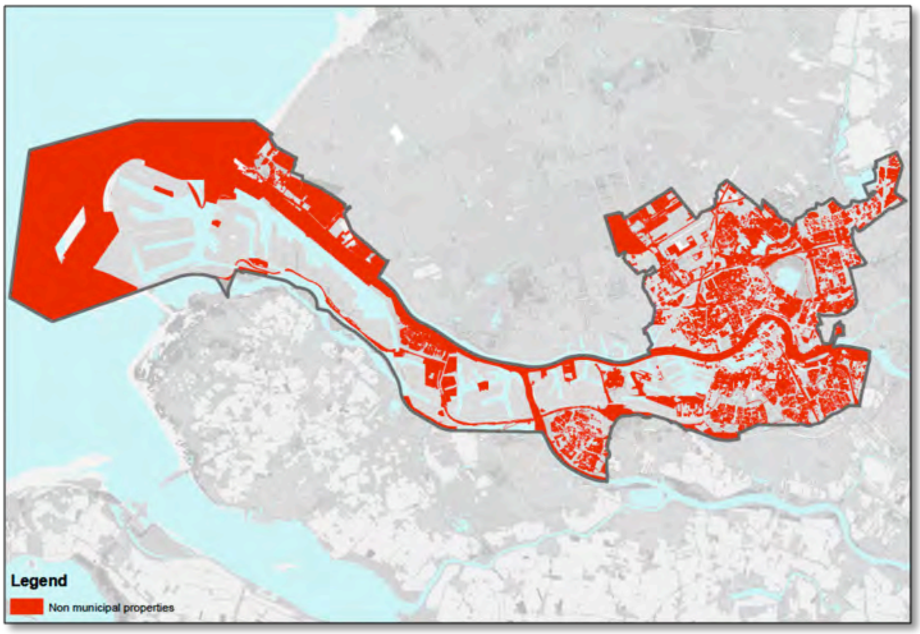


***Fig 5.2.2 In red colour the areas not owned by either city authority or port authority; mainly privately owned or owned by state (waterways). Non-coloured areas owned by municipality or port authority**.*
Source: Stadsontwikkeling Rotterdam

5.2.3 Heritage

Archaeology is one of the four sectors of the Cultural Heritage Agency of the Netherlands. The other fields are: Monuments, Landscape and Art. Rotterdam does not have a lot of monuments and protected landscapes. Since 1960 the city of Rotterdam has its own archaeological department: BOOR. The BOOR team does archaeological research in Rotterdam and also acts as archaeological advisor for a number of neighbouring cities in the Rotterdam Region. There is already a lot known about the archaeological history of the city and its surroundings. In 2007 the law on preservation of archaeology came into force. From then, each municipality became responsible for its own archaeology policy. In Rotterdam, the City Council in 2008 prepared a policy document on the Archaeology of Rotterdam. This policy implies an obligation to investigate the soil concerning archaeological finds prior to construction works being carried out. The intensity of the required investigation is dependent on the expected archaeological value of the site involved. This means that different areas have a different value or risk of yielding archaeological artefacts. BOOR assesses construction plans of building sites and advises how to conduct works in the subsurface in accordance with this archaeological policy. To preserve the archaeology in the subsurface and to avoid costly delays, it is important that archaeologists are involved from the start of city development projects.

5.2.4 How does planning acknowledge / consider the subsurface?

For the last 2-3 decades urban planners have not considered the subsurface as a very important factor that has to be taken in account whilst planning. The most relevant issues that were considered were: archaeology and soil pollution. These issues have/had to be considered because of national and international laws. Other themes like groundwater (levels and flow patterns), geotechnical capacities and subsurface space were only taken into account when evidently influencing the project, in stead of the project influencing the environment. All these issues are considered on a project scale. During the last five years attention for all themes in the subsurface is increasing. The fact that the subsurface has to be considered in city planning is more and more recognised.

The reason for this change is probably that bringing in the subsurface too late and/or in an unstructured way in the spatial development cycle has led **to financial complications and delays** more than once**.** The attention for all aspects of the subsurface is increasing from local, to provincial and national levels. At national level there is a Committee STRONG that is currently engaged in creating an integral structural vision on the subsurface.

5.2.5 Zoning plans: 3D and subsurface

The Dutch law implies that all the plans and visions should be accessible in digital format to everyone. This means that all documents need to be digitised, a process that is currently taking place at the various levels of administration. Structure visions / zoning plans presently are available only in 2D. There is only one municipality (Oud-Beijerland) in the Netherlands that is using a 3D zoning plan, although the subsoil is not truly integrated. This is something Rotterdam strives to achieve, see Fig 5.2.5. For several years Rotterdam experimented with 3D visualisation, first on project base and over the last four years also in a more structural way for the city as a whole.

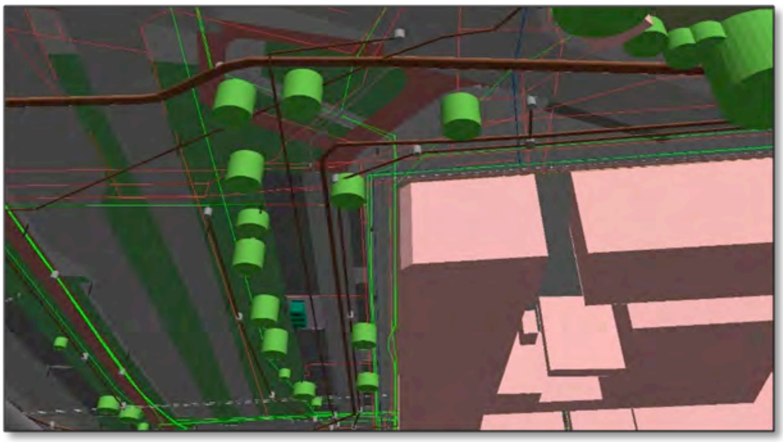


Fig 5.2.5 3D subsurface visualisation, green cylinders: visualisation of space occupied by tree roots.
Source: Stadsbeheer Rotterdam

A committee of the national government is currently working on a zoning plan/ structure vision for the Dutch subsurface. Instead of the 'first come, first served' principle, the subsurface usages should be evaluated and weighed against each other and furthermore also prioritised in order to make sustainable use possible in the longer term. The document is necessary in order to align the policies of the different authorities that are involved in subsurface usage. The Ministry of Economic Affairs is responsible for the deep subsoil, while the shallow subsurface falls under the authority of the provinces, municipalities and water boards.
Nowadays there are some rules regarding the subsoil, for example the already described Archaeology law. Other themes like groundwater (levels and flow patterns), geotechnical capacities and subsurface space are only taken into account on a project scale.

5.2.6 Ownership of the subsurface

Ownership of land extends to the subsurface and landowners are free to use the underground beneath their property. Cable companies have the right to lay cables in the subsurface but it is mandatory for them to declare their activities in the subsurface to the authorities. The Dutch mining law states that all resources (mineral resources, oil& gas) in the subsurface are owned by the Dutch state as far as these resources are present at depths exceeding 100 metres (for geothermal the law applies to heat extraction below 500 m).
Private landowners benefit from local revenues from the subsurface in various ways:

- The municipality invests in underground parking lots with a green park on top. This gives a much higher value to properties in the neighbourhood. In a TEEB (The Economics of Ecosystems and Biodiversity) study this mechanism is confirmed;
- Revenues can also come from the application of Shallow Geothermal Energy (energy from depths less than 500 m) in the subsurface. Private landowners don't have to pay for the use of this ecosystem service, see Chapter 6.3.2.

6. **Underground usage**

Previously city planners only considered planning at ground level and above ground level, see Fig 6a. These days underground specialists try to influence them in considering the subsurface as well, see Fig 6b. In order to visualise the contents of the “black box” of the subsoil we have adapted a multi-layered model for our public space volume.

Fig 6a Unilever plant in Rotterdam. Recently added office space above 19th century plant
Source: Peter Dorsman

Our present subsurface model consists of four layers. This subdivision is based on practical grounds (geology, usage) but also relates to the level of the supervising authority that is involved:

- From 100 metres onwards, in the deep layer where oils and gas is extracted, the Mijnbouwwet (Mining Law) is applicable. The Ministry of Economic Affairs is the supervisor and responsible for the management and owns the rights to oil, gas and mineral exploration and for geothermal activities at depth below 500 m.
- The provinces are responsible for the activities in the (drinking) water zone.
- The municipalities supervise the management of shallow zones.
- The zone above the drinking water zone initially consisted of one layer. At the request of the civil engineering department of the Engineering division of the City of Rotterdam this layer was split in two : the solid Civil Construction zone at the base and the soft Shallow Subsurface layer on t.

The information-density is different for each of these layers, see Fig 6c. The density of information is extremely high for the shallow layer: many different objects are present in this layer and for each object detailed information is available. The density of information is decreasing rapidly towards the deep layer.

With this division it becomes more clear that certain functions in the subsurface compete with each other for the same space (like roots of trees and pipes and cables) whereas other functions do not interfere with each other, see Fig 6d.

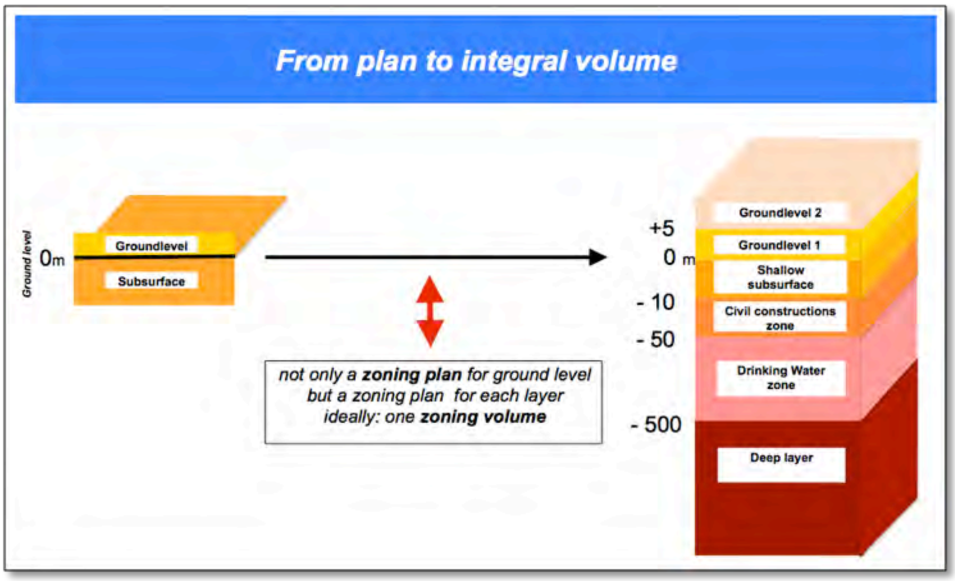


Fig 6b From single zoning plan (2D) at ground level to integral zoning volume (3D)
Source: Stadsontwikkeling Rotterdam

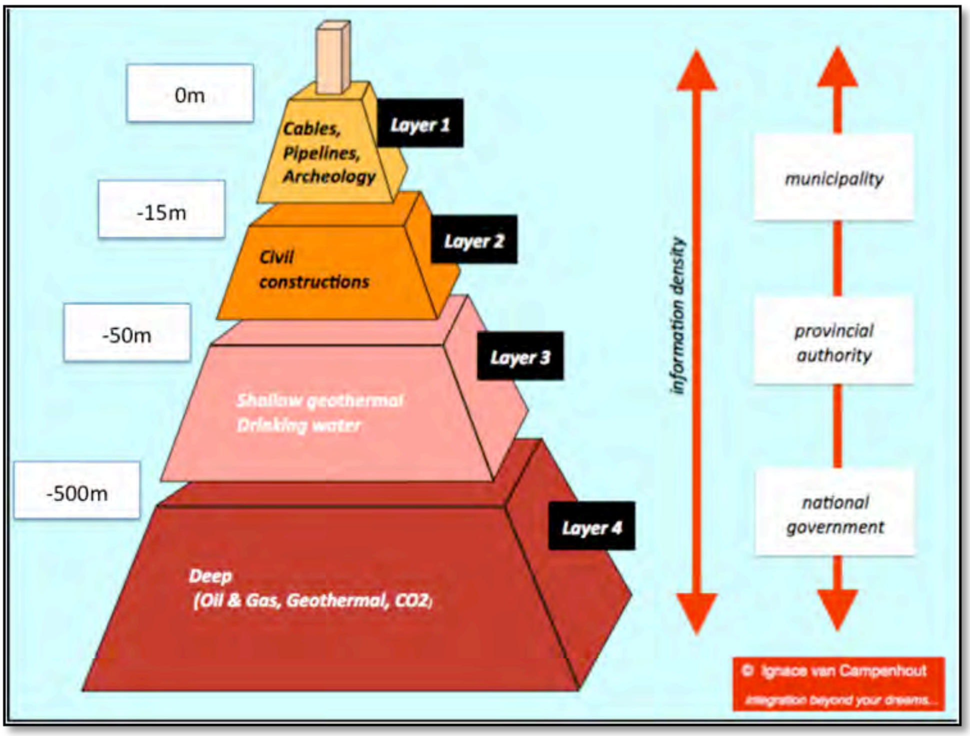


Fig 6c The four layer Rotterdam Subsurface model: from Cables to Carboniferous
Source: Stadsontwikkeling Rotterdam

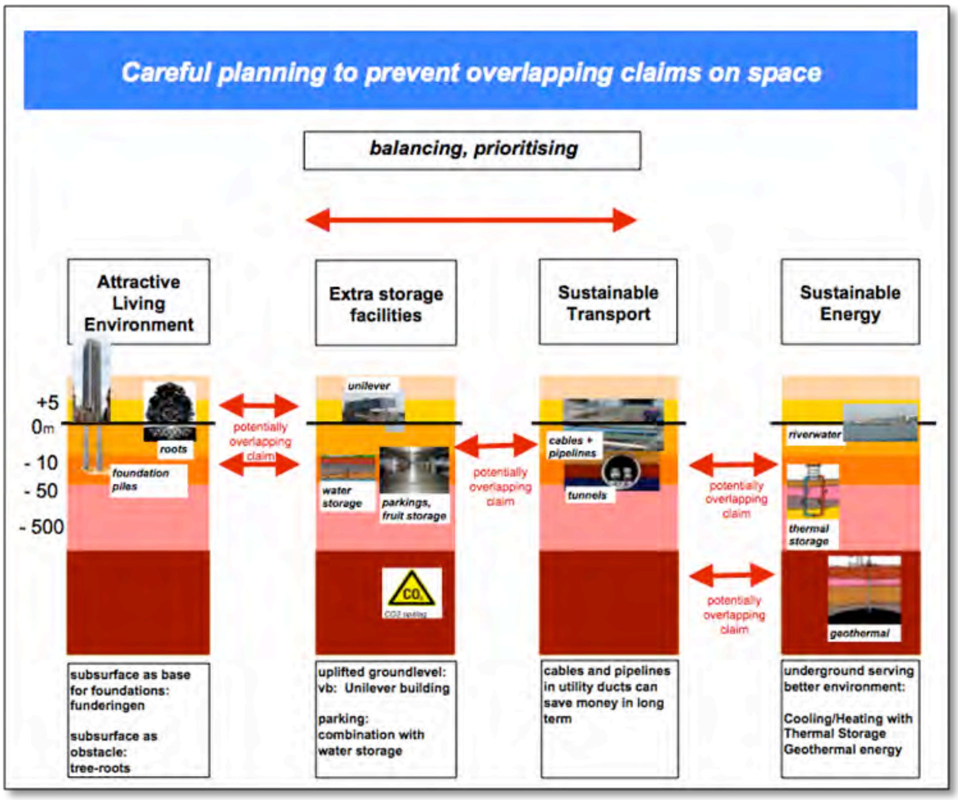


Fig 6d Preventing overlapping space claims
Source: Stadsontwikkeling Rotterdam

6.1 Layer 1: The Shallow Subsurface

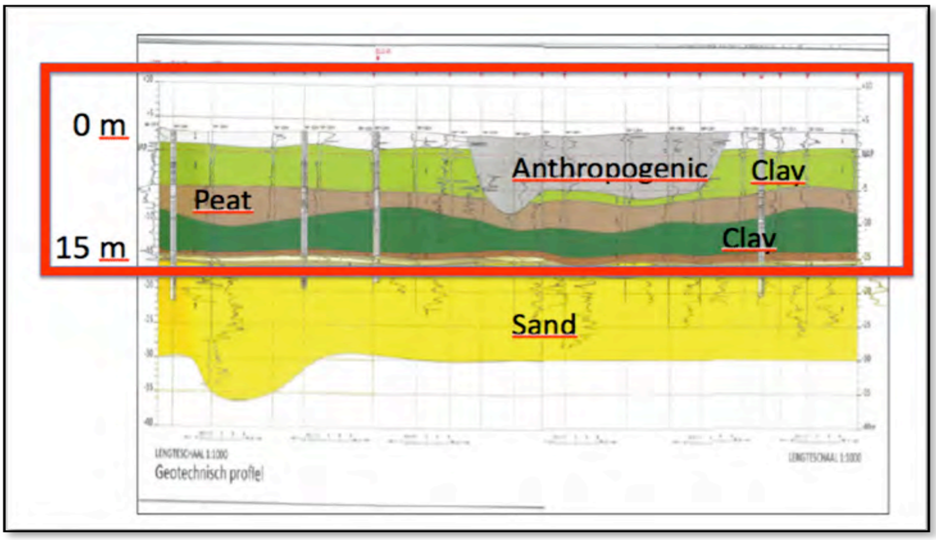


Fig 6.1 The Shallow Subsurface between 0-15m
Source: Stadsontwikkeling Rotterdam

6.1.1 Groundwater

As mentioned earlier in this report, Rotterdam is situated along the river Nieuwe Maas, with higher areas along the riverbanks of the Nieuwe Maas and polder areas further landward (both north and south of the river). There is a difference in groundwater regime as a result of the surface water of the polder areas being actively drained, see Fig. 6.1.1. The groundwater level in the urban polder areas is about one metre below ground level.

Besides the drainage by polder ditches, there is only limited management of groundwater levels. At locations where high groundwater levels are (expected to be) a problem, drainage tubes are used at the moment that a sewer system is replaced.

For construction of projects with underground components it is usually necessary to temporarily lower the groundwater level by extraction. Rules and permits of the water boards regulate this extraction.

In the (deeper) polder areas seepage of deep groundwater is an issue. Seepage occurs when the head of the deep groundwater is higher than the shallow groundwater level. In most parts of Rotterdam there is a separating layer of clay and peat (thickness: usually 10 tot 15 metres) between the deep and shallow groundwater, which limits vertical groundwater flow. In the deep polder areas the ground level is often lower than the head of the deep groundwater, combined with a relatively thin separating layer because of peat mining in the past. This leads to seepage and therefore to increased shallow groundwater levels. Because seepage water is usually brackish, with a relatively high content of iron and nitrates, it can also lead to a decrease in surface water quality.

Problems associated with (shallow) groundwater:

- High groundwater levels can result in damage of road constructions, water in basements, squashy gardens etc.
- Low groundwater levels can lead to rotting of wooded pile foundations of older buildings when the wood is (periodically) above groundwater level (oxidised conditions). This degradation can eventually lead to damage of buildings.
- Settlement of buildings without a pile foundation. This will reduce the distance between surface and groundwater level, which can therefore create groundwater problems.
- Groundwater contamination by industrial/commercial activities in the past

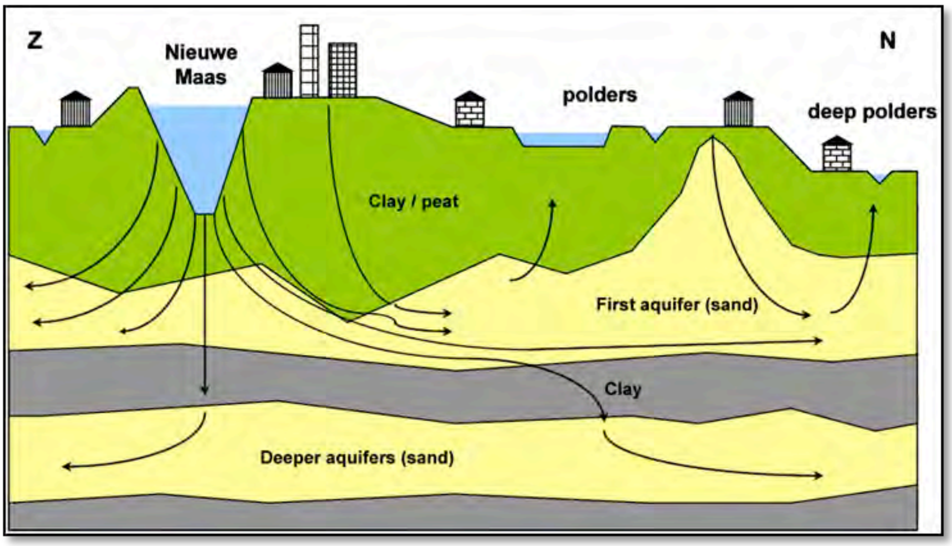


Fig 6.1.1 Groundwater flows in Rotterdam area
Source: Stadsontwikkeling Rotterdam

Climate change is likely to have an influence on groundwater levels by expected changes in rainfall. Rainfall events are assumed to become more intense and longer periods of drought may occur in the summer. The latter will lead to low groundwater levels, which can lead to degradation of older wooden pile foundations, increased settlement and possibly a shortage of groundwater available for vegetation. More intense rainfall will lead to a higher flux of (waste) water to be drained by the urban sewer system, which should therefore get a higher capacity in the future. To avoid rainwater to be drained by the sewer system, infiltration in the shallow subsurface is applied at places where both the groundwater level and the shallow subsurface stratigraphy / lithology are suitable for this purpose. Infiltration can take place from underground tubes, underground water storage basins, special road constructions, wadis, etc. In Rotterdam there are many examples of facilities for infiltrating rainwater in the shallow subsurface.

6.1.2 Cables and pipelines

Rotterdam has a dense network of cables and pipelines in the subsurface, see Fig. 6.1.2a, b and c. Everyone who wants to construct a pipe or cable in the subsurface of the public space of the city of Rotterdam needs a permit for this activity. House connections shorter than twenty-five metres in the city area are excluded from this rule, but in the harbour area for every activity of this kind a permit is required because of the special safety regulations in this area. A permit can be requested online. The procedure takes about 6-8 weeks. Specialists of the city of Rotterdam review each request according to several municipal regulations. Their job is to protect the safety of the inhabitants of the city of Rotterdam and to guard the compliance with applicable laws and regulations:

- Leidingenverordening Rotterdam: regulation for cables and pipelines Rotterdam (procedure)
- Telecomverordening Rotterdam: regulation for telecom-cables Rotterdam (procedure)
- Handboek leidingen Rotterdam: guideline cables Rotterdam (technical guidelines)

Operator	**Product**	**M' in Urban area**	**M' in Port area**	**Totaal**
Eneco	Public lighting	1.224.100	312.300	1.536.400
	Gas	1.763.100	336.000	2.099.100
	District heating	284.900	41.400	326.300
	Electricity	4.923.400	2.764.500	7.687.900
Evides	Water	1.763.400	419.600	2.183.000
Municipality	Gravity sewer	2.270.300	260.600	2.530.900
	Pressurised sewer	193.100	38.300	231.400
Other (pipes)	Gas, Oil, Kerosine, Oxygen, Nitrogen, etc	126.500	1.255.100	1.381.600
Other (cables)	Electricity	444.200	757.300	1.201.500
KPN	Telecommunication KPN	10.134.400	2.141.500	12.275.900
UPC	Telecommunication UPC	1.717.600	187.300	1.904.900

	Cable television	1.329.500	51.400	1.380.900
Remaining	Telecommunication	5.679.300	1.350.300	7.029.600

Fig 6.1.2a City of Rotterdam: cables and pipelines in numbers, length in metres. (August 2015)
Source: Stadsbeheer Rotterdam

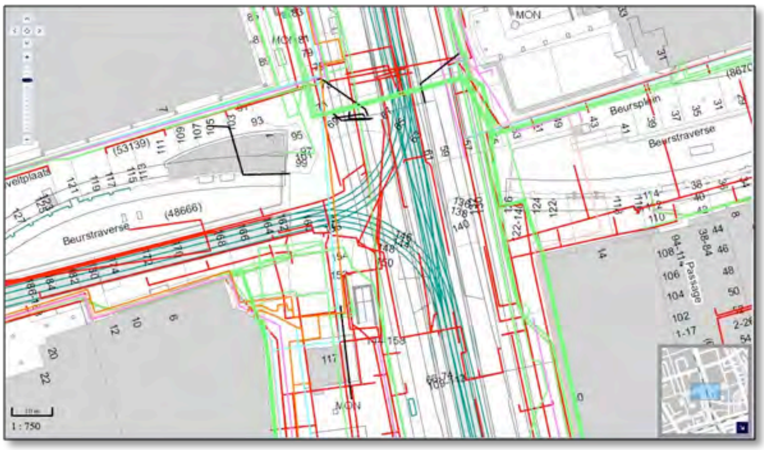


Fig 6.1.2b Cables and pipelines in the city centre (Coolsingel)
Source: Stadsbeheer Rotterdam
Legend:

Fig 6.1.2c Cables and pipelines in the harbour area
Source: GisWEB Stadsbeheer Rotterdam

Construction of the district heating, see Fig. 6.1.2d, was started after World War II and was halted in 1961, after discovery of gas in giant Groningen gas field in the north of the Netherlands. Ten years ago the network was extended to Nesselande, a new suburb in the NE of the city. At present 48.000 households are connected to the city heating network. Until recently the heat for the network was supplied by two gas plants. In order to fulfil the Climate Initiative ambitions, the heat produced by the gas plants is replaced by residual heat from a waste disposal plant in the harbour area (Dot 1 at Fig. 6.1.2e). A new pipeline network is under construction.

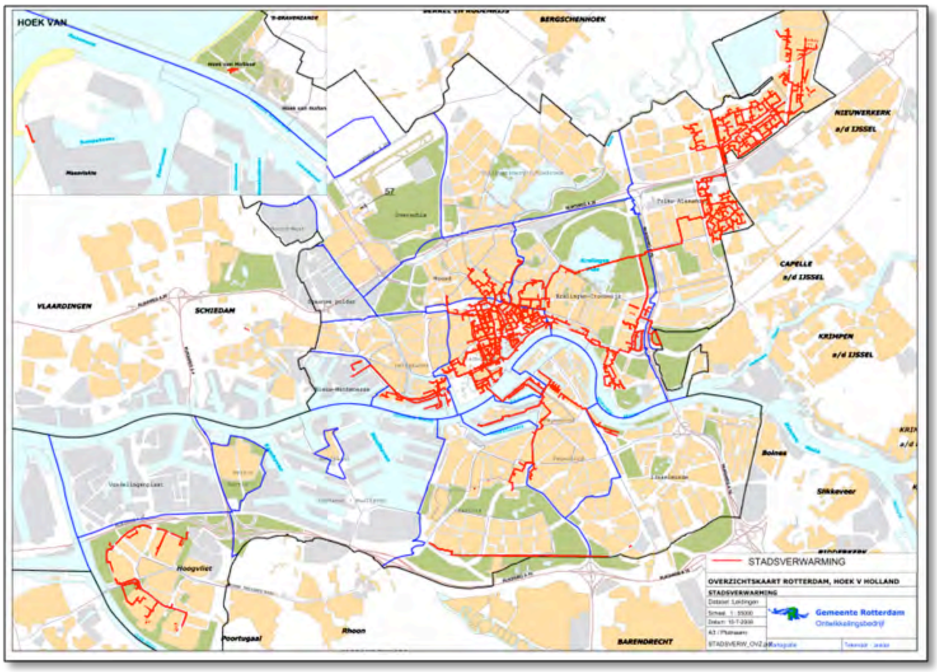


Fig 6.1.2d District heating network in red.
Source: Stadsbeheer Rotterdam

Fig 6.1.2e District heating sources and stations
Source: Stadsbeheer Rotterdam

6.1.3 Environmental

Throughout the industrial history of Rotterdam parts of the soil have been contaminated. The risks of this contamination to human health and the ecosystem, makes it necessary to gain insight into the soil quality. In addition, contaminated soils also hinder site development and spatial planning and therefore represents an economic factor.

Soil quality can be divided in diffuse contamination and local contamination. Diffuse contaminations are caused by a diversity of sources in a larger area such as heavy metals that leach from deposited debris. An overview of this contamination is aggregated in the Soil Quality Map. It provides generalised soil quality information per subarea and is based on data available within each area. The main objective for compiling this map is to enable the reuse of soil, see Fig 6.1.3a.

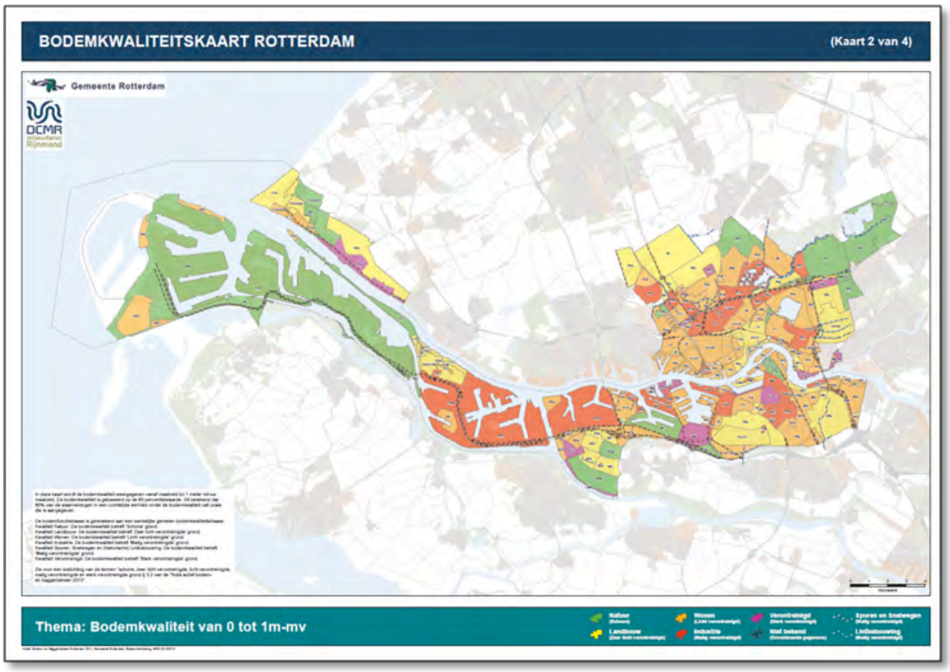


Fig 6.1.3a Soil quality map of Rotterdam for the zone 0-1 m below ground level. A similar map exists for the layer of 1- 2 m below ground level. Total amount of environmental drilling holes is 183.000, of which 95% is shallower than 3 metres and 5% penetrate the Pleistocene sand layer at around 15 m below mean sea level, see Chapter 6.2.
Source: Stadsontwikkeling Rotterdam

Local contamination is caused by historical activities at the site, which vary from gas plants to minor leakages of fuel. Because of the relationship between groundwater and soil, contaminated soil often implies contaminated groundwater. Because of the groundwater flow, contaminants in the aquifers could spread easily, creating environmental risks. In the city area of Rotterdam a regional top layer of clay and peat is present, which restrains large-scale transportation of contaminants to the underlying groundwater layer. This protecting top layer of clay and peat layer is absent in the port area of Rotterdam. Combined with the presence of large sources of pollutants this has lead to contamination of the groundwater layer in the port area. Collective groundwater management in this area is a potential way to prevent further spreading of the contaminants.
Contamination may lead to remediation of areas of the upper part of the soil and/or the groundwater. This can be obtained by removal or natural attenuation as well as reducing risks by isolation of the contamination. Over time Rotterdam has build a large database of soil quality parameters of both top soil layers and aquifers, which can now be used to roughly indicate the soil quality in an early stage of urban planning. This knowledge results in taking into account the occasionally considerable costs and time-consuming procedures in advance. Gathered data of the soil is available by Geographic Information Systems (GIS) and includes (among others) soil composition, accredited chemical sample analyses of ground and groundwater, historical activities, soil diggings, excavations, soil investigations and remediation plans. Fig 6.1.3b shows an example of data of monitoring wells in a small area of Rotterdam. The total amount of groundwater monitoring wells in Rotterdam is around two thousand.

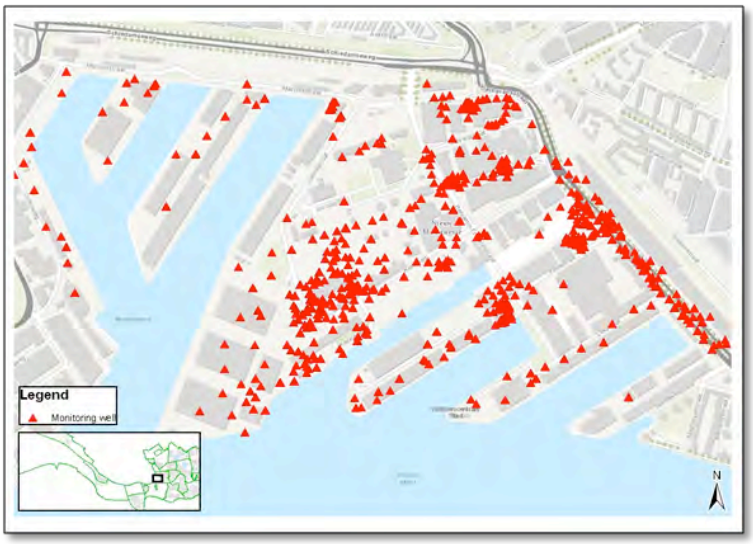


Fig 6.1.3b ***Monitoring network of environmental wells in the Stadshavens area***
Source: Stadsontwikkeling Rotterdam

6.1.4 Archaeology

The purpose of this map is to make visible the areas of archaeological interest. The archaeological finds and expectation map, see Fig 6.1.4, forms the base for drawing up a policy map, which can then be used for monitoring spatial development plans on the possible presence of archaeological values. In this way, archaeology can be taken into account during city development projects. See also chapter 5.2.3.

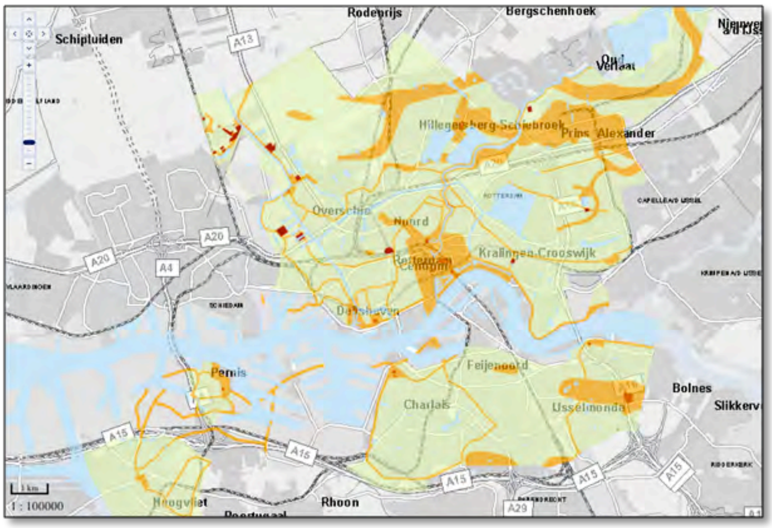


Fig 6.1.4 Archaeological finds and expectations map. Areas with high archaeological expectation in orange. Archaeological finds in red.
Source: BOOR, Stadsbeheer Rotterdam

6.1.5 Unexploded devices from World War II

Fig 6.1.5a Rotterdam after the bombardment in 1940.
Source: City of Rotterdam

During the Second World War the city of Rotterdam was bombed over two hundred times. Most of the bombardments were small but also a few large bombardments took place. The best-known bombardment is that of May 14th 1940 which destroyed a large portion of the centre of the city. Now, seventy-five years later, unexploded bombs from the Second World War can still be found in the subsurface of the city. To address this problem a large scale historical investigation is in progress. The recent opening of archives have revealed interesting information that helps to locate the areas within the city and harbour area with big risks of finding unexploded bombs / ordnance.
To assure that developers of construction projects in the risk-areas are aware of this possible danger a map is available in the City where locations can be checked on risks, see Fig 6.1.5a. Also during the process for a building permit, the project teams are informed of this possible danger.
The policy of the city of Rotterdam is to locate, search and destroy the unexploded bombs only if a project is planned in the neighbourhood of a possible bomb location. If there are no projects / activities it is not obligated to remove the bombs, which are usually located 8-10 metres below street level, because of high costs and very small chances of an explosion).

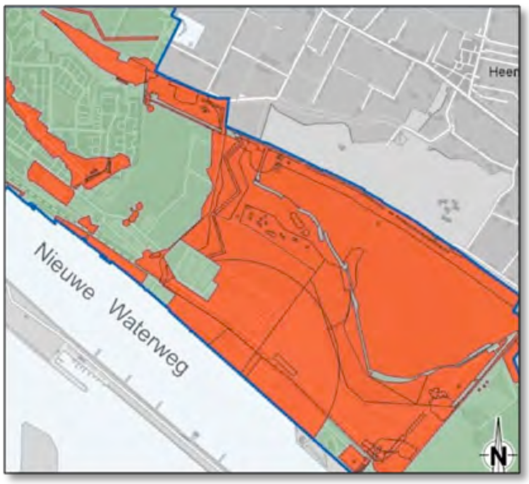


Fig 6.1.5a Unexploded devices: Example of Risk map. Risk sectors in red.
Source: Stadsbeheer Rotterdam

6.1.6 Ecology: Nature map of Rotterdam

Fig 6.1.6a GIS analyses: Potentially good habitats for ecological runways for fauna
Source: Stadsontwikkeling Rotterdam

Nature as buffer
Nature areas in a city will provide biological processes which are necessary for cooling, water buffering, wave flattening, shadowing and food supplies. Nature areas in a city provide part of the biodiversity of a country in species of plants and animals with an important role in crops & food, medicines and ecological prey/predators relations. The challenge is to better connect the green areas in the city as well as in the region, see Fig 61.6a.

Climate change: Heat island effect of cities and developing future temperatures
The Urban City and the harbour areas are and will be too hot in summers for comfort and good health of their citizens and workers. This is due to a great areal extent of pavements and buildings, stony areas which have a high capacity to collect and maintain heat, see Fig 6.1.6b. In Rotterdam a wide river runs through the inner city. This gives coolness during the day but during the night it gives warm air in the surroundings due to a slow cooling down of the high volume of water.

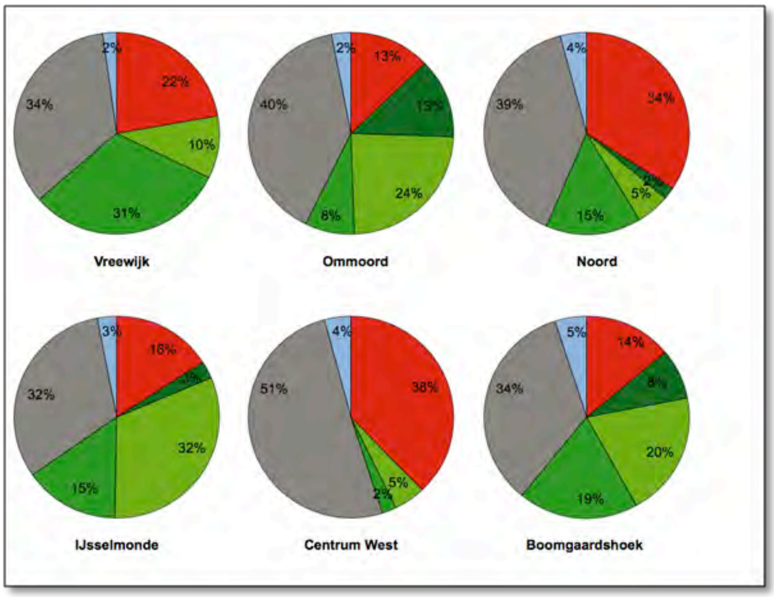


Fig 6.1.6b Various districts of Rotterdam showing distribution of buildings (red), pavement and roads(grey), green and water (blue).
Source: Stadsontwikkeling Rotterdam

Green areas cool down much faster and are therefore of great benefit for urban districts. Cool air will spread out via green streets and parks. The soils in the green areas provide water for evaporation, which is the main cooling process for green areas. See Fig 6.1.6c.

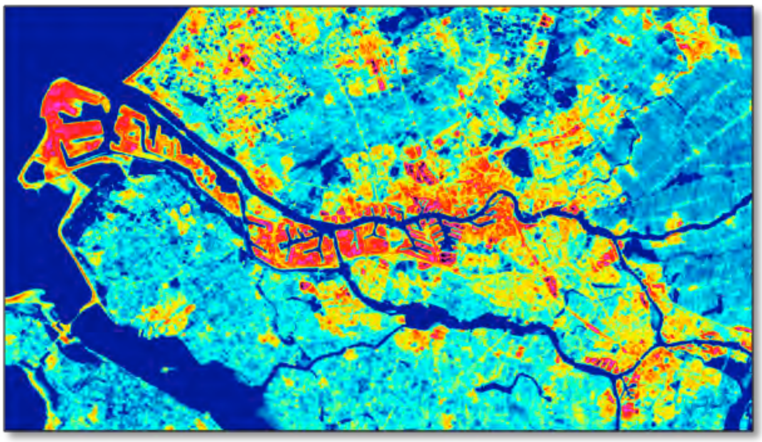


Fig 6.1.6c Heat islands in red and purple.
Source: Stadsontwikkeling Rotterdam

6.1.7 Urban agriculture

Urban agriculture (UA) is a global trend due to the benefits that it can bring to urban environments. The range of benefits is very diverse, from environmental (storm water mitigation, urban cooling, circular food supply, reducing food transport, etc.) or social (food security, education, recreation, physical activity, improvement in healthy eating, improved social cohesion etc.) to economical (income generation, added real estate value, supplying niche markets etc.). In the context of the Netherlands, a highly industrialised country, food security is not currently the main motivation behind the practice, but rather the effort to increase awareness of the importance of local food and its impacts. Rotterdam is a pioneering city in terms of UA, hosting more than one hundred active initiatives besides the allotments, see Fig. 6.1.7a. The city of Rotterdam stimulates urban farming inside and around the city by connecting food producers to local markets and restaurants.

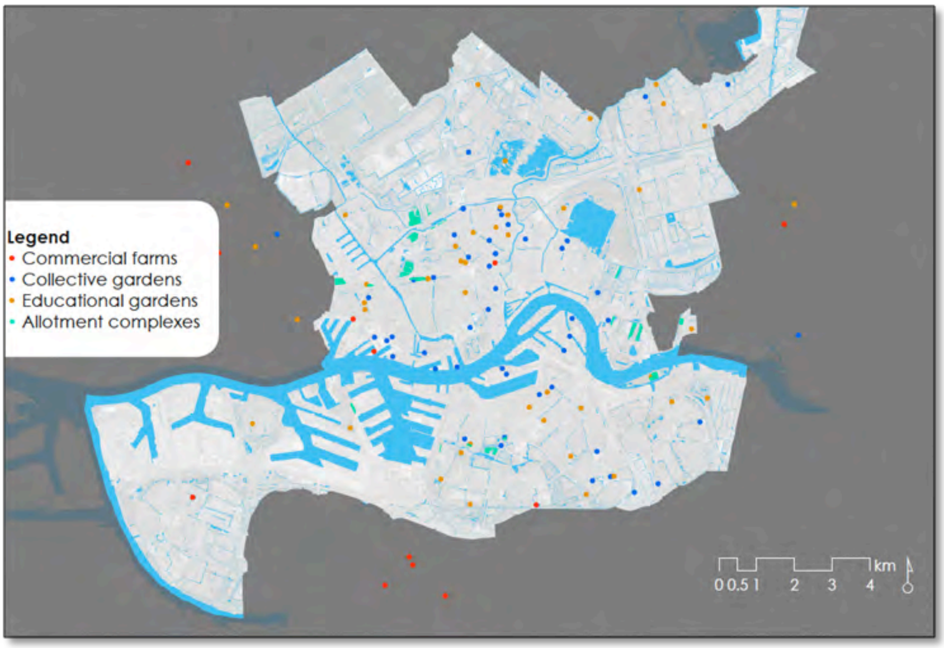


Fig 6.1.7a Urban agriculture in Rotterdam
Source: Stadsontwikkeling Rotterdam

One of the main issues of the city is the need for non-polluted soil. Approaches for solving this issue vary from mixing the existing soil with compost and clean soil to placing an entire top layer of clean soil, as they did in the largest urban farm in Rotterdam, “Uit je eigen stad”. The subsurface is important for growing food but in the absence of soil alternatives are present, like hydroponics and aquaponics (growing plants in water based nutrient solutions).

Looking beyond the subsurface, Rotterdam has nine hundred hectares of flat roofs possibly suitable for urban agriculture, which could be converted to green spaces (rooftop farms or green roofs) to the greater benefit of the city. Atop the Schieblock, a lightweight soil structure has been created using plastic shells, cloth, volcanic rock, soil and compost, which is now the largest soil based rooftop farm in Europe, see Fig 6.1.7b. On a larger scale, the “Rotterdam Dakpark”, a 1000 m long and 5 0m wide park built on top of a shopping mall shows potential of converting some of its surface to food production, as it currently grows a few herbs and fruits and hosts a greenhouse restaurant. These approaches can be seen as literally expanding the subsurface to new heights.

During the first stage in evaluating the potential for urban agriculture information a GIS analysis can answer questions like “where are the unpaved / build areas?” and “which flat rooftops are strong enough for agriculture?”.

Fig 6.1.7b Rooftop farm Schieblok, central Rotterdam
Source: Kees de Vette

A local study has determined that, based on GIS data, besides the already mentioned nine hundred hectares of flat roof area, also 3.900 hectares of land (excluding private lands) with no serious contamination are very promising areas for establishing urban agriculture initiatives. Such areas were determined by identifying lands with access to soil as well as with minimum levels of contamination (where data was available). The suitable rooftops were identified using roof angles and surfaces in combination with building function and age (as an indication of roof strength). Even converting a small percentage of these surfaces into green spaces would have considerable impacts in the city. Many plots scattered around Rotterdam can benefit from the added functionality brought about by urban agriculture.

6.1.8 Trading Soil

In a city the size of Rotterdam a lot of construction is taking place during which the excavated soils are transported. The soil layers are removed at one location and re-used at another. The municipal land bank is the matchmaker in this process of supply and demand, see Fig. 6.1.8a.
The land bank of Rotterdam has an average turnover of 1.000.000 tonnes of soil/year. From this amount of soil 200.000 tonnes directly matched with another project (Fig 6.1.8b, red locations) and 100.000 tons could be reused after temporary storage (Fig 6.1.8b, blue locations). For the surplus of 700.000 tonnes the soil bank creates demand projects (Fig 6.1.8b, green locations).

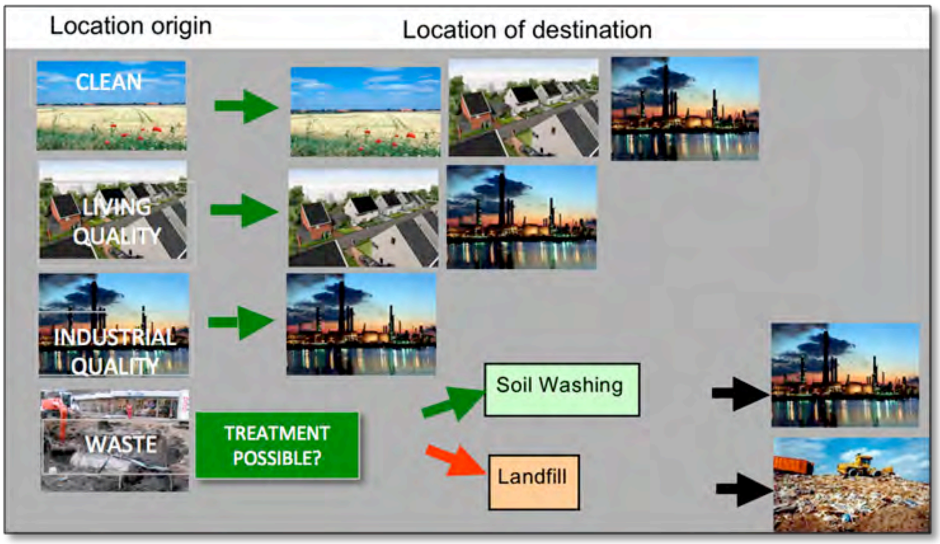


Fig 6.1.8a Trading soil: the match making decision model.
Source: Stadsontwikkeling Rotterdam

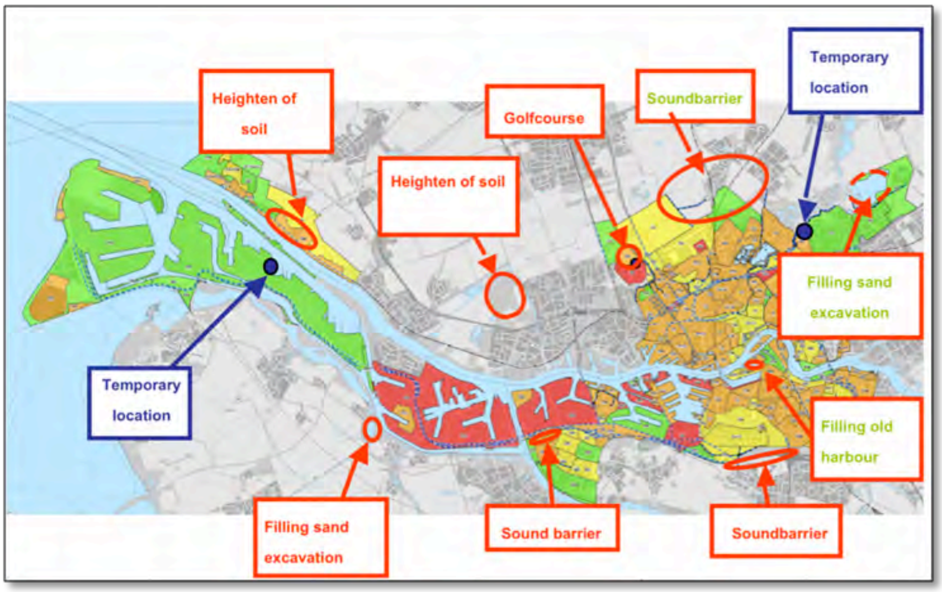


Fig 6.1.8b Blue locations: Location for temporary storage; Red locations: Present demand locations; Green locations: Demand locations in development Background map shows soil quality map (see chapter 6.1.3)
Source: Stadsontwikkeling Rotterdam

Re-using soils: present policy
The Dutch Soil Quality decree stipulates that it is not allowed to deteriorate soil quality at a given location. One is not allowed to re-use soils of a poor quality area in an area where soil quality is qualified as high. The basis for this policy is the soil quality map of Chapter 6.1.3. Also by creating a demand project for the surplus you must create several projects for the intake of soil of the various qualities. For example: Filing a sand excavation is possible with soil of poor physical quality. And soil for a fly-over for a road needs high physical quality.

In Fig 6.1.8c the cost reductions for the city of Rotterdam are presented. The green arrow shows a perfect match. The “River city” project in this figure had a supply of soil than can be directly reused in a simultaneous “Demand” project. River city has no costs for disposal of the soil, while the Demand project has a free supply of soil.

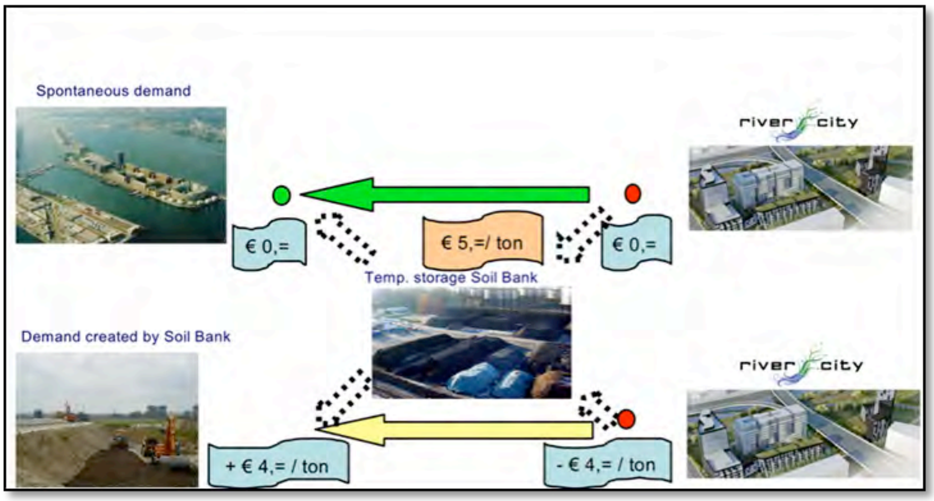


Fig 6.1.8c Trading soil: match making.
Source: Stadsontwikkeling Rotterdam

The yellow arrow represents the situation in case a direct match is not possible. The Soil bank of Rotterdam must create a demand project for the re-use of soil. The project with a surplus of soil must pay for the demand project. This money is used to finance the demand project. The dotted arrows represent the situation in when temporary storage is required. This option costs extra money. You must pay the storage place, and extra transport and handling. The activities of the Soilbank of Rotterdam are financed with mediation costs. These cost are paid by the surplus project and are about € 0,50 per m3 soil. On a yearly basis about 6 million Euros is saved as a result of good matchmaking.

6.1.9 Peat and clay

In the Rotterdam region for centuries dried peat was an important source of energy. On a large scale peat was dug out and dried. Sometimes several metres of the top layer excavated and land changed in lakes. Some of these man made lakes are still present in the northern part of Rotterdam (Kralingseplas) With help of windmills and later steam engines most of these lakes were transformed into land again at the end of the 19th century. One of this so-called “droogmakerijen” (dry polders) is the Zuidplaspolder (6,7 m below sealevel) just east of Rotterdam. Clay was used as building material for dykes. It is still used for soil improvement in agricultural processes. In the Rotterdam region clay was also used for the production of bricks. Several brick factories existed alongside the Hollandsche IJssel, a river in the Rotterdam region. In the 17th century the brick industry flourished in this region. This remained an important branch of industry but in the 19th century followed a strong downturn. The reason for this was the canalisation of the Hollandsche IJssel, which reduced the amount of sludge left in the river. In the early 19th century, there were still some thirty factories along the Hollandsche IJssel. But in the early 20th century there were only five left. The bricks produced by these plants exhibit a distinctive yellow colour and they are relatively brittle.

6.1.10 Challenges in the Shallow Subsurface

Ground water level (Described in Chapters 1.3.1 and 6.1.1)

Soft soils and ground water: at minus 4 m below mean sea level a soft peat layer of 1- 2m thick is present. Layers above and below consist of soft clays. This package is subsiding continuously; in order to maintain the requested balance between groundlevel and groundwater level it is necessary to decrease the ground water levels. Houses build before the 2nd Word-War are vulnerable to low groundwaterlevels: Older houses are founded on wooden piles instead of concrete piles. These wooden foundations reach up to 10-50 cm below the lowest naturally occurring groundwater level. The lowering of the ground water level can result in exposure of the upper part of the wooden piles above the groundwater level. When the wooden foundation piles are for a longer period above groundwater level, the chances for oxidation and the effects of micro-organisms increase: the piles start to rot and subsequently the rotten piles cannot support the weight of the houses any longer: houses subside, crack and risk partial or total collapse, see Fig 6.1.10a. Repair of the foundation is very costly, up to 60.000 euro /house. Private owners can get in financial problems when their house is getting a negative value and also for professional owners it might be hard to maintain the value of their properties at an acceptable level.
In Rotterdam there is a citizen’s information point for foundation issues (funderingsloket) where people can gather information on this issue. They can get a relatively cheap loan to help them to finance the

foundation repair. About 6.000 houses in Rotterdam encounter foundation problems in various stages. (in the Netherlands it affects about 250.000 houses)
One of the solutions is to influence the groundwater level. In Rotterdam it is still an issue for study and progress is made slowly, because the responsibility for groundwater is shared amongst several authorities (municipality, water board), see Chapter 5.2.1. There is also a research centre for foundation problems (KCAF).

Fig 6.1.10a Drievriendenstraat in the Centre of Rotterdam, June 2013. 19th century houses collapsed due to foundation problems.
Source: RTV Rijnmond

Maintenance of infrastructure
The maintenance of roads and underground infrastructures such as sewer pipes and drinking water pipes, utility ducks, telecom cables and the city heating network, is a challenge in Rotterdam due to the soft soils in the area, especially in areas with thick layers of peat and soft clay. The settlement problems have big impact on the cost of construction and maintenance of roads, highways and rails way. In Rotterdam the maintenance of roads and sewer pipes is the responsibility of the maintenance department of the municipality (Stadsbeheer Rotterdam). Programmatic maintenance has been done for many years now but due to cost reduction taking place over the last years a new `asset-management' methodology will be introduced in the maintenance department. This asset management is a more risk-based form of maintenance. Another possible solution to reduce costs for maintenance is to improve the geotechnical quality of the topsoil layer by adding lime or other stabilising materials to the soft soils. The use of these "smart soils" will be the subject of research in the coming years. "Smart soils" can also reduce costs by preventing leakage from sewer pipes.

Tree roots and cables competing for the same subsurface space
Some years ago the Meent, a street in the centre of Rotterdam was redeveloped. The street used to be known for the presence of a number of employment agencies and had a low quality image attached. Over the past years the employment agencies were slowly replaced by expensive boutiques. The city council decided to upgrade also the exterior of the street and to turn it into an attractive yuppie style-shopping street. Architects and city planners came up with their interpretation of an attractive street where car parking was restricted to one side of the road and where a row of trees was designed on the other side, adding to the few trees that were already present, see Fig 6.1.10b.

Fig 6.1.10b The Meent, a street in the city centre.
Green dots: existing trees. Why not planting more trees?
Source: Stadsbeheer Rotterdam.

This certainly looked as an improvement. However what city planners did not take into account was that below the surface cables and pipelines already occupied the space necessary for the roots of the trees, see Fig 6.1.10c. Redirecting the cables appeared too expensive: the consequence was that the extra trees were eliminated from the final designs.

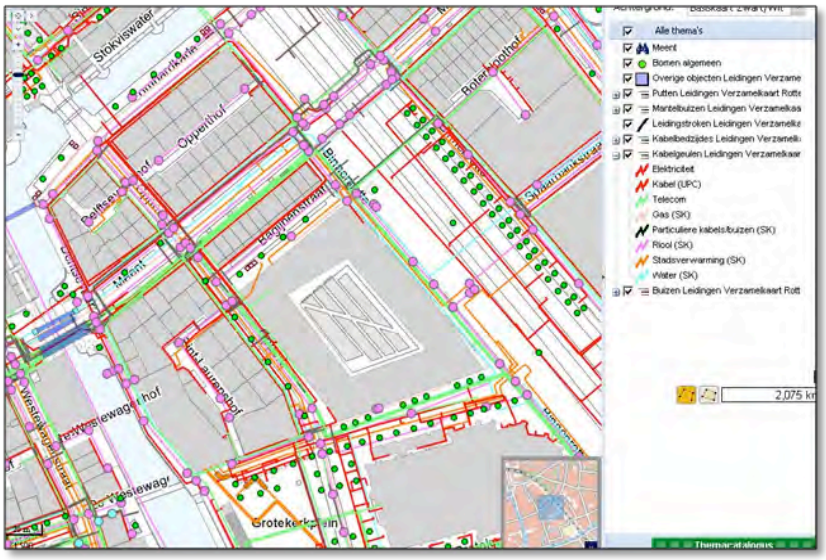


Fig 6.1.10c The Meent, approximately 1 metre below street level:
***cables and pipelines*: no space for extra trees**
Source: Stadsbeheer Rotterdam

Sink holes
Unequal settling of the soil can damage drinking water pipes. After many years this will result in leakage. This may cause sinkholes to form and this happens a few times a year. Sometimes a car encounters a problem and in 2013 a girl entered a sinkhole whilst cycling in Rotterdam-Noord.

6.2 Layer 2: The Civil Construction Zone

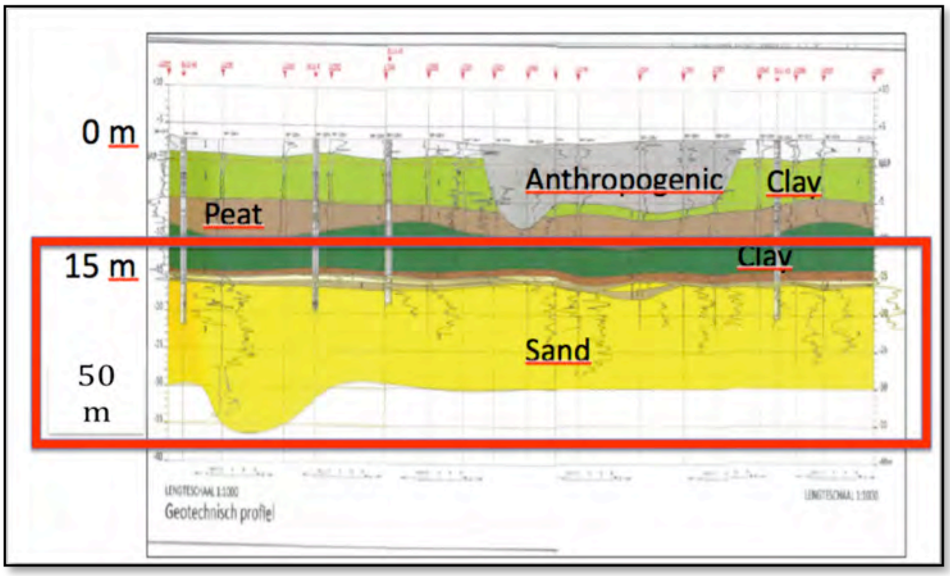


Fig 6.2 The Civil Construction Zone between 15-150 m
Source: Stadsontwikkeling Rotterdam

6.2.1 Geotechnical aspects

Geomorphologically, Rotterdam is located in the valley of the Maas river, a flat plain that is characterised by its vulnerability to flooding. A predominant process has lead to the development of this delta: the fluvial process. The fluvial sediments rest on top of the Pleistocene sand layer, which has been deposited by marine processes, see Fig 6.2.1a. The fluvial sediments consist of clay, peat and sand. Generally the transition between Pleistocene and Holocene is characterised by the presence of a layer of peat. The depth of top of the Pleistocene sand is variable and it slopes gently towards the sea in the west, see Fig 6.2.1b. The Pleistocene sand layer serves as a solid bed for foundation of (house)piles, and for the positioning of tunnels. It is a basic requirement that each construction carried out in the city of Rotterdam needs a detailed geological-engineering study. The construction of sheet piling for parking garages, the construction of metro stations, and the extension of the port zones, are just some examples of such projects.

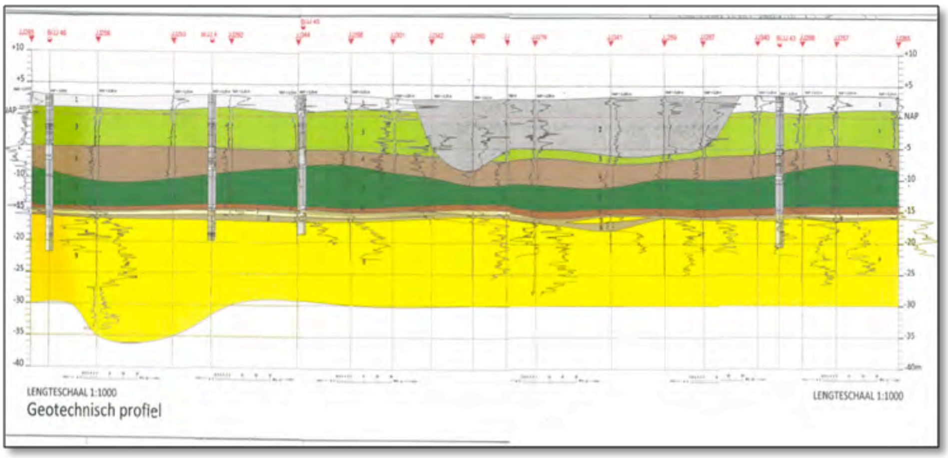


Fig 6.2.1a. SW-NE Geological cross-section. Depth in metres. Yellow = Pleistocene sand layer. Brown = peat, green = clay and grey = anthropogenic
For further information on the anthropogenic layer see chapter 3.1
Source: Stadsontwikkeling Rotterdam

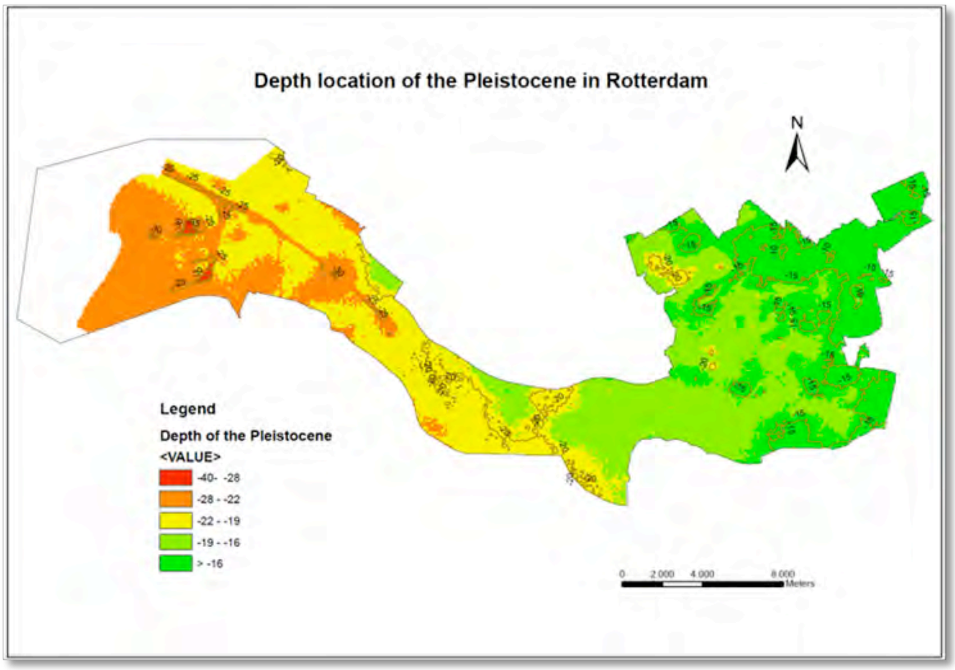


Fig 6.2.1b Top Pleistocene depth map. Depth in metres below mean sea level. The Pleistocene sand layer is used for foundations of the buildings.
Source: Stadsontwikkeling Rotterdam

6.2.2 Foundation of buildings

The Pleistocene sand layer is used as the foundation layer for civil constructions. In the City Centre only few old buildings remain. These buildings are based upon wooden piles. All new buildings are based upon concrete piles, see Fig 6.2.2a and Fig 6.2.3a.

Fig 6.2.2a Centre of Rotterdam, reconstructed after Second World War in green: concrete pile foundations; in brown: wooden pile foundations (historic buildings)
Source: Stadsontwikkeling Rotterdam

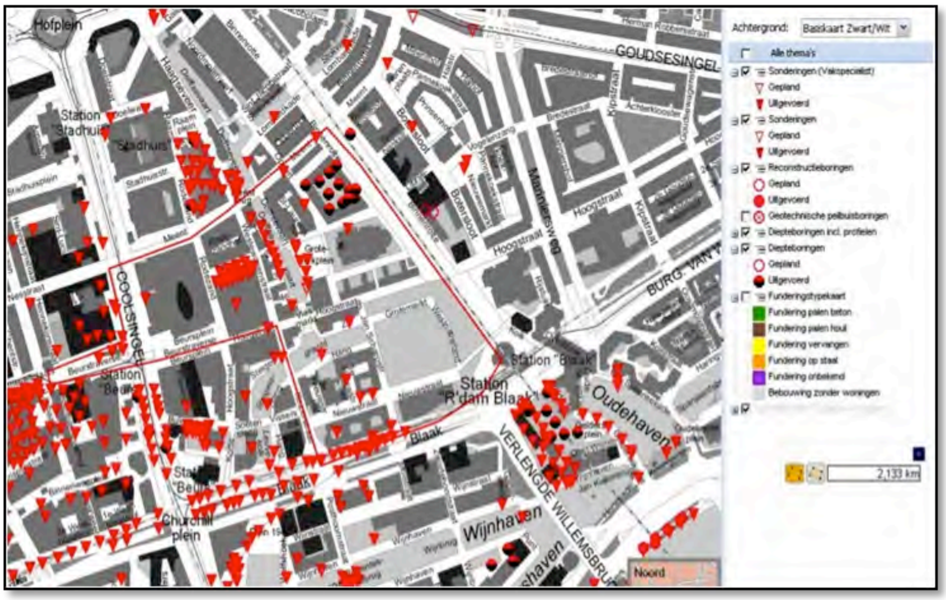


Fig 6.2.2b Centre of Rotterdam. Total amount of geotechnical boreholes: 6000. Total amount of CPT's: 65.000. Circles = Geotechnical boreholes; Triangles = Cone Penetration Tests (CPT).
Source: Stadsontwikkeling Rotterdam

6.2.3 Infrastructure: Train

In the 1870's the Rotte river that gave Rotterdam its name was muted in favour of the construction of a railway air track for the railway connection from Rotterdam to Breda.

Fig 6.2.3a Centre of Rotterdam. Wooden piles used for the construction of the railroad air track over the trajectory of the former Rotte river.
Source: City of Rotterdam

Fig 6.2.3.b The railroad air track constructed above the muted Rotte river.
Source: City of Rotterdam

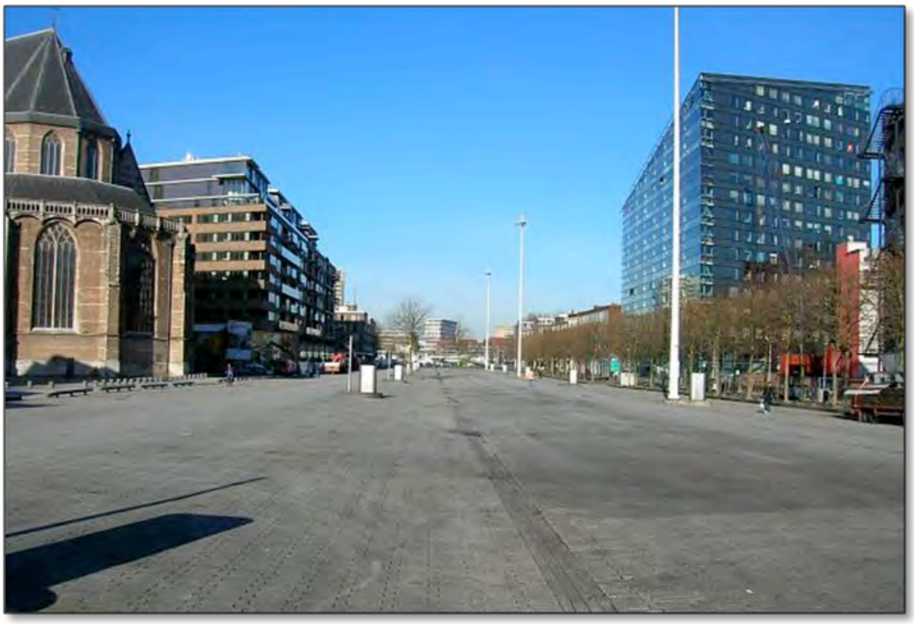


Fig 6.2.3c Same trajectory as on previous photographs: from river to air track in 1870 and from air track to empty space in 1990. Every Tuesday and Saturday this area used for the city-market. Railroad track is currently in a tunnel below this surface.
Source: City of Rotterdam

6.2.4 Infrastructure: Metropolitan railway

In 1968 Rotterdam was the first Dutch city to open a metro system. Currently the metro system consists of a NS and an EW line.

Fig 6.2.4a The city aorta: the Coolsingel. In 1966 construction of the Metro started.
Source: City of Rotterdam

The tunnel was largely built with the open excavation method. The trajectory chosen for the tunnel was the Coolsingel: a former canal that became the main traffic aorta through the centre of the city after the Second World War.

Fig 6.2.4b The Coolsingel in 1890
Source: City of Rotterdam

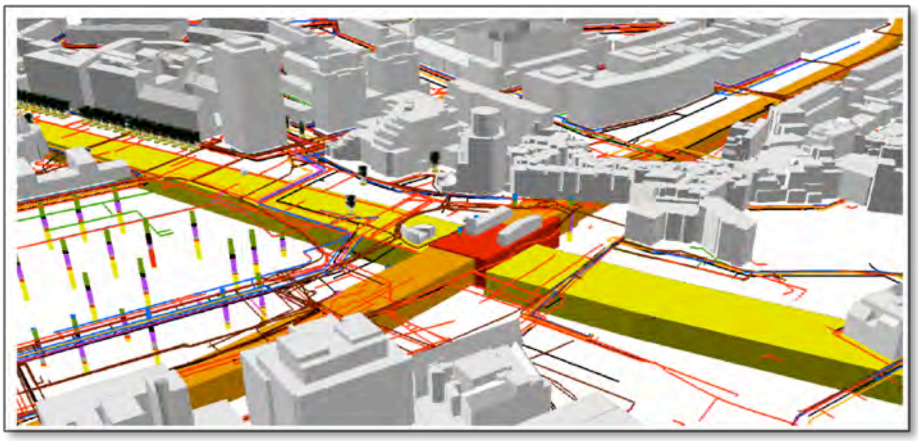


Fig 6.2.4c The Coolsingel in 1890. N-S Railroad tunnel in yellow and the E-W Metro trajectory in orange; also showing cables, pipelines and boreholes.
Source: City of Rotterdam

6.2.5 Infrastructure: Cars

De Maastunnel was constructed between 1937 en 1942, together with the partly deepened "s Gravendijk tunnel trajectory. It still is a busy aorta through the centre of Rotterdam, and residents complain about the noise- and pollution levels.

Fig 6.2.5 The Maastunnel
Source: City of Rotterdam

6.2.6 Parking

In the city are many municipal parking facilities. In the centre these parking lots used to be constructed at and above ground level. Over the past years parking lots were made underground. In the City Centre there are currently 4 large underground parking lots with a joint capacity of 3.000 cars. The City Council wants to make the city more liveable but also still accessible for cars. The parking lot "Kruisplein garage", is over 20 m deep, see Fig 6.2.6a. On top of the garage a green entrance to the city centre from the central railway station has been constructed.
Not every area is very suitable for these underground constructions because of the water pressure of the groundwater and the risks for breaking the bottom of the building pit (uplift).

Fig 6.2.6a Kruisplein parking, adjacent to Central Station
Source: Stadsontwikkeling Rotterdam

Near the Central Station a large underground bicycle parking was constructed recently. It can accommodate over five thousand bicycles, see Fig 6.2.6b.

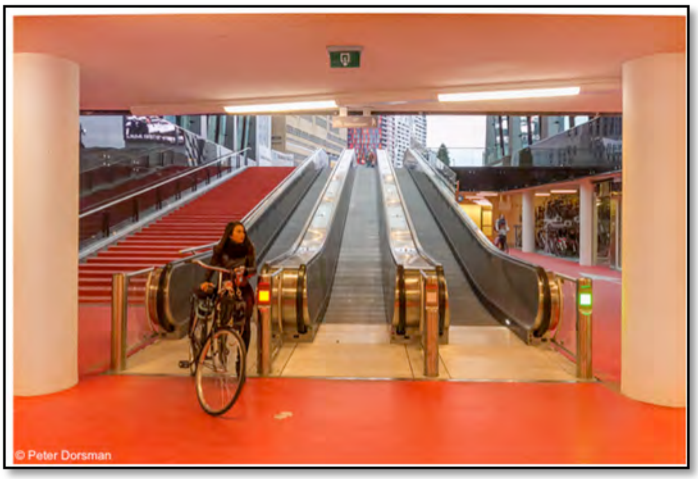


Fig 6.2.6b Parking facility for 5100 bicycles, adjacent to the Central Station
Source: City of Rotterdam

6.2.7 Waterstorage

In the coming years, Rotterdam will have to store more rainwater than is currently the case. The Municipal Sewage Plan already contains many relevant measures. One of the measures is to create more space for open water. This is particularly possible in the neighborhoods earmarked for redevelopment. Where there is no or little space, the focus is on innovative and alternative ways of retaining water. Examples are wadis, water gardens, water squares and green roofs.
In the coming five years Rotterdam needs extra water storage facilities for a volume of about 600 million liters of water. Equal to one hundred football fields with a water layer of 80 cm. The water boards and the City Council have made up an action program: the Rotterdam Adaptation Strategy, that is part of the Rotterdam Climate Initiative. This strategy offers a wide range of concepts with solutions. For example creating more open water, or water storage in the underground, like they did in the underground Museumparkgarage. Creating green rooftops with investment subsidies. Or creating new concepts like a water square. On the Bellamyplein the first water square has been established in cooperation with the water boards; in the same period also the water square on the Benthemplein was constructed. The natural capacity of open soil for water storage is also stimulated, to stop the increasing pavement area in private and public gardens and public space. In this way over the last four years a length of two kilometres of "geveltuin" (small gardens along the houses, not more then 30 cm wide) has been built.

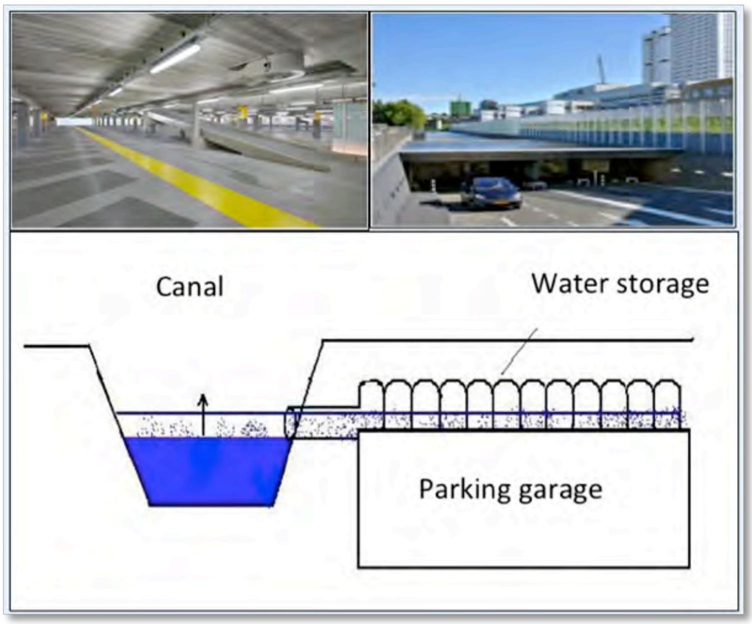


Fig 6.2.7 Combined parking garage and water storage in Museumpark
Source: Stadsontwikkeling Rotterdam

6.2.8 Shopping centre “Koopgoot”

In the City Centre an underground shopping centre was constructed in the nineties, the “Koopgoot”. People can also use the Koopgoot as an underground crossing of the Coolsingel in order to avoid the busy traffic on that city aorta.

Fig 6.2.8 The Koopgoot. The underground shopping centre in the City centre.
Source: City of Rotterdam

6.2.9 Sand and gravel

In the nineties sand from the Zevenhuizerplas was used for construction of the neighbouring Rotterdam district of Nesselande. The Zevenhuizerplas was enlarged during the process, and it now serves as a recreational lake for the Nesselande population.

Fig 6.2.9 Zevenhuizerplas, formerly a sand pit;
currently leisure area in the new Nesselande suburb.
Source: Stadsontwikkeling Rotterdam

6.2.10 Challenges in the Civil Construction Zone

Presence of aquifers with high piezoelectric values compared to the surface or compared to the possible excavation levels of constructions, could result in the occurrence of "uplift". This is one of the issues that always have to be checked. Besides the dynamic properties of the aquifers, a good characterisation of the layers and a proper geotechnical profile at the construction site, are important during this analysis. In case that uplift occurs, then water pumping has to be applied under condition that the radius of influence of the drawdown does not affect the constructions in its vicinity. During construction projects in the second layer, the challenges of the first layer (see previous chapter) also need to be tackled. During the assimilation of the "polder" areas for setting up a new suburb (vinex location), drains have to be installed to accelerate the settlement process. This action are closely supervised and during long time monitored in order to ensure a long life to the constructed area.

Geotechnical issues can play an important role in the construction projects in Rotterdam. To what extent these issues lead to delays and extra costs during the construction programme depends upon the priorities set by the decision makers in advance of the moment when one needs to decide between cost reduction and risk reduction. In the process of building the Museumpark underground car parking lot with an integrated water storage facility, serious geotechnical problems were encountered. Professor F. Van Tol (Technical University Delft) describes the case and he comes to the conclusion that the geotechnical complexity of the underground building construction was underestimated in favour of the budget constraints. Geo-risk management has since then become standard practice in every geotechnical assessment executed by the City of Rotterdam.

6.3 Layer 3: The Drinking Water Zone

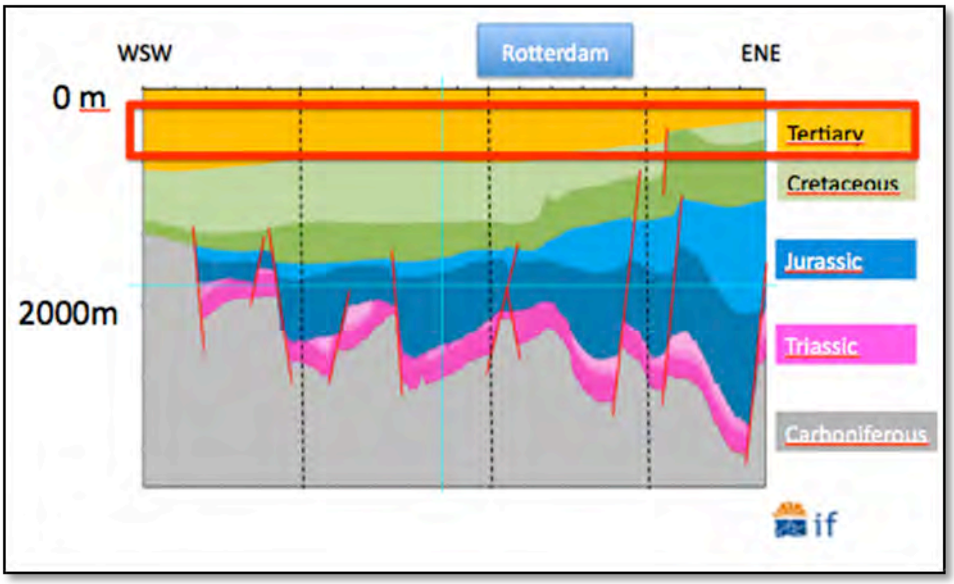


Fig 6.3 The Drinking Water Zone between 50-500m
Source: Stadsontwikkeling Rotterdam

6.3.1 Drinking water management

Evides is the water company in the province of Zuid Holland. Evides is responsible for the drinking water supply in the province. Contrary to some of its' neighbouring cities, the drinking water supply for Rotterdam is not extracted from the subsurface but from river water that is filtered in basins in the Biesbosch area, south of Rotterdam.

6.3.2 Thermal storage: Shallow Geothermal Energy

The Water zone in the subsurface of the Rotterdam area is appropriate for the use of shallow geothermal energy (SGE). See Fig 6.3.2a.

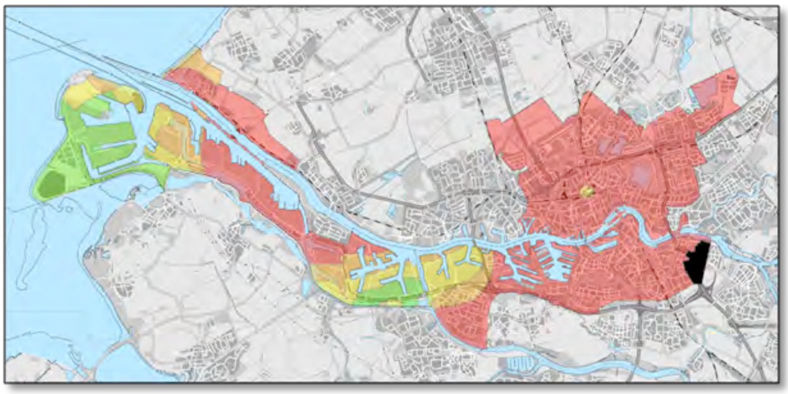


Fig 6.3.2a Potential for SGE in the combined 2nd and 3rd aquifers. Red is high potential, green is low potential.
Source: Stadsontwikkeling Rotterdam

This technique is used for the heating and cooling of buildings. Two types of SGE systems can be distinguished: open systems, which pump up and infiltrate groundwater using underground thermal energy storage, and closed systems, also referred as Borehole Heat Exchangers. See Fig 6.3.2b.

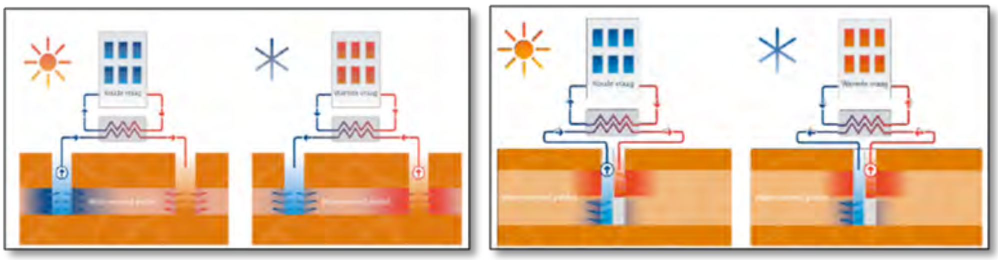


Fig 6.3.2b SGE: open system (left) using groundwater pump and closed system (right) using Borehole Heat Exchanger
Source: IF Technology

Using SGE gives 30-50% reduction of energy use compared with conventional energy sources. The city of Rotterdam is committed to achieve a reduction in CO2 emission of 50% by the year 2025. An important aspect is the use of sustainable energy for heating and cooling of buildings. Rotterdam aims at using waste heat from industrial processes in combination with SGE (mainly) for cooling.

SGE systems can conflict with other use of the subsurface. See Fig 6.3.2c. Close to and at the surface, the dimensions of a system are relatively small. Nevertheless such a system needs to be fitted in with other functions of the subsoil, like both existing and planned infrastructural works and underground objects.

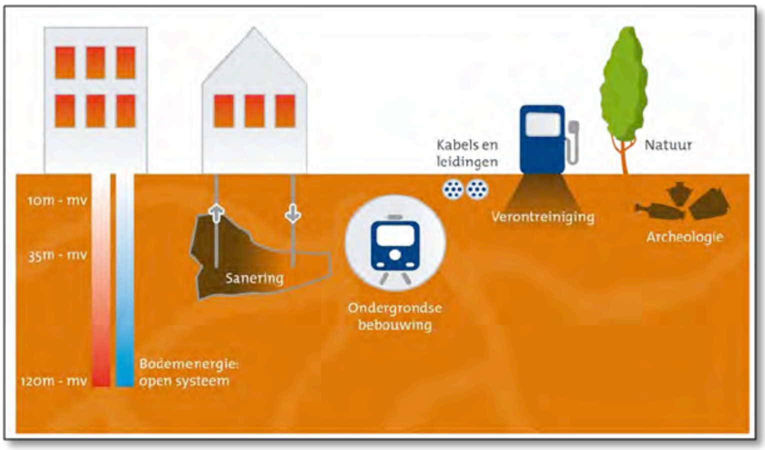


Fig 6.3.2c Diverse usage of the subsurface.
Source: IF technology

Open shallow geothermal systems, which use groundwater pumps, are not allowed in the first aquifer (NAP -15 m – NAP -35 m) in urban areas in the Province of South-Holland. Extracting groundwater at these shallow depths might cause too many negative effects on buildings and the urban water management system. SGE systems should not be placed too close to existing SGE systems, because negative interference may occur which reduces the efficiency and proposed reduction in energy use. For the installation of a SGE system a permit should be required, for which one needs to be prove that no negative interference occurs. The geothermal storage capacity of the subsoil is limited, which is an important aspect in urban development areas. In these areas Borehole Heat Exchangers are only allowed above NAP -80 m, where SGE systems using groundwater wells are only allowed deeper than NAP -90 m, see Fig 6.3.2d.

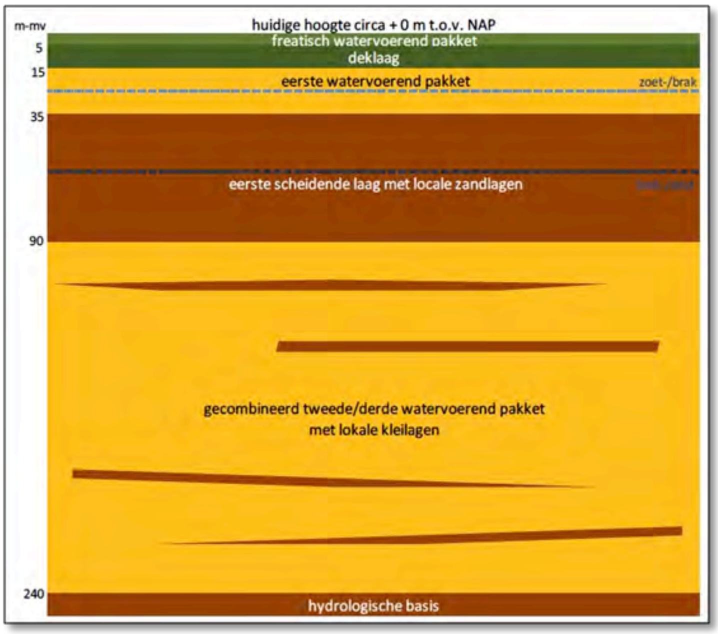


Fig 6.3.2d First aquifer 15-35 m depth below ground level.
Combined second and third aquifer from 90-240 m.
Yellow = sand, brown = clay
Source: IF technology

6.3.3 Challenges in the Drinking Water Zone

Due to lack of planning in the past, several SGE installations interfere with each other leading to suboptimal exploitation, see Fig 6.3.3a.

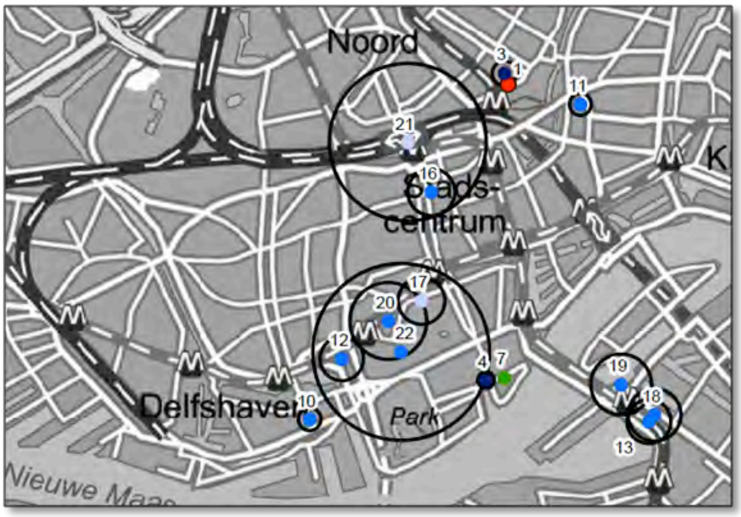
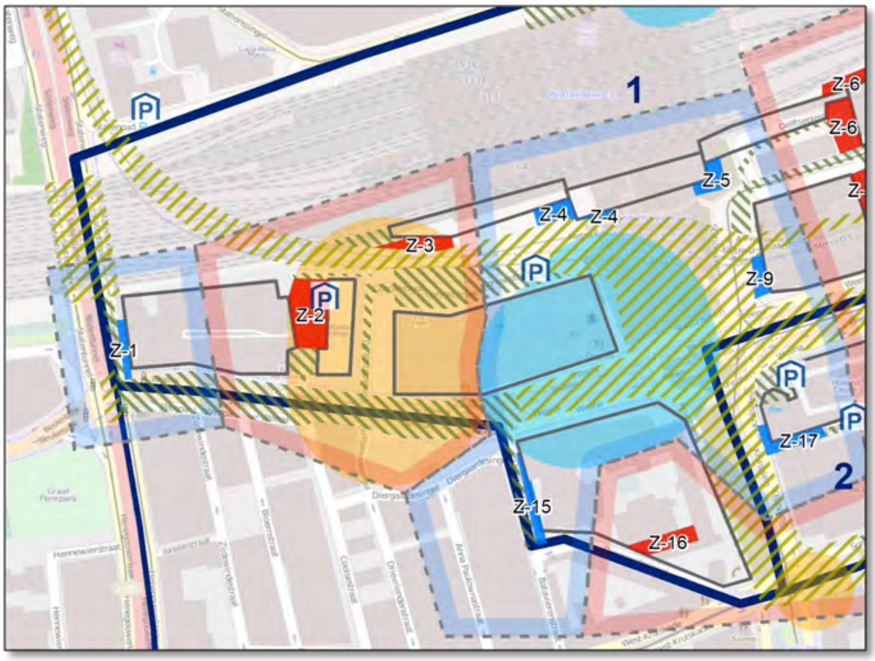


Fig 6.3.3a Coloured dots: SGE installations in the Centre of Rotterdam circles of influence of several systems overlap, leading to suboptimal output.
Source: Stadsontwikkeling Rotterdam

In Rotterdam City Centre the demand for SGE is already so high that more regulation is required. An extensive SGE plan is created for this area. The goal of this SGE plan is to optimise the use of geothermal storage capacity, taking into account the different functions of the subsoil in that area. For the City Centre the SGE plan indicates distinctive areas for the position of the groundwater wells and their area of geothermal influence, which may not reach outside a calculated contour, see Fig 6.3.3b.



- Search area cold groundwater wells
- Search area warm groundwater wells
- Thermal influenca area (1,5°C contour)
- Thermal influence area existing SGE systems
- Subterranean infrastructure
- Overground infrastructure
- Development of Building Structure
- P Subterranean parking facility

Fig 6.3.3b Detail of the map of the SGE plan Rotterdam City Centre
Source: Stadsontwikkeling Rotterdam

6.4 Layer 4 The Deep Subsurface

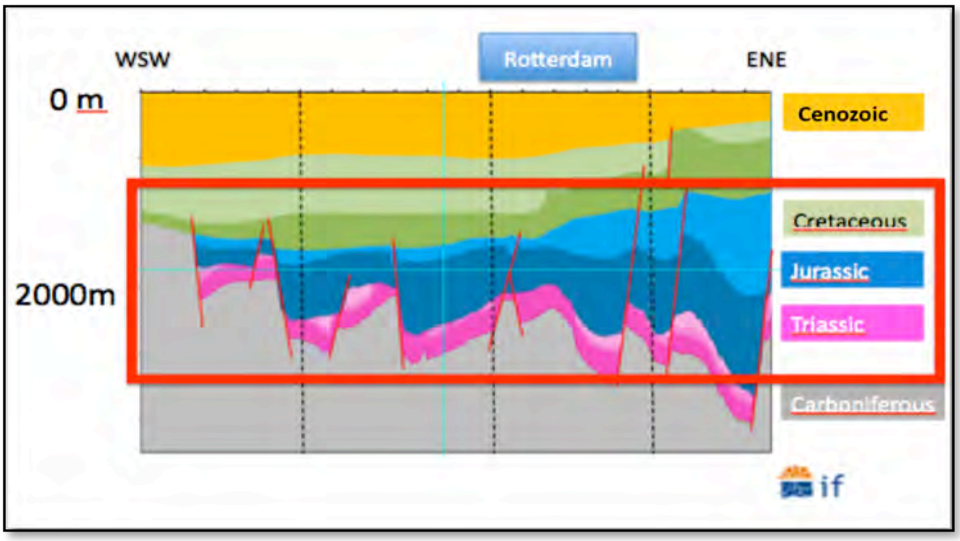


Fig 6.4 The Deep Subsurface below 500m
Source: Stadsontwikkeling Rotterdam

6.4.1 Oil&Gas

Oil in the SW of the Netherlands was first discovered in 1938. During the World Petroleum Congress a demonstration well in the Hague was drilled by the Bataafse Petroleum Maatschappij (BPM) and this well found traces of oil at a depth of 464 metres. The first recoverable quantities of oil in the province of Zuid Holland were discovered in 1953 in Rijswijk.
In the Province of Zuid Holland an intensive drilling programme in the 1950s led to the discovery of the Rijswijk, Pijnacker, De Lier, IJsselmonde, Wassenaar, Zoetermeer and Moerkapelle oil fields, see Fig 6.4.1a. Exploration from the late 1970s to early 1990s resulted in further discoveries, (Berkel, Barendrecht, Rotterdam, Pernis and Pernis West oil fields).
Many of the fields have both gas and oil present in sandstones of the Upper Jurassic to Lower Cretaceous in complicated structural traps, see Fig 6.4.1b, also see Chapter 3.1. The presence of gas is often a downgrading factor, as it reduces the potential oil volumes in traps, while it is not sufficient to justify development. In 1996, the oilfields of Western Netherlands were abandoned except for the Berkel oil field in Rotterdam that came into production in 1953 and was abandoned in 2013. See Fig 6.4.1c.
Exploration for gas in Zuid-Holland started only in 1982. The gas play is mainly from sandstones of Triassic age. In accumulations in the neighborhood of Rotterdam gas is found in association with oil, (Pernis West, Spijkenisse Oost en Botlek gas fields).

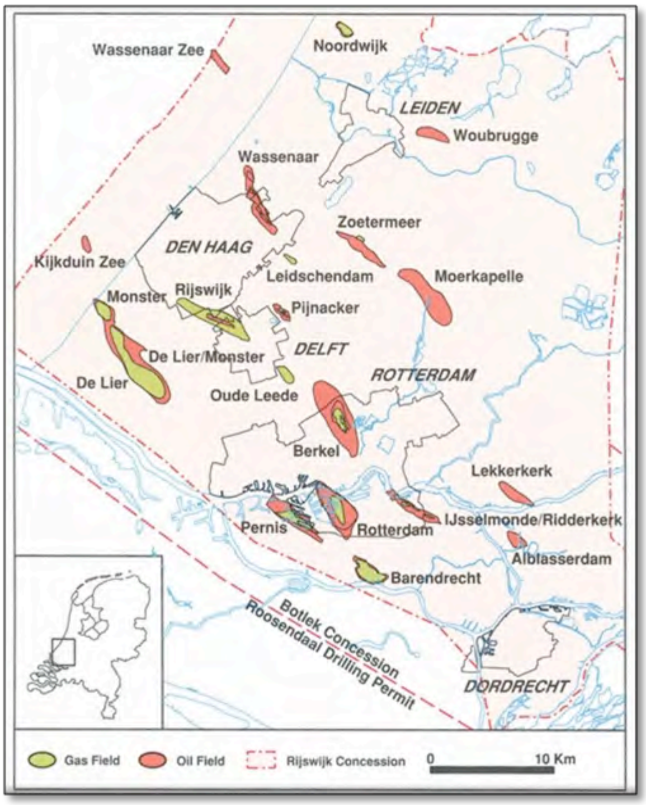


Fig 6.4.1a Oil and gas fields in SW Netherlands. The map includes abandoned, undeveloped and non-commercial Accumulations.
Source: Alvara Racero-Baena

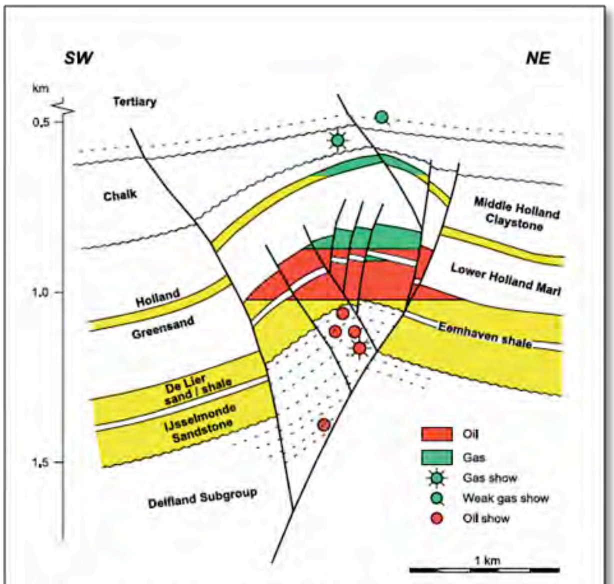


Fig. 20. Example of a trap in the Upper Jurassic and Lower Cretaceous in the West Netherlands Basin (IJsselmonde-Ridderkerk field). Several stacked reservoirs are present, the younger of which contain more gas and the deeper more oil.

Fig 6.4.1b Geological trap for oil and gas.
Source: Duin et al.

Fig 6.4.1c Nodding donkeys active at Berkel field location until 2013. Oil from the Berkel field was produced from a depth of 1250 metres from the Berkel sandstone reservoirs of the Lower Cretaceous.
Source: NAM

6.4.2 Shale gas

The organic Posidonia Shale Formation, a potential shale gas producing rock formation, is present in the Rotterdam region. See Fig 3.2c and also Fig 6.4.2.

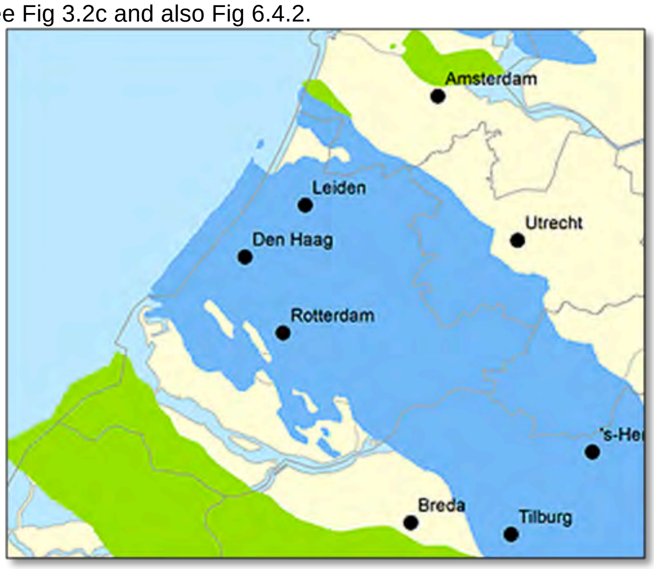


Fig 6.4.2 Areal extent of Posidonia shale in blue.
Source: TNO

6.4.3 CO2 Storage

Shell did prepare a project to store CO_2 produced at their refinery in the Rotterdam harbour in a former gas field near Barendrecht, south of Rotterdam. After a first test in which 1 million tons of CO_2 was to be stored in the Barendrecht field at a depth between 1,5 and 2 km, a larger field, Barendrecht Ziedewij, was supposed to store 9 megaton of CO_2. Such a Carbon Capture Storage (CCS) project aligns well with the objectives of the Rotterdam Climate Initiative to restrain the emission of CO_2 in the atmosphere. After fierce protests by the local population and by other stakeholders, the Dutch government cancelled the issue of the necessary permits in 2010 for this project.
The present status in the Netherlands is that it is only allowed to store CO_2 in offshore fields. GDF Suez applies this CCS method currently in North Sea field K18-B. Energy companies E.On and GDF Suez Energy have plans to store CO_2 produced from their new coal based gas plants located in the Rotterdam

harbour in their North sea P15 and P18 fields. Permissions have been granted, but both energy companies have not decided yet go ahead with the required investment.

6.4.4 Geothermal energy

Aquifers in province of Zuid-Holland from which the oil and gas was produced could also serve as source for geothermal heat extraction. The average geothermal gradient in the Netherlands is about 3°C per 100 metres. At various locations the temperature of the water in the reservoirs of Triassic, Jurassic and Lower Cretaceous age is in excess of 70°C, more than sufficient for use in households and for greenhouses.

Partners slaan handen ineen voor Aardwarmte Rotterdam

01 februari 2013

Op 1 december 2012 is een samenwerkingsovereenkomst ondertekend voor de ontwikkeling van aardwarmteprojecten in de regio Rotterdam. De samenwerkende partijen zijn Eneco, E.ON Benelux, Hydreco GeoMEC en Visser & Smit Hanab. Zij hebben de afgelopen tijd verschillende opsporingsvergunningen aangevraagd in de regio Rotterdam en hebben besloten de handen ineen te slaan.

Het onderzoek naar de mogelijkheden van aardwarmte in Rotterdam maakt onderdeel uit van het programma Duurzaam van de gemeente Rotterdam en draagt bij aan de doelstellingen van het Rotterdam Climate Initiative.

Fig 6.4.4a February 2013: Rotterdam partners announce Cooperation on geothermal exploration in the Rotterdam Region
Source: City of Rotterdam

Geothermal energy is regarded as a sustainable form of energy, and the City of Rotterdam with partners have in February 2013 decided to investigate the potential for geothermal energy in the Rotterdam region, see Fig 6.4.4a. The City of The Hague, 23 kilometres from Rotterdam, has started with a geothermal project in 2007. The first well was drilled in 2010, see Fig 6.4.4b. From a depth of 2200 metres water with a temperature of 73°C was produced from Jurassic reservoirs. This heat was intended to be used for heating up to 4000 new homes. In The Hague there is also potential to produce water with a temperature of 110°C from a depth of 3 km.

Fig 6.4.4b Geothermal production unit in The Hague Leyenburg*.*
Source: City of the Hague

Other geothermal wells in the Province of Zuid-Holland were drilled for the purpose of heating of greenhouses. The first well was drilled in 2007. See Fig 6.4.4c. Depth of the reservoir in these wells is in the range of 1600-2300 metres, from Jurassic and Lower Cretaceous reservoirs. Oil and gas are frequently encountered as (un)wanted side products whilst drilling for hot water. As from 2012 production of geothermal energy is subsidised by the Dutch government.

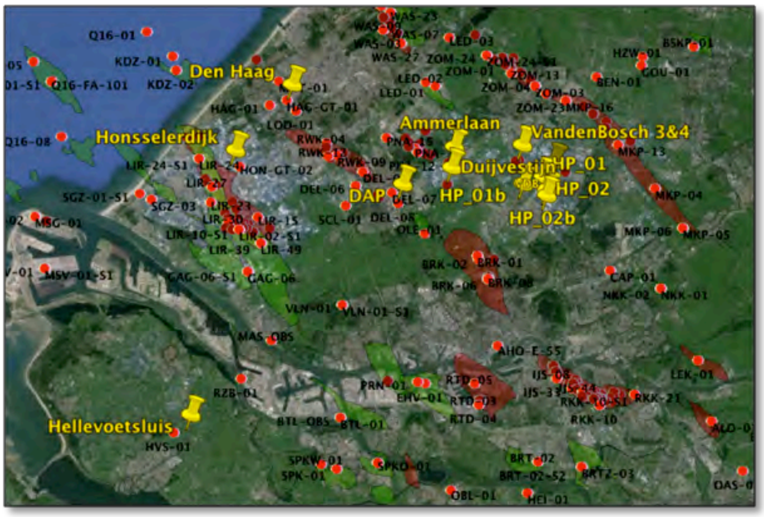


Fig 6.4.4c The Province of Zuid Holland around Rotterdam:
Red dots: oil and gas wells; green areas: former gas fields; red areas: former oil fields; yellow markers: geothermal wells.
Source: TNO, NLOG, Platform Geothermie

Fig 6.4.4d shows the current status of exploration and production licenses in the Province of Zuid Holland.

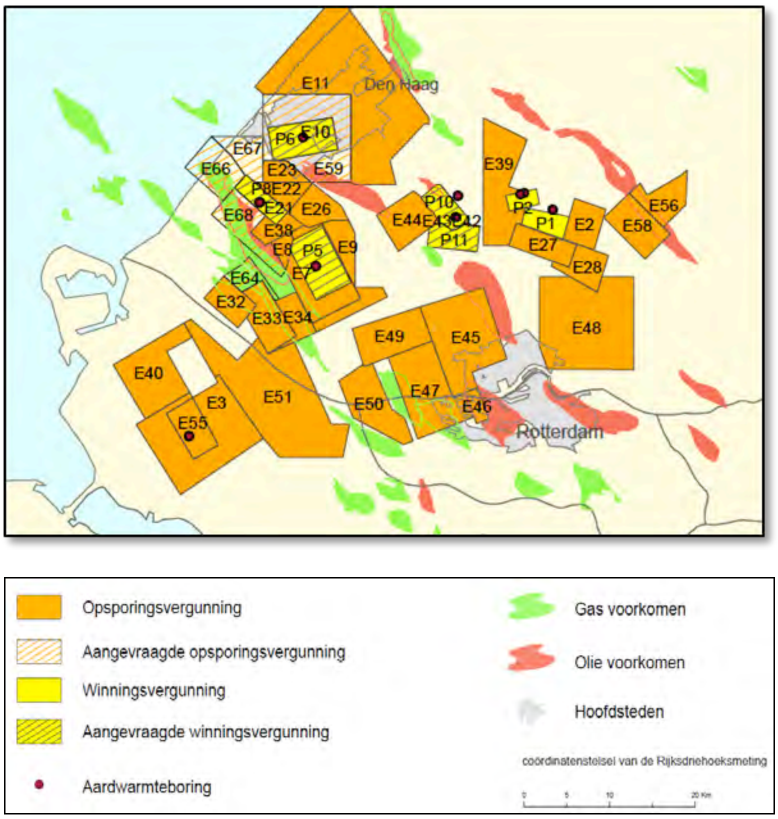


***Fig 6.4.4d Geothermal exploration and production licenses in Zuid Holland, January 2016**.*
Source: TNO nlog.nl

6.4.5 Challenges in the Deep Subsurface

Geothermal Challenges

The oil and gas fields from the deep layer have played an important role in the energy supply of the province over the past decades. Numerous wells have been drilled in the province (Fig 6.4.4c), lots of 3D seismic surveys have been acquired over the years (Chapter 3.2), and a vast amount of knowledge and experience has been built up from interpreting these data. The oil and gas industry has built up an excellent reputation in the Netherlands as far as safety is concerned. And the industry is well organised on all levels: from regulatory bodies at the level of the National government down to the integrated companies involved in exploration and production processes.The organisation of the geothermal branch is presently at the opposite end of the scale: the Dutch state is still more interested in oil/gas, too many small companies are involved in the process chain, and the developers of the deeper subsurface levels, the integrated oil and gas companies, are not yet involved in geothermal.There are many similarities between exploring/producing for oil and gas and for geothermal in Zuid-Holland: the geology, the type of data and information, methods of investigation and drilling, the risks involved, and the costs of drilling a well. The only major difference is the profit margin. Geothermal energy can potentially contribute significantly to reaching the objectives of the Rotterdam Climate Initiative. But in order to optimise its contribution it is crucial that:

1. The geothermal energy industry can fully take advantage of the experience and the knowledge about the deeper layers of the subsurface that is present within the oil and gas community
2. The Dutch government applies the rules and regulations which apply to the oil and gas industry also to the geothermal industry.
3. The geothermal industry organises itself accordingly

At present these conditions are not yet fulfilled.

CO2 storage

Also CO2 storage can contribute to reducing CO2 emissions. The Rotterdam region could become a forerunner in this field in the Netherlands and in Europe and Rotterdam could become a centre of knowledge for this technique.The CO2 plans for the Barendrecht area were shelved by the government as a result of protests by the residents of Barendrecht, see Fig 1.3.3b. These protests happened although the proposed operator of the project, Shell, has a longstanding and excellent reputation for safety and has already for decades been involved in gas production from the deep reservoirs in this region. The main challenge seems to be communication. What applies to the whole subsurface (subsurface is not appreciated or given high priority, see Chapter 3) applies even more to the deep layer: it certainly is not appreciated by the public. And people are not well informed about this layer. Two requirements need to be fulfilled in order to change the public opinion concerning CO2 storage:

1. Inform, inform and inform, visualise etc (see Chapter 7)
2. Make sure residents can make a profit of CO2 activities in their neighbourhood (e.g. reduction of energy costs), make them proud of their local CO2 project.

Shale gas exploration

In the discussions about shale gas exploration in the South of the Netherlands (Province of Noord Brabant) it appears that the public is very afraid of the possibility that gas from the deep layer escapes from the deep layer, percolates through the drinking water zone and contaminates the drinking water. Drinking water in the Rotterdam region is not extracted from the water zone (see Chapter 6.3.1), so that discussion will not be relevant for Rotterdam. But as soon as the potential of shale gas exploration and exploitation of the region will come on the news agenda in this area other dangers such as ”fracking”” of gas shale and oil shale certainly will show up in the arguments. After the technical risks have been fully understood and evaluated then the communication issue will remain and needs to be solved

6.5 Summary

The subsurface of Rotterdam has potential for use but there are several complexities involved in the fields of safety, health, economics, environmental and politics. This potential is not unlimited so various potential functions should be weighed, balanced and prioritised carefully. That requires a lot of technical expertise on individual topics. But to avoid delays, costs and to make optimal use of opportunities the subsurface offers it is also necessary to:
- Adapt a holistic view on the subsurface and develop knowledge of the subsurface as a system.
- Bring in the subsurface as early as possible into the urban planning process.

The City Rotterdam is actively involved in developing a holistic view on the subsurface since it took part in a program on spatial planning of the subsurface, initiated in 2008 by the Ministry of VROM. The next Chapter explains the various fields of activity necessary to establish such a holistic view.

7. Urban planning and the subsurface in Rotterdam

7.1 The slow road from awareness to standard practice

Regarding the subsurface as an integral part of the public space (Fig 6b) and subsequently including the subsurface automatically during the urban planning process is not yet standard practice. The **subsurface is unknown territory for most city planners and developers**. And unknown makes unloved. Rotterdam is actively involved in changing this situation since it took part in a program on spatial planning of the subsurface, initiated in 2008 by the Ministry of VROM, and the city has participated in numerous national and provincial projects on the topic since then.
It has appeared to be a tough learning exercise and a difficult development process, for both urban planners and underground specialists. The process has been subdivided into several stages by SKB, the national organisation that was actively engaged in research on this topic. These stages are presented in the figure below.

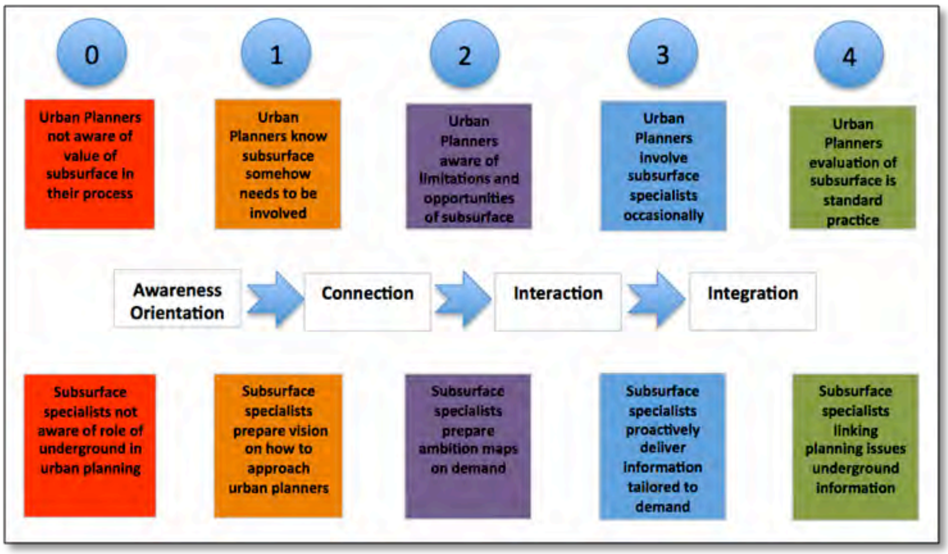


Fig 7.1a The Tower model of SKB: the journey for both urban planners and subsurface specialists.
Source: SKB

Fig 7.1a sketches two development processes that need to interact with each other. Subsurface specialist and urban planners of the same organisation are probably not all in the same stage of their journey, also influenced by where the interaction process is initiated. Thus that the task is twofold: developing your own sector as well as trying to involve the other sector and get them to develop along the same trajectory. Each stage requires different products and processes.
The word subsurface was not even mentioned once in the Spatial Development Strategy published in 2007. Since then some subsurface specialists in the City of Rotterdam, have been actively promoting the subsurface. What activities were developed to get city planners enthusiastic about the subsurface, to make them not only plan at ground level but to make them think about the total volume of above- and below ground level space? The undertaken activities over the past seven years are presented in our "Wheel of Underground Activities", see Fig 7.1b.

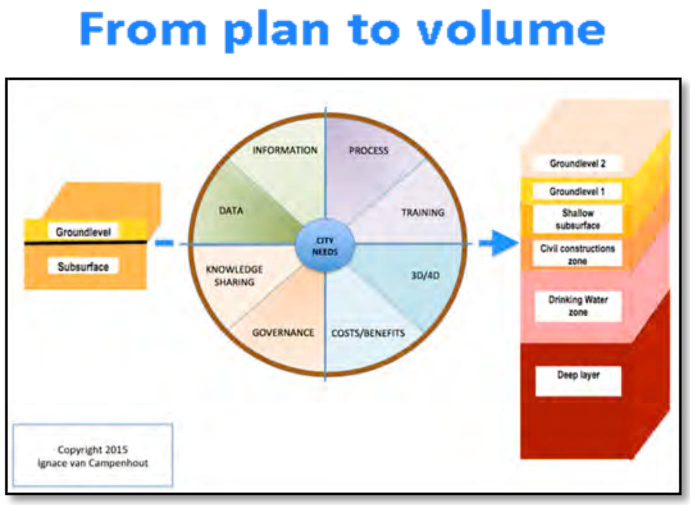
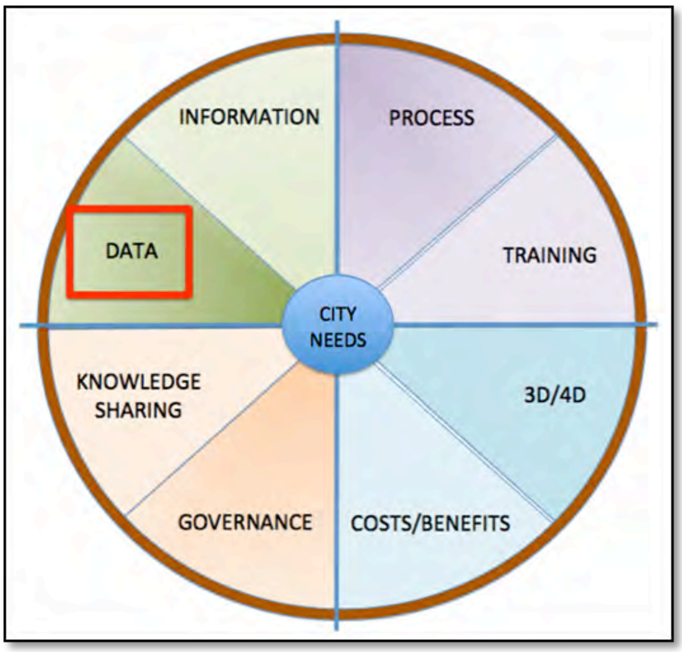


Fig 7.1b.The 'Rotterdam Underground Wheel of Activities'
Source: Stadsontwikkeling Rotterdam

7.2 Data



7.2.1 Data handling

There is a vast amount of data, information and knowledge available on the subsurface of Rotterdam. These data are gathered by numerous specialists from various disciplines, working in different locations and for different organisations. Urban development projects require an integrated approach, in which all the information from these different disciplines can be evaluated in an integral way. Collaboration between different disciplines and organisations is the key word. The foundation for good cooperation is **willingness** and the **ability** to share and evaluate information with each other.
This requires that the data:

- are up-to-date and reliable
- can be presented in conjunction
- are transparent
- and instantly accessible

INSPIRE is the EU initiative to establish an infrastructure for spatial information in Europe that is geared to help to make spatial or geographical information more accessible and interoperable for a wide range

of purposes supporting sustainable development". Based on these European directives the Dutch governmental initiative GIDEON has developed national directives that force governmental organisations and Dutch universities to harmonise their basic data handling.
Already 150 years ago Gemeentewerken, the public works organisation of the City of Rotterdam and predecessor of the present Stadsontwikkeling Rotterdam had its own engineering department that collected and archived data and information on the subsurface in a well-organised way. These days **all geographical data of the whole city** that is collected by Stadsontwikkeling and by the other city departments is well maintained and stored and archived in central Oracle databases. As over 90% of these data have a geographical component these data are available for viewing in GISWEB, a GIS viewer developed by Stadsontwikkeling. At present Stadsontwikkeling has made over 500 layers (maps) available to its employees. Maps from other departments and from other organisations can also be integrated in GISWEB as long as they are presented via WEB services. Stadsontwikkeling has adapted GIDEON's organisational principle of **"Single storage, multiple use"** of data. Within Stadsontwikkeling there is at present a new initiative to set up a proper organisation around the handling of maps and geographical information. Within this organisational framework the following three roles and responsibilities have been defined:
Resource holder: manager, team leader, client who facilitates the finances to prepare the map. Coordinates Resource administrators in his team. Resource holder cannot be resource administrator at the same time.
Resource administrator: Responsible for the content (process description and metadata) and the technical preparation of the map and for making the map available to the users on the GIS network. Within Stadsontwikkeling the role of Resource administrator is occasionally carried out by a person without necessary GIS knowledge to take care of technical aspects. This technical part can be transferred to the GIS specialist, (though the responsibility for the realisation remains his).
GIS-specialist: Specialists on GIS and Data management, trained on these subjects and working for at least 80% of their time in these fields. Takes care of technical preparation and launching of maps. Can also be resource administrator.

7.2.2 Organisation

In Stadsontwikkeling Rotterdam geographical data are handled, analysed and reworked in dedicated GIS software programs like ARCGIS. Either by the sectored specialists themselves or by GIS professionals that are part of the team.
Subsurface specialists in the City of Rotterdam are organised in teams along disciplinary lines These different disciplines (archaeologists, geo-hydrologists, environmental- and cables and pipelines specialists, geotechnicians, ecologists, etc) all have their own professional conventions and standards of editing, analysing and presenting data and information on maps.

Fig 7.2.2 Sectored organisation of subsurface disciplines & information.
Source: Stadsontwikkeling Rotterdam

7.2.3 Phases of evolution of a project

During the different stages of development of a spatial project different data are used, and different models and visualisations are produced. During the early stage the scale and details can vary significantly from a later stage. Models produced during a first stage are partly reworked in following stages whilst additional data are added. INSPIRE and GIDEON describe how to handle "basic" data. How an organisation like Stadsontwikkeling Rotterdam is taking care of all information and models produced is certainly a major challenge.

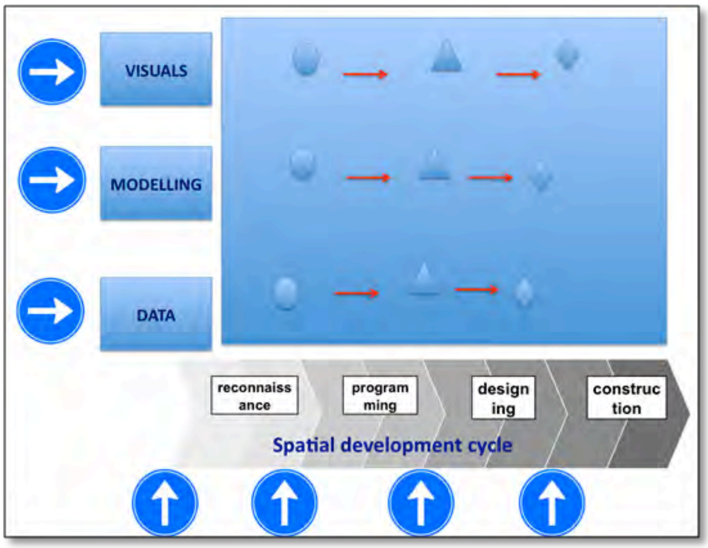
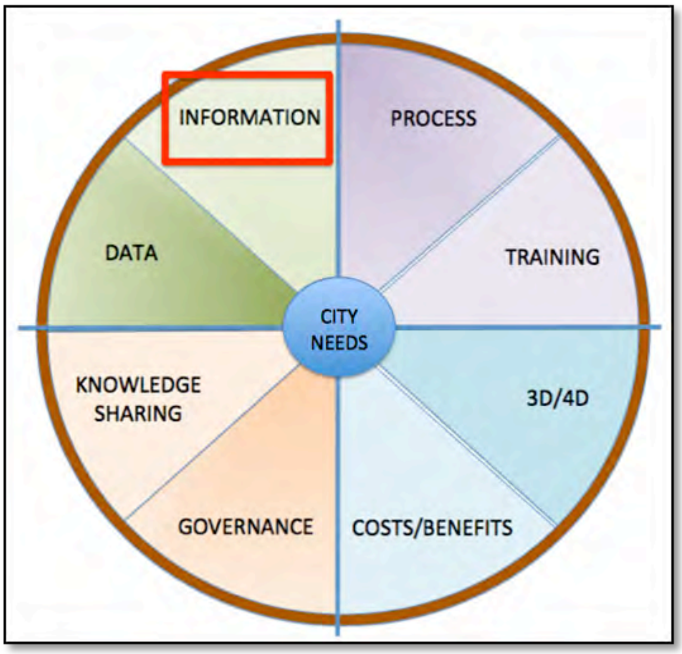


Fig 7.2.3 Phase of a project decides what data is required and in which format.
Source: Stadsontwikkeling Rotterdam

7.3 **Information**



7.3.1 The old approach

In the old field approach the underground was mainly seen as an obstacle: cables and pipelines, soil-pollution, archaeological remains, debris: all things that can slow down area development and make it more expensive.

Within Stadsontwikkeling Rotterdam much knowledge about the subsurface is present, fragmented across different subsurface sectors, see Chapter 7.2. The maps made by underground specialists of a certain discipline are designed to be used by other specialists belonging to the same discipline. These maps are not designed to **communicate** their information to specialists from other disciplines (nor to the public). However these specialists' maps were presented to the urban planners: basic information (e.g. drilling holes), furthermore these maps were presented on different scales with legends that could not be understood. Urban planners need to receive relevant, clear material that informs them unambiguously about costs, opportunities and risks. Instead they often received information they could not understand. See Fig 7.3.1.

Fig 7.3.1a "Your language is not his language"; an advertisement in Rotterdam's Metro-railway in 2012.
Information exchange? Yes; communication? No.
Source: City of Rotterdam

Potential obstacles which can have serious impact on the exploitation of a project as well as on the time framing of a project were not communicated, and thus resulted in frictions, delays and in higher costs. Furthermore because this information was presented in a incomprehensible way, urban planners preferred to leave the underground issues until the end of their work process, when it was too late for them to incorporate the potential opportunities which the subsurface would offer in their plans. As an example: Shallow geothermal energy, the possibilities to improve the identity of an area with archaeology or to improve exploitation of plans by making smart combinations.

Undesired situation 1

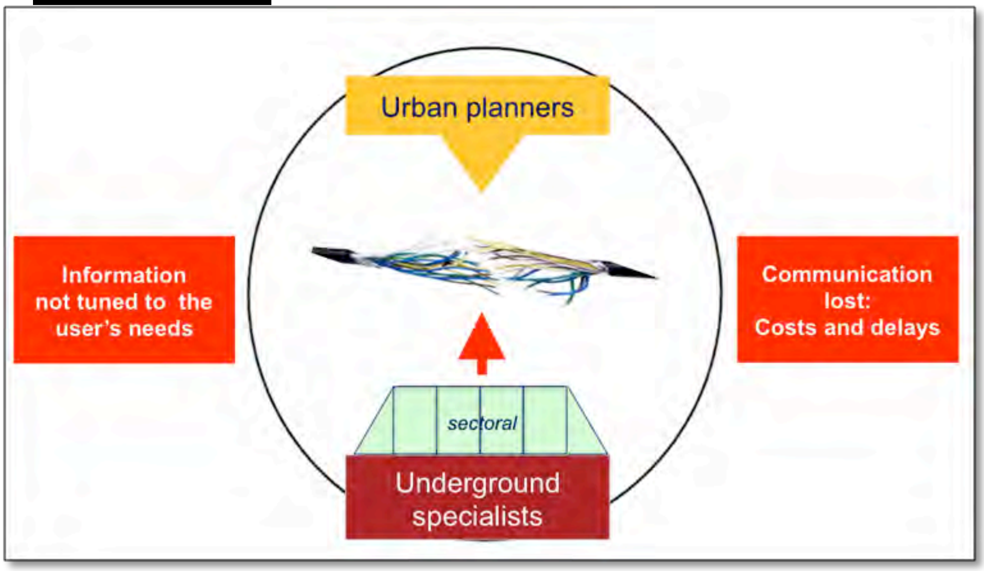


Fig 7.3.1b "Your language is not his language". Underground information incomprehensibly presented to urban planners.
Source: Stadsontwikkeling Rotterdam

Undesired situation 2

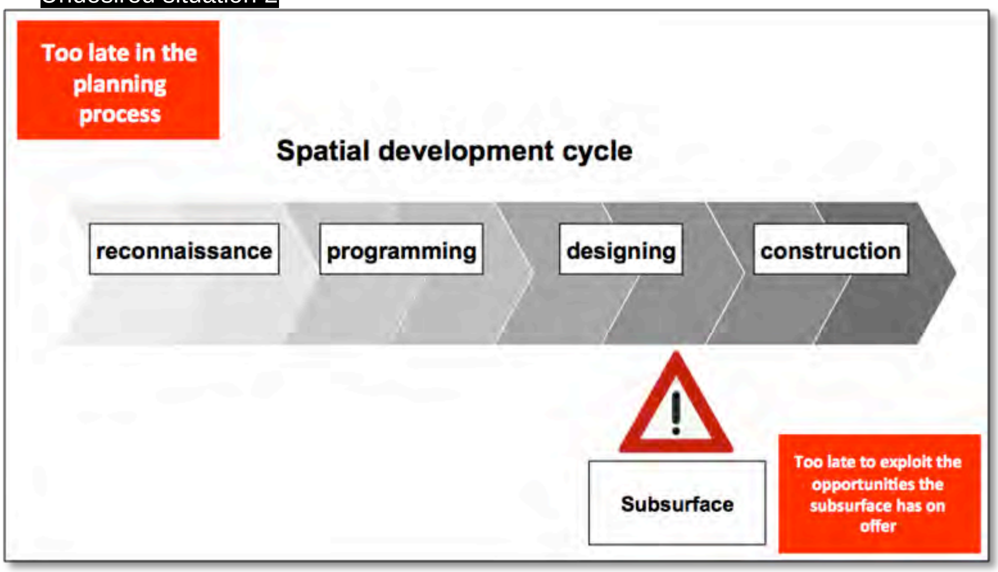


Fig 7.3.1c Underground information introduced too late in the urban planning process..
Source: Stadsontwikkeling Rotterdam

7.3.2 The new approach: The U-scan

Together with TU Delft and Deltares, Rotterdam has developed the "U-scan" methodology. This Underground scan bridges the gap between stages 2 and 3 in Fig 7.1. The first U-scan has been carried out for the project Kop van Feijenoord in 2009. Since it has been applied to several urban development projects in Rotterdam (Stadshavens, Binnenrotte, Agniessebuurt, Lupine) as well as in The Hague (Binckhorst). Recently Rotterdam and TU Delft jointly organise "U-scan" workshops for students who study Urban Planning at TU Delft. Currently Rotterdam, Deltares and TUDelft further develop the methodology in the EU Snowman project ""Balance 4P"' (balancing decisions for brownfield regeneration). During the projects where the U scan is applied the different subsurface sectors need to cooperate with the aim of improving the information given to the urban planners. Basic information is aggregated, analysed and combined with GIS in quality- and economical maps. Possibilities which the subsurface offers were marked on opportunity maps, which provided answers to questions such as "Which areas in the plan area are less or more suitable for developments?" and "Which area is less

costly to develop than others”. Clever combinations could be made between different themes, which gave rise to an improved plan for exploitation. See Fig 7.3.2a.
Maps were presented on a uniform scale and visualised in a clear manner and with readable “traffic light” legends. Maps that could directly be compared with the ambition maps of the urban planners. In this way the urban planners as well as the underground specialists gained understanding of and insight into the spatial cohesion of the main themes above and below ground level.

Fig 7.3.2a Example of “traffic light” map.
Source: Stadsontwikkeling Rotterdam

U scan improvement 1

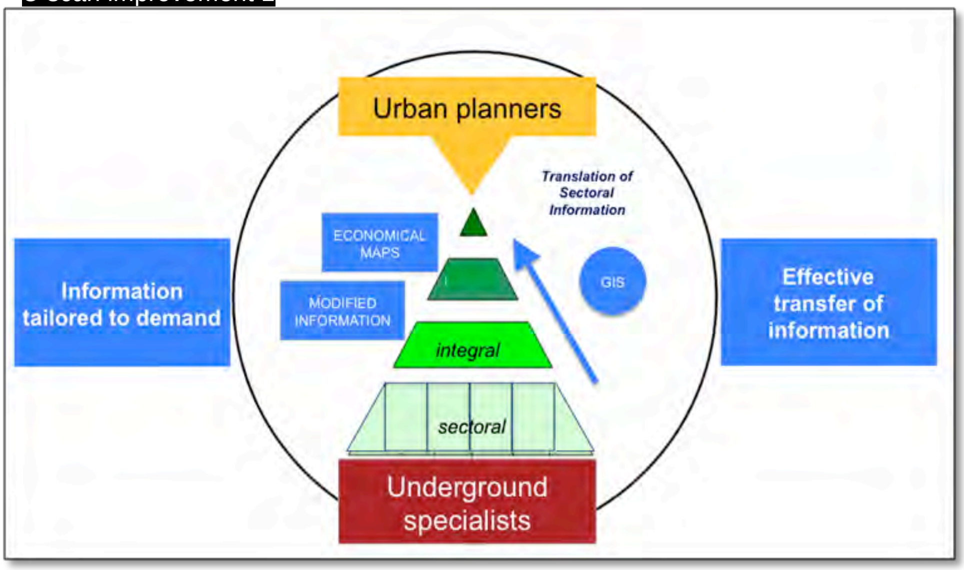


Fig 7.3.2b From incomprehensible information to information tailored to demand.
Source: Stadsontwikkeling Rotterdam

U scan Improvement 2

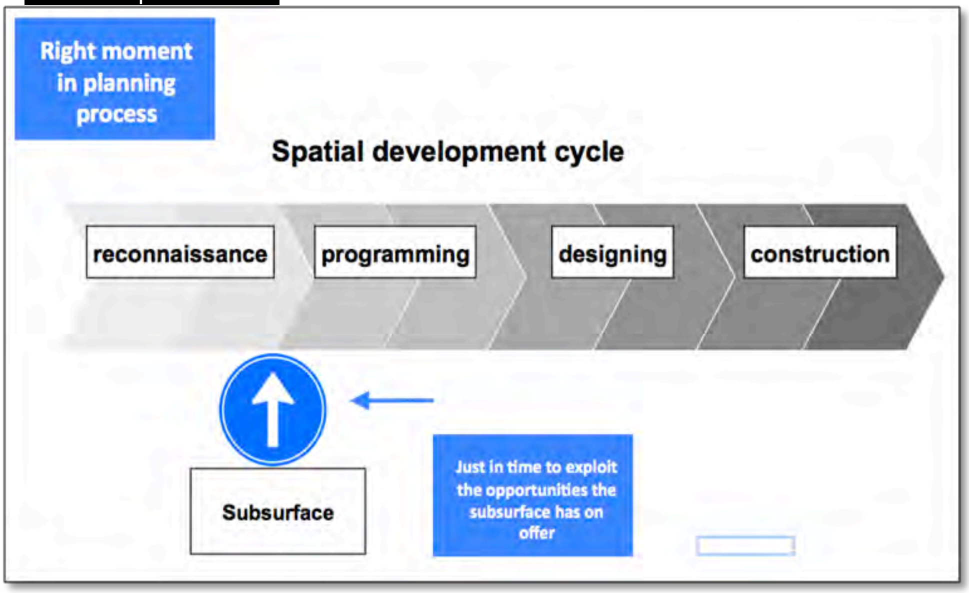
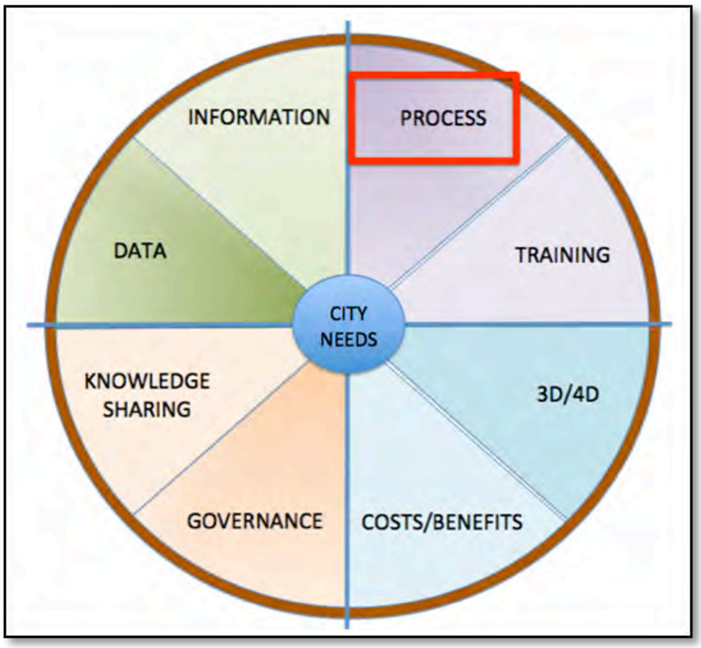


Fig 7.3.2c Presenting the right information as early as possible in the planning process.
Source: Stadsontwikkeling Rotterdam

7.4 Process



7.4.1 Workshops

The new maps are presented in two workshop sessions with surface specialists and city plan economists. During these sessions urban planners present their ambitions to the subsurface specialists and the subsurface specialists present their knowledge of the area to urban planners. Maps are stuck on the wall in uniform scale and the subsurface specialists act as 'living legends', see Fig 7.4.1a. This way lively discussions develop during which supply and demand are fine-tuned. Both parties develop a better understanding of each others' way of thinking and for the needs of the others. A bond grows between both parties, one starts to feel part of the same team and an atmosphere of thrust evolves between subsurface specialists and planners.

Fig 7.4.1a "Living legends" in action.
Source: Stadsontwikkeling Rotterdam

During the workshops the "Fransje table", a spreadsheet developed by TUDelft, is used in which the language of the subsurface specialist (in columns) is directly compared and occasionally even confronted with the language of the urban planners (in rows), see Fig 7.4.1b. Relationships between below- and above ground level topics can be visualised in this way and all participants feel happy because their terminology is respected.

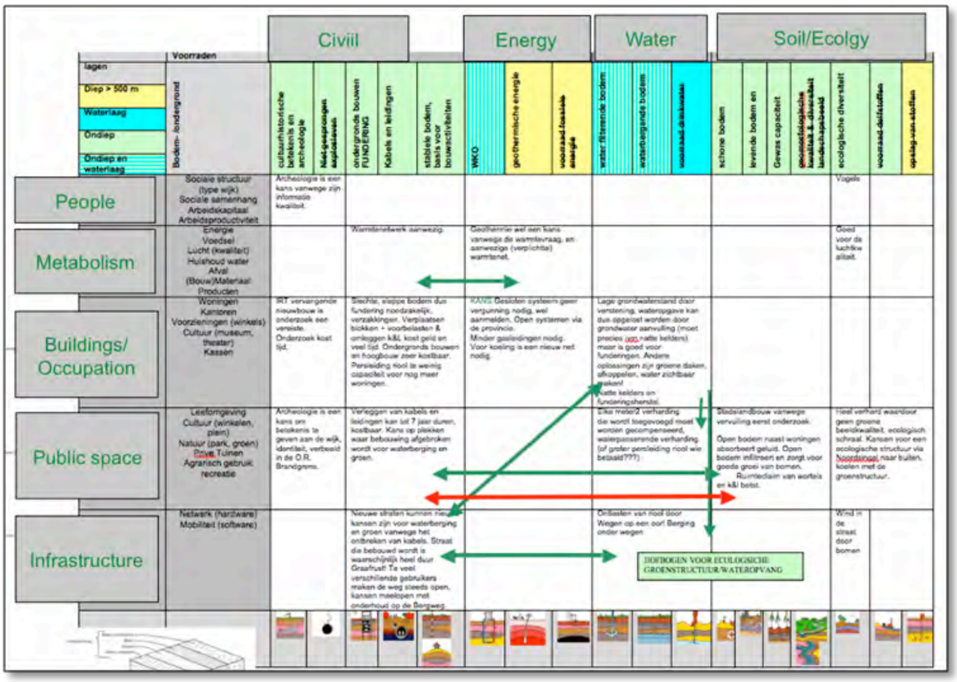


Fig 7.4.1b The "Fransje table" combining the languages of bothe planners and subsurface specialists. In rows: the language of urban planners; in columns: the language of the subsurface specialists.
Source: TU Delft

Results of the "U- scan" approach
The experience for urban planners with the 'U-scan" approach seems to be positive. Examples of this are statements such as: 'Finally maps that we can read" and "…Maps that contain only important and highly relevant information" and 'We would like such an atlas in the early-stage for all projects '. The final maps are published along with a description of the applied methodology in an atlas on paper as well as in a digital format (a pdf GIS). A dedicated project GIS has been set up for each project.
By bringing together the different disciplines and letting everyone cooperate in a work shop environment causes new opportunities to be discovered and smarter solutions being found. The cost of the workshops and the invested time of the participants seems, after their initial scepticism (e.g. "Do we really need two workshops?") to be a very worthwhile investment that actually saves costs and time in later phases of the project.

Another advantage of the “U-scan” process is that everyone involved gets a much better idea what the issues are and how the subsurface can play a role. The shared experience connects and motivates everyone to make a contribution from their own expertise. Finally, urban planners and subsurface specialists know where to find each other and visit each other at an earlier point in time when issues appear.
The most important lesson from these workshops is that there needs to be time spent by both groups to better understand each others’ work, work habits, background and environment. Maps are an important means of communication. Genuine interest in each other creates a “two-way street”. Not just about subsurface information, but also on the content of the project and the challenges that are met. Sharing interests creates positive energy and there are much more possibilities in the remaining part of the process.

Organisational aspects
In helps enormously if there is **process facilitator**, a person who knows about the contents and has the ability to form a bridge between urban planners and subsurface specialists. In larger organisations like Stadsontwikkeling Rotterdam it makes sense to also have a '**broker**', who organises the workshops, who manages the coordination between the underground specialists and who arranges the production of the maps. Someone who has knowledge about the area, the organisation the topics and the technology

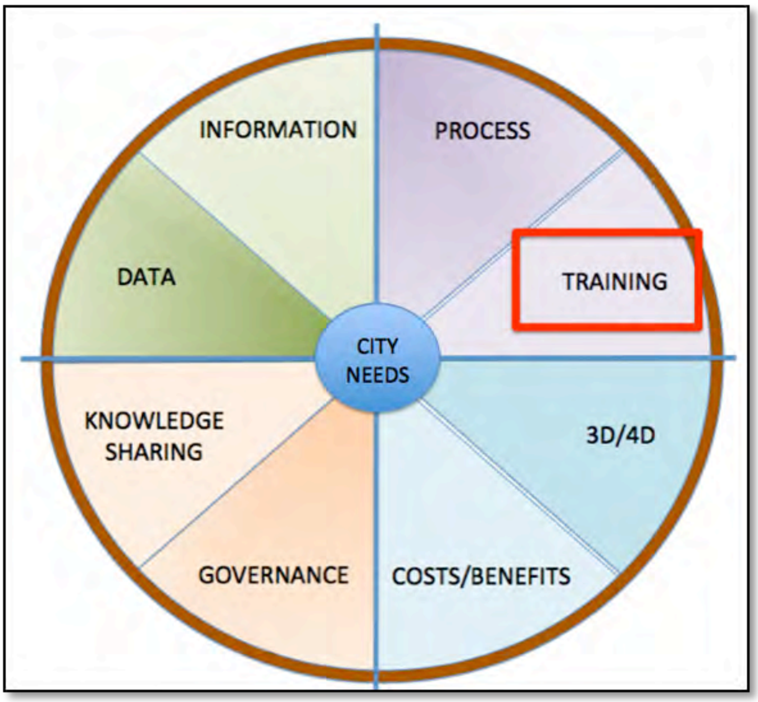
7.4.2 From qualitative- to quantitative results

Preparing the “traffic light” maps for the “U-scan” involves a lot of manual work and they only supply qualitative information for the urban planners, who prefer quantified facts. In order to produce maps faster and with less manual involvement and also with quantitative information attached to them, Stadsontwikkeling Rotterdam is currently developing a GIS based Scantool for that purpose. This Scantool makes it possible for the user to select all requested GIS data layers in the system within a given perimeter, see Fig 7.4.2. The system subsequently churns out the available data layers and for each layer, to the extent it is appropriate; it calculates and supplies attached quantitative information, (areas, distances, etc.).

Thema	Aanwezig	Aantal	Lengte (m)	Oppervlakte (m2)
Werkgebieden totaal		**22**		**324162991,4**
Werkgebied (FID = 21)				**4931496,9**
Archeologische Vindplaatsen ()	**Ja**	**12**		**79383,7**
Archeologische Waardenkaart (Waarden)	**Ja**	**13**		**4930254,9**
1. Archeologisch Belangrijke Plaatsen				75717,1
2. Zeer hoge archeologische verwachting				2236912,9
3.1 Redelijk tot hoge archeologische verwachting direct onder mv of dieper.				1318561
3.2 Redelijk tot hoge archeologische verwachting beneden 0m NAP				524398,4
4. Redelijk tot hoge archeologische verwachting, waterbodems				814610,3
Bodemonderzoek DCMR ()	**Ja**	**21744**		**1943313,6**
Bodemfunctie ()	**Ja**	**15**		**4145051,4**
Wonen (Licht verontreinigd)				4145051,4
Bodemkwaliteit L1 ()	**Ja**	**15**		**4145051,4**
Industrie (Matig verontreinigd)				6737,7
Landbouw (Zeer licht verontreinigd)				2287292,8
Wonen (Licht verontreinigd)				1851020,9
Bodemkwaliteit L2 ()	**Ja**	**15**		**4145051,4**
Industrie (Matig verontreinigd)				3600,7
Verontreinigd (Sterk verontreinigd)				1012328,2
Wonen (Licht verontreinigd)				3129122,4
Bodemtoepassing ()	**Ja**	**15**		**4145051,4**
Landbouw (Zeer licht verontreinigd)				2287292,8
Wonen (Licht verontreinigd)				1857758,6
Buizen (product)	**Ja**	**11170**	**366082,4**	
Drinkwater			89403,2	
Gas			70886,2	
Overig			6045,8	
Rioolwater			137267,8	
Stadsverwarming			62576,8	
Kabels (product)	**Ja**	**33391**	**706559,6**	
[Geen waarde ingevuld]			1	
Elektriciteit			320351,1	
Kabeltelevisie			74408,8	
Telecom			336713,3	
KWO Diep ()	**Ja**	**3**		**4325918**
hoog potentieel voor woningen, kantoorgebouwen en bedrijventerreinen				12062,2
hoog potentieel voor woningen, kantoorgebouwen, bedrijventerreinen en lichte glastuinbouw				156894,9

Fig 7.4.2 With the Scantool extracting quantitative results for each GIS layer
Source: Stadsontwikkeling Rotterdam

7.5 Training



Once a year students of the Urban Planning Faculty from the TU Delft are given the opportunity to work with subsurface data from the City of Rotterdam, see Fig 7.5.1. They learn how to incorporate subsurface information in their 3D Plans and they are requested to make urban designs that make optimal use of the subsurface potential, see Fig 7.5.2 and Fig 7.5.3.

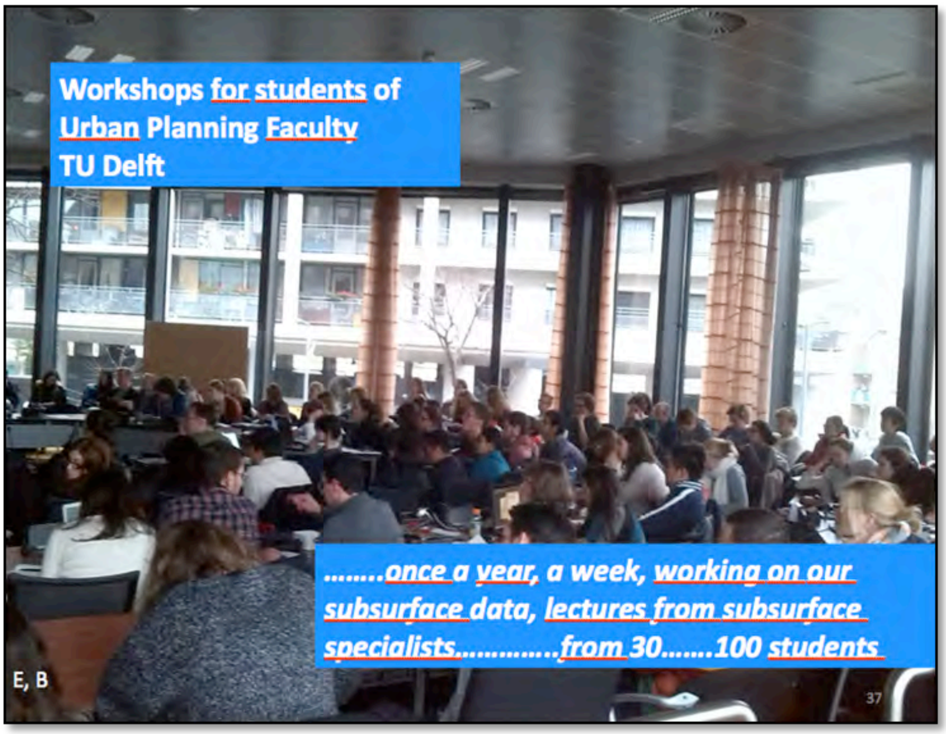


Fig 7.5.1 Group of students receiving lectures from subsurface specialists.
Source: Ignace van Campenhout

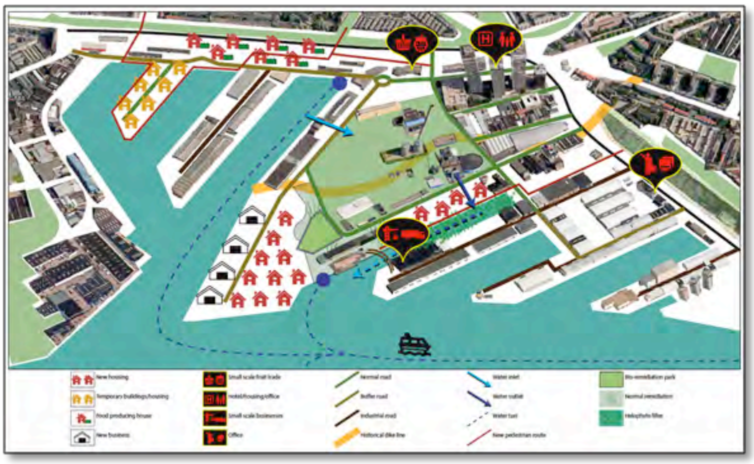


Fig 7.5.2 Urban design incorporating the subsurface potential map of previous figure
Source: Sanne Mooij/ TUDelft/ Stadsontwikkeling Rotterdam

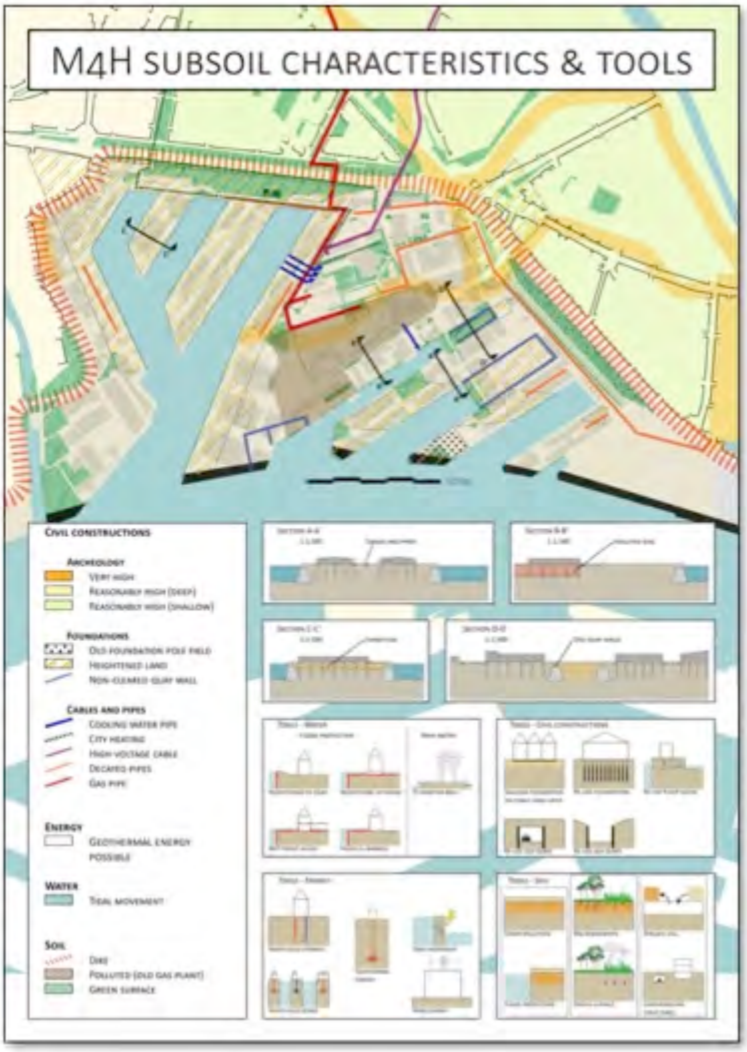
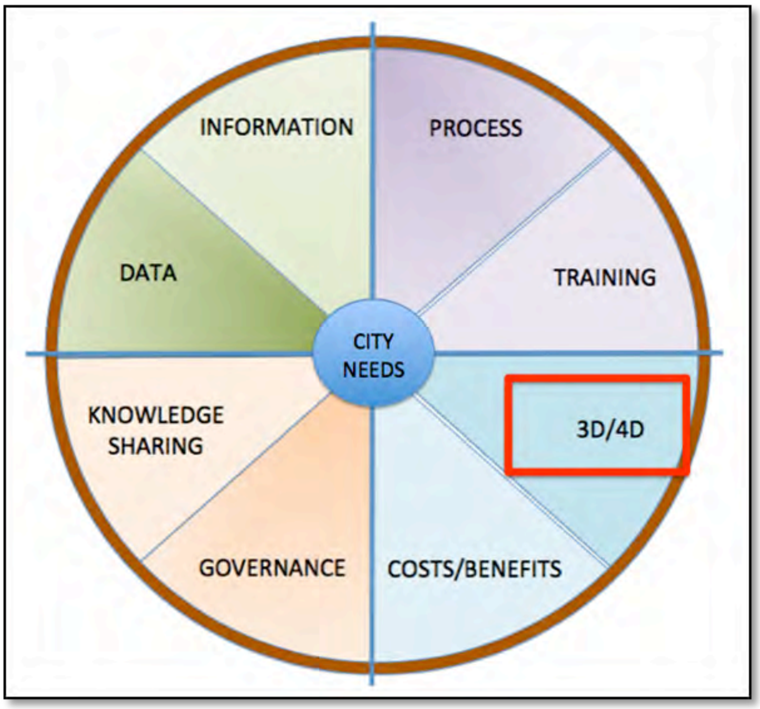


Fig 7.5.3 Excellent example of subsurface potential map
Source: Sanne Mooij/ TUDelft/ Stadsontwikkeling Rotterdam

7.6 From 2D "U-scan" to 3D "U-scan" to 4D Scenario tool



As explained in Chapter 6, we should move from a single zoning plan at ground level to at least four zoning plans for all four distinguished subsurface levels and ideally aim for a "zoning volume" for the entire public space, which means ground level and all underground layers. During the various stages of a project development cycle different models are requested, see Fig 7.2.3. During the designing and construction phases, detailed level of modeling is required and modeling is done with dedicated software specifically designed for a specific discipline. At the start of the spatial development cycle, during discussions and workshops with urban planners, it is not necessary that a visualisation of the subsurface contains a high level of detail: it is only important to know that there is a volume claimed by an archaeological find of a specified dimension at a certain location and depth; not to know if it is a Roman body or a French, see Fig 7.6a. Experimenting with LEGO building blocks during a "U-scan" workshop at Stadsontwikkeling has led to conclusion that a simple 3D model would help enormously to give urban planners insight into how the subsurface is built up and also how specific functions are claiming dedicated space, see Chapter 6. Different 3D modelling softwares do exist: urban planners themselves make extensive use of 3D interactive programmes like TNO's Urban Strategy, with which they can quickly run through scenarios and answer question like "What are the consequences for the environment if I change the course of this road". The "Gebiedsontwikkelaar", developed by Strategis, quickly goes through the economical effects of such measures. Below ground level civil engineers make use of their BIM softwares and in the same shallow zone TNO/ Geological Survey of the Netherlands has presented several geological/ geohydrological 3D models. The petroleum industry's use sophisticated softwares for the geological evaluation of the Deep Layer. Unfortunately exchange of information between these various platforms is still complicated, see Fig 7.6c.
For a small area in Rotterdam where a new spectacular office location for Stadsontwikkeling has been constructed recently, Stadsontwikkeling/ Stadsbeheer Rotterdam together with TNO and Strategis are developing a subsurface model that incorporates both geology and "artifacts", see Fig 7.6b.

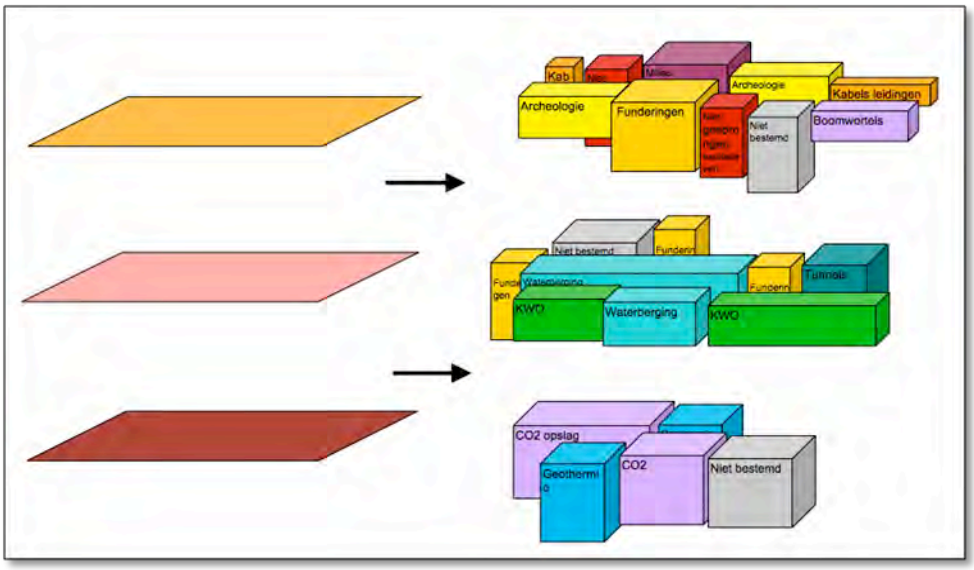


Fig 7.6a From 2D U scan to 3D U scan: different colours for different functions. Such a "LEGO" block model is sufficient for modeling the subsurface layers during the discussions with urban planners at the start of a spatial development cycle.
Source: Stadsontwikkeling Rotterdam

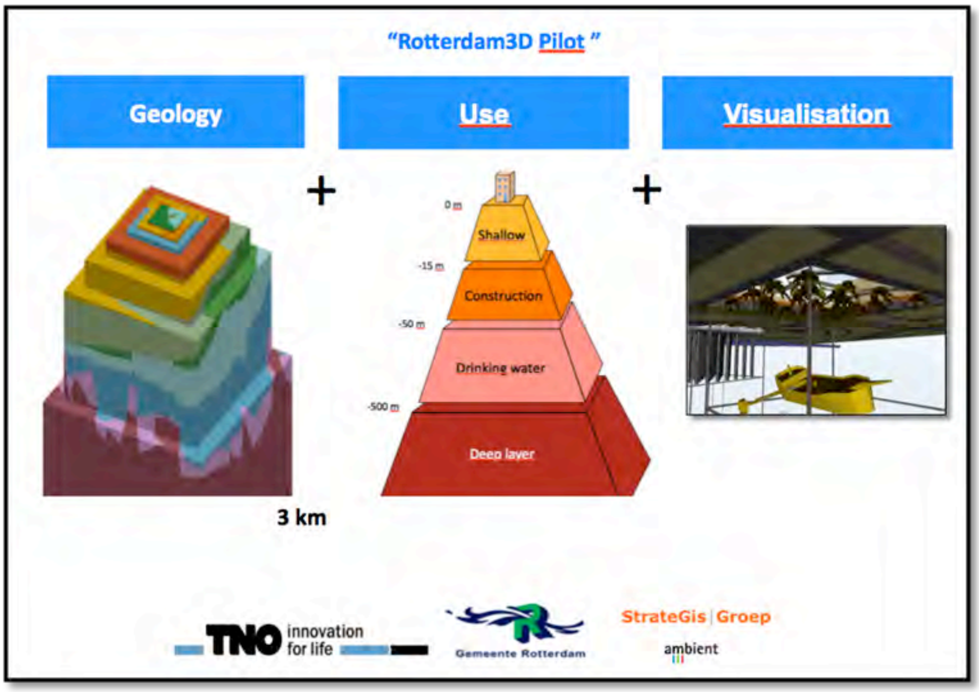


Fig 7.6b Geology and Use and Visualisation
Source: Stadsontwikkeling Rotterdam

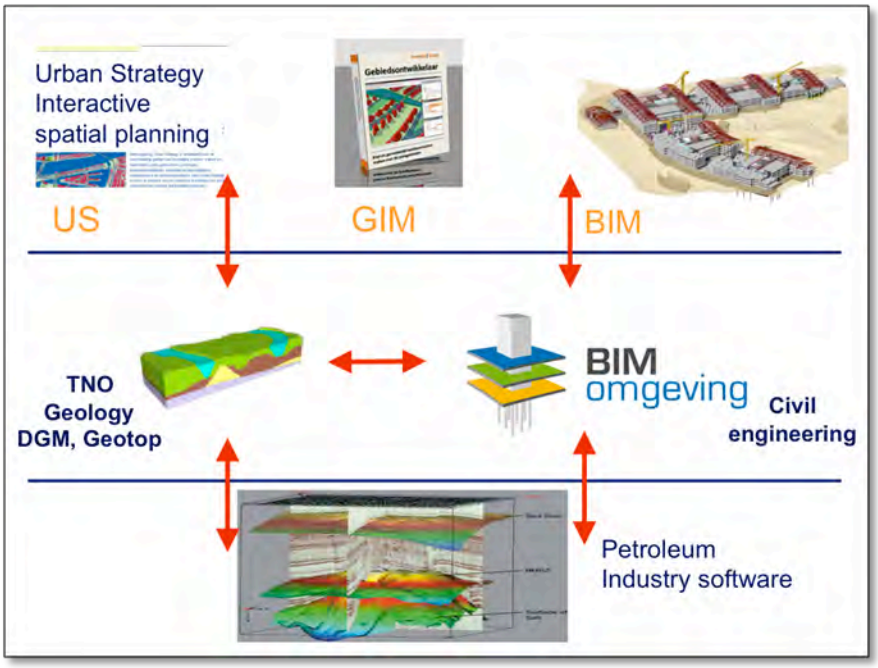


Fig 7.6c Sophisticated modelling and visualisation softwares for the public space exists but exchange between the various platforms is presently difficult.
Source: Stadsontwikkeling Rotterdam

7.6.1 3D Serious Game

Although with the "U-scan" we have already presented the subsurface as early as possible in the Spatial Development Cycle, it appears over and over again that it can never be introduced early enough. Urban developers appear at the start of a "U-scan" but as explained in chapter 1.3.3 but they do not know a lot about the subsurface. Like the rest of the public they do not have a picture about how the subsurface looks like. They cannot imagine how the subsurface could contribute to their urban designs. If you do not study a subsurface subject in the Netherlands, you have received little information on this subject during your educational years.

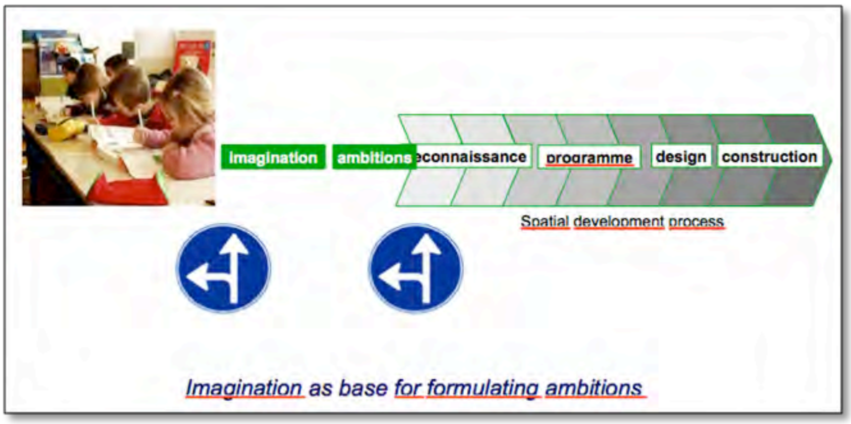


Fig 7.6.1a The motivation to develop the Serious Underground Game
Source: Stadsontwikkeling Rotterdam

Before urban planners take part in a "U-scan" they should have formulated an ambition about what they want to do with the subsurface. With the "3D Serious Game of the Subsurface" we stimulate their imagination. An equally important aspect as "**Imagination is the basis for formulating the ambitions"**, see Fig 7.6.1a. A consortium of provinces, municipalities TNO and SKB for that purpose, constructed the "serious game of the subsurface", see Fig 7.6.1b.

Fig 7.6.1b The Consortium of municipalities, provinces and private companies that constructed the serious game.
Source: Stadsontwikkeling Rotterdam

During the game the players become aware that:

- An integrated approach to space is necessary to avoid overlapping claims on space in the subsurface, see Fig 6b and Fig 6d.
- The subsurface is layered, see Fig 6c.
- They need to cooperate in order to be able to win the game

In the game four stakeholders (the Municipality: the Energy company, the Housing Corporation, the Water company) bear the responsibility to create an attractive city by making optimal use of the possibilities the subsurface has to offer.
The participants may take measures (geothermal, tunnels, underground shopping centre) with which they can score on performance indicators such as people and planet, see Fig 7.6.1c. They also have a limited budget and they will need to act in cooperation with other stakeholders if they want to succeed.
The game can be played via the web: http://www.urbit.nl/ondergrond/game_s.html

Fig 7.6.1c A consortium of municipalities, provinces and private companies constructed the serious game.
Source: Stadsontwikkeling Rotterdam

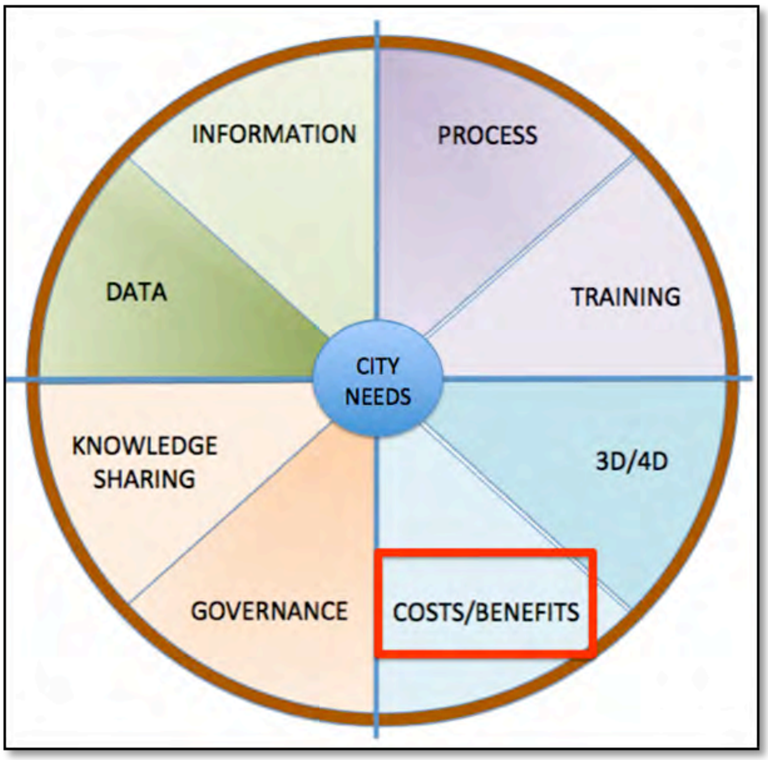
7.6.2 3D reality model: the Underground City Walk

One Sunday per month Stadsontwikkeling Rotterdam organises an Underground City Walk in the Centre of Rotterdam. During the walk the public, generally 30 persons per walk, gets insight into the subsurface of all the kind of topics which are discussed in this report, "from Cables to Carboniferous'.
Just like the Serious Game, the Underground City Walk is also designed to create awareness, so it fits in the first stages of the "Development model for the Subsurface" as discussed in chapter 8.1
During the walk the relationship between the subsurface and the historical development of the city is explained, major engineering interventions in the subsurface that have taken place in the city are discussed and the public is introduced to the way engineers at Stadsontwikkeling Rotterdam acquire and

manage subsurface data and information and visualise the information in maps and 3D models. Once a year the same tour is done with school children. At the moment an Underground Cycling Tour is in preparation.

Fig 7.6.2 Underground walk in the city centre; each Sunday morning.
Source: Peter Dorsman

7.7 Costs and benefits



Underground developments are often considered to be more costly than the developments at ground level and therefore they are chosen only when there is no alternative at ground level. That is certainly the case if we only consider the gross cost of construction. But if the cost of land and the exploitation costs are included, underground projects are often competitive. The cost of projects should be assessed on the entire life cycle of the infrastructures (i.e. construction, exploitation, removal/destruction, land costs). Additionally, for a full evaluation of costs and benefits not only physical assets should be taken into account, but also natural, ecological assets; it is not only about “economics“, also about “values”

Benefits are more difficult to quantify than costs. An additional complication is that "who pays for the costs is often not the same as who receives the benefits". It is all about having a balance between Costs, Performance and Risks; about creating a "maximum of utilisation and optimal protection", see Fig 7.7.1
Once Costs, Benefits and Risks are properly defined the process of Prioritising can start and choices can be made. E.g should one choose for:

- One geothermal project or for 100 Shallow Geothermal Units?
- Reserving the underground space for Shallow Geothermal Unis or for infrastructure?
- Reserving the shallow subsurface for trees or for cables and pipelines?

New developments should be taken into account (e.g. 4D development) and evaluations should not be "project" based but "system" based. This is a new subject for the City of Rotterdam and Stadsontwikkeling is currently exploring this topic with partners Deltares and University of Hasselt.

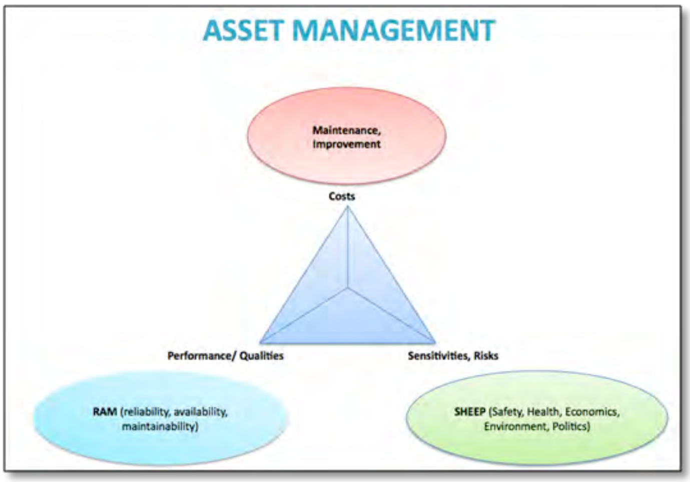
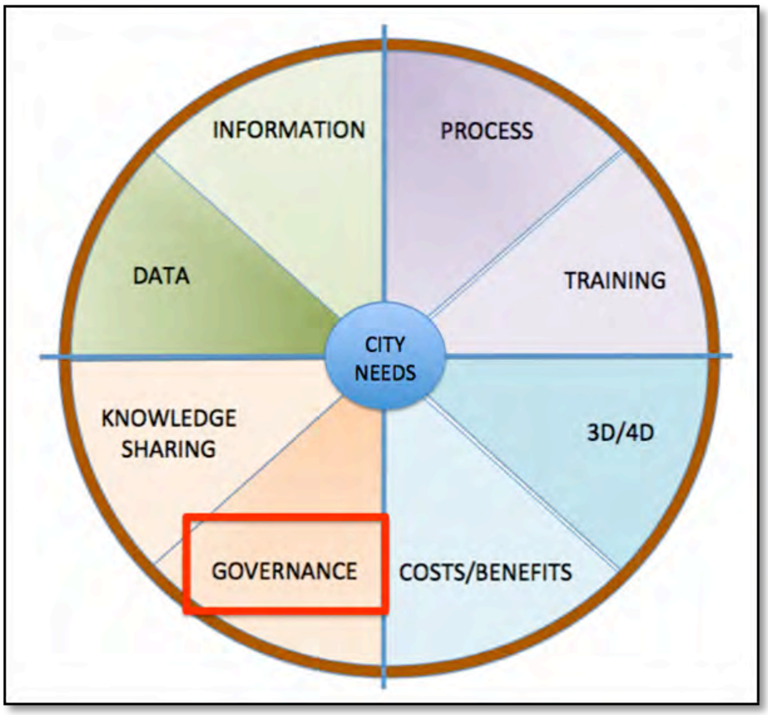


Fig 7.7.1 Asset management: striving for a balance between Costs, Risks and Performance
Source: Linda Maring, Deltares

7.8 Governance



Responsibilities for the subsurface in the Netherlands are shared between various authorities:

- Municipalities take care of the shallow layers, but concerning water issues they share the responsibilities with the water boards.
- Provinces are responsible for the intermediate layers, the layers where drinking water and shallow geothermal energy is being produced.
- The national government is responsible for the activities in the subsurface below 100m with activities like oil and gas exploration/production and geothermal energy.

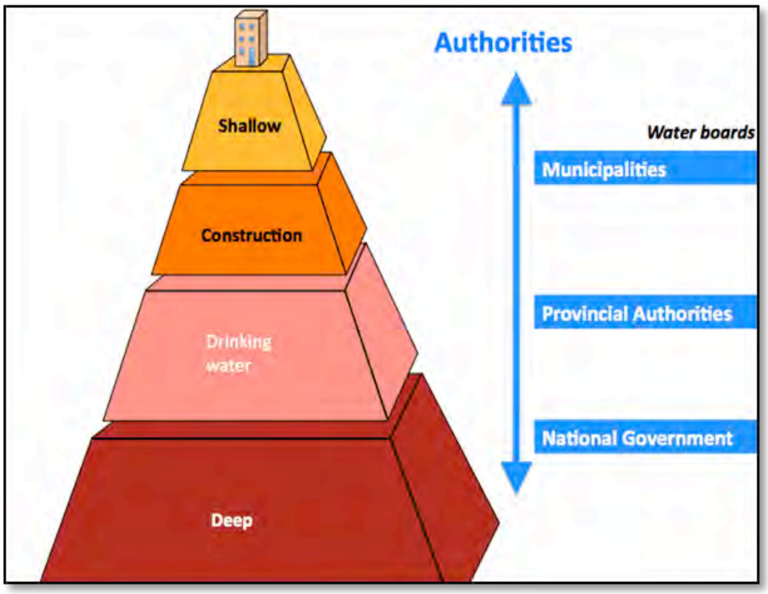


Fig 7.8.1 Responsibilities for the subsurface shared between various authorities.
Source: Stadsontwikkeling Rotterdam

Unfortunately this sharing of responsibilities complicates matters significantly, for instance in the following cases:

- In Chapter 1, the pile rot issue has been discussed. Restoring problems caused by pile rot could cost house owners up to EURO 60.000. The municipality refers owners to the water board and vice versa.
- If a citizen wants to construct a Closed Shallow geothermal Unit, he/she needs contact the municipality; for an Open Shallow geothermal Unit the province needs to be contacted, but the water board handles the associated groundwater risks.
- Drilling into the deep zone for oil & gas or for geothermal energy involves drilling through the sensitive drinking water zone. Drinking water companies are however not entitled to the drilling data concerning the drinking water zone.

Due to the increasing use of the subsurface it is necessary to adapt a vision on the subsurface where both demand for space for various functions as well as suitability of the subsurface are properly balanced. Instead of the principle of 'first come, first served', that has been applied so far to the use of the subsurface, careful assessment of effects of proposed use on other potential use in all underground layers should be the base for approval. The Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs are therefore currently preparing a vision on the subsurface (“STRONG”), together with provinces and Municipalities. This will offer a framework for the efficient and sustainable use of the subsurface. With such a vision subsurface activities that can reinforce each other or in contrast, are in each other’s way, can be identified and confrontation of claims can be avoided. Rotterdam is playing an active role in preparing this structure vision.

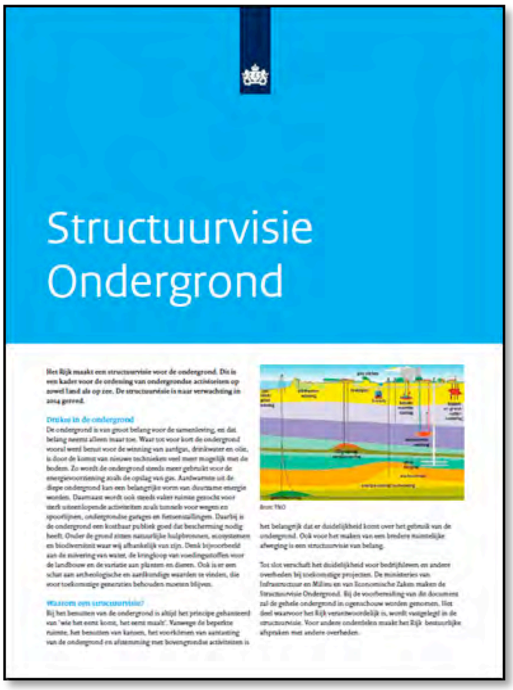
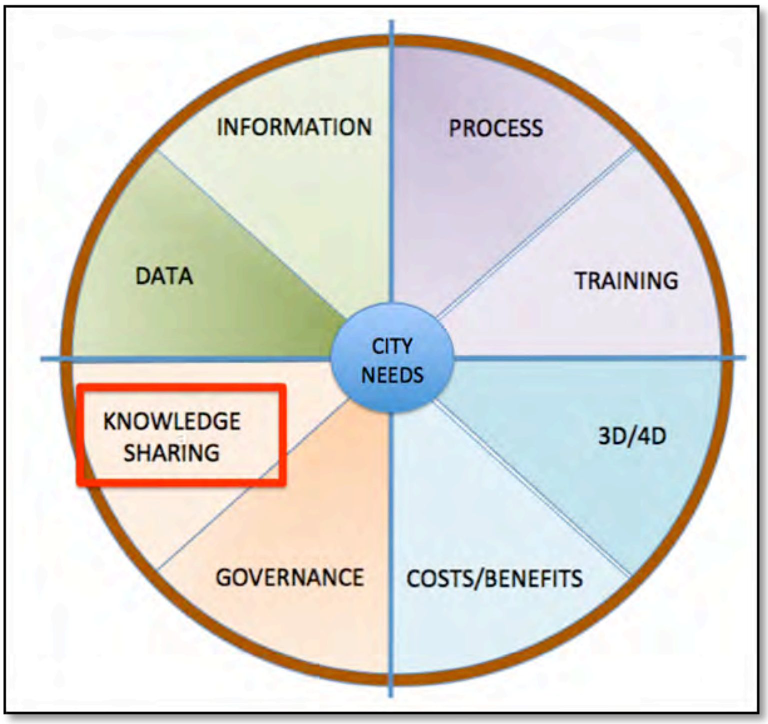

Structuurvisie
Ondergrond

Fig 7.8.2 Structure vision on the subsurface (STRONG), currently in preparation
Source: Ministry of Infrastructure and the Environment and Ministry of Economic Affairs

7.9 Knowledge Sharing



7.9.1 Rotterdam in its national context

The Ministry of the Environment (VROM) started in 2007 with a programme on approaching the subsurface in an integral way. Rotterdam, together with the cities of Enschede, Utrecht and Arnhem participated in this pioneering programme.

Fig 7.9.1a In 2007: the kick off of the integral approach of the subsurface
Source: Ministry of Infrastructure and the Environment (VROM)

Within the Rotterdam Stadsontwikkeling department and its predecessor Gemeentewerken Rotterdam, a team dedicated to the integral evaluation of the subsurface (pRODEO) was established in 2008. pRODEO has been active in major urban developing projects and programmes. The pRODEO team members act as "brokers" between subsurface specialists and urban planners.

pRODEO
Professionals op het raakvlak van
Ruimtelijke Ontwikkeling, Duurzaamheid, Energie en Ondergrond

Fig 7.9.1b The Stadsontwikkeling pRODEO team: professionals at the intersection of spatial development, sustainability, energy and the subsurface.

The results obtained so far by the pRODEO team have been reached by intense cooperation with other teams in the Rotterdam Stadsontwikkeling and –Stadsbeheer departments and with other municipalities, provinces, ministries and public- and private companies and network organisations, see Fig 7.9.1c.

Fig 7.9.1c Partners of the City of Rotterdam in getting the "integral approach" message through.
Source: Stadsontwikkeling Rotterdam

During the 1014 and 2016 editions of the International Architecture Biennale Rotterdam pRODEO organised together with partners the Urban Underground event; an event where the integral approach of the subsurface was promoted and where representatives from various the underground and above ground disciplines shared their knowledge, see Fig 7.9.1d.

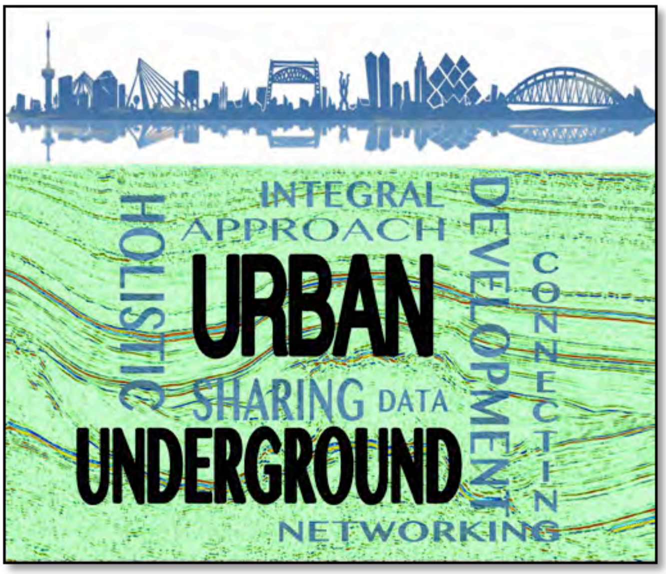


Fig 7.9.1d The Urban Undergound day during the International Architectural Biennale Rotterdam.
Source: Stadsontwikkeling Rotterdam

7.9.2 Rotterdam in European context

Rotterdam participates in COST SUB-URBAN, a European network to improve understanding and use of the ground beneath our cities. http://www.cost.eu/COST_Actions/tud/TU1206
The main aim of this network is to provide a long-needed contribution to greater interaction and networking, and so transform the relationship between experts who develop urban subsurface knowledge and those who can benefit most from it - urban decision makers, practitioners and the wider research community, see Fig 7.9.2. This will lead to improved understanding and use of subsurface by urban decision makers during policymaking, planning and construction of projects.

In order to maximise the economic, social and environmental benefits of urban subsurface resources and ecosystem services on which cities depend, the network will:

- Draw together collective research capabilities in 3D/4D characterisation, prediction and visualisation of the subsurface
- Deliver this in appropriate forms
- Provide training and continuing support and advice to better inform and empower decision makers and other end-users
- Foster development of policy which reflects the importance of the urban subsurface
- Recommend the basis for improved availability, initial use and re-use of subsurface data

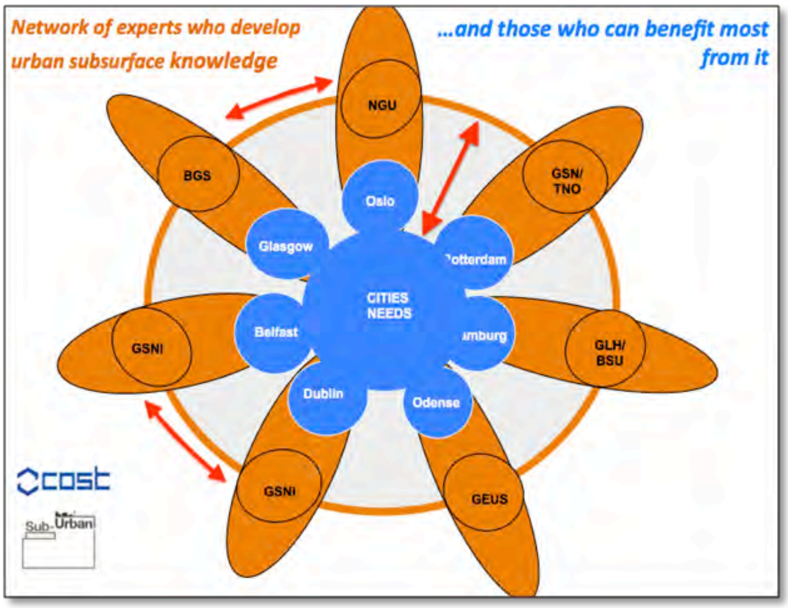


Fig 7.9.2a The COST SUB-URBAN network
Source: Stadsontwikkeling Rotterdam

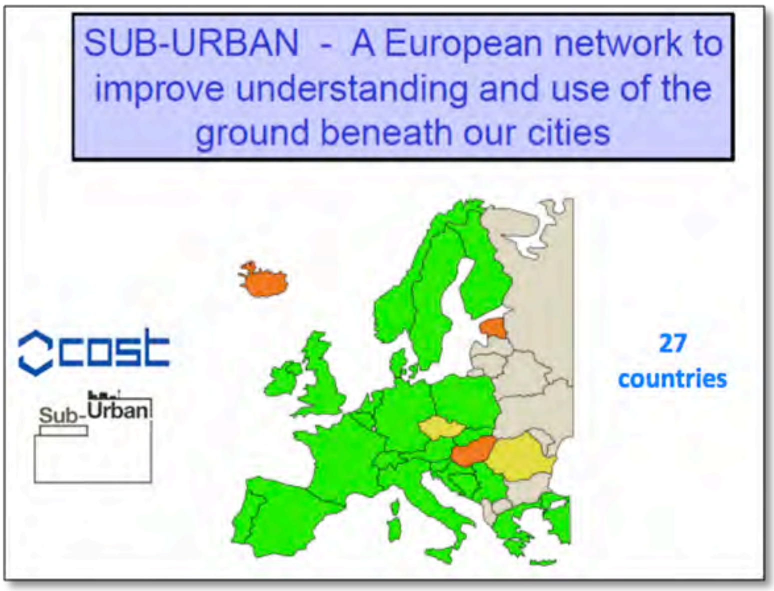
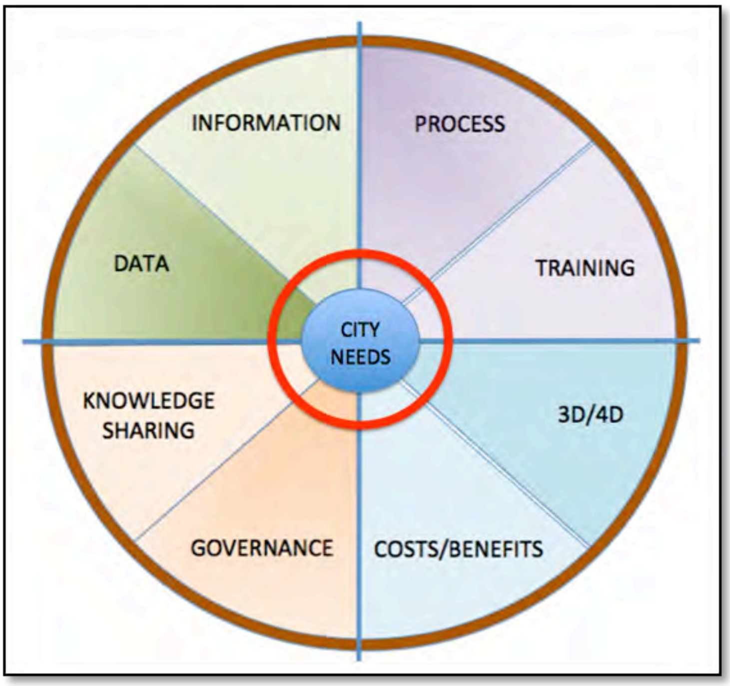


Fig 7.9.2b Participating countries in the COST SUB-URBAN network
Source: COST SUB-URBAN

7.10 **City Needs**



So far a lot of energy trying to integrate the subsurface as early as possible in the urban planning process has focused on the “”supply side”. Now time has come to focus on the “”demand side””, on the “City Needs”. The challenge is to make clear to urban decision makers that subsurface specialisms like geohydrology, archaeology, geology, cables and pipelines play a vital role in maintaining cultural heritage of our cities and keeping them healthy and clean and safe, see Fig 7.10.1a.

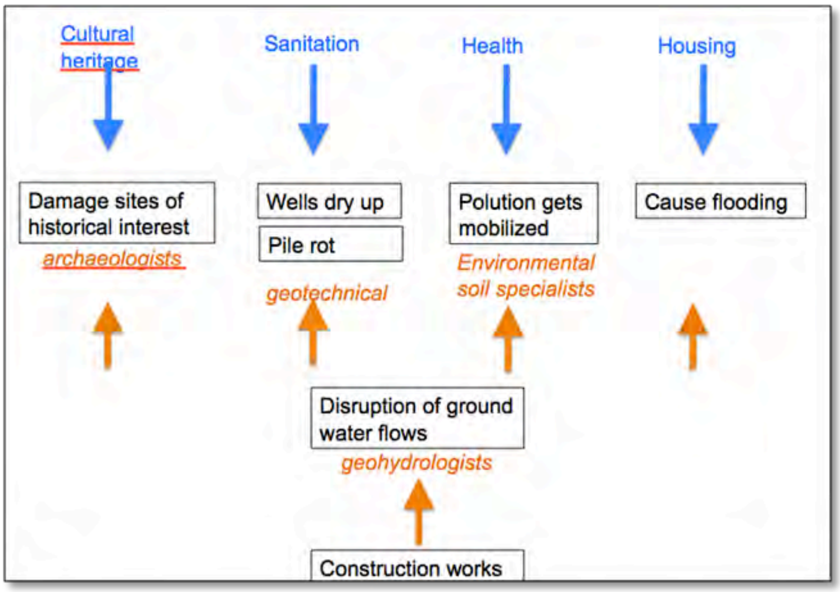


Fig 7.10.1a Linking subsurface topics to urgent city themes
Source: Stadsontwikkeling Rotterdam

The City of Rotterdam participates in the City Resilience Framework, an international program that focuses on making cities resilient. The subsurface could play an important role in reaching this goal.

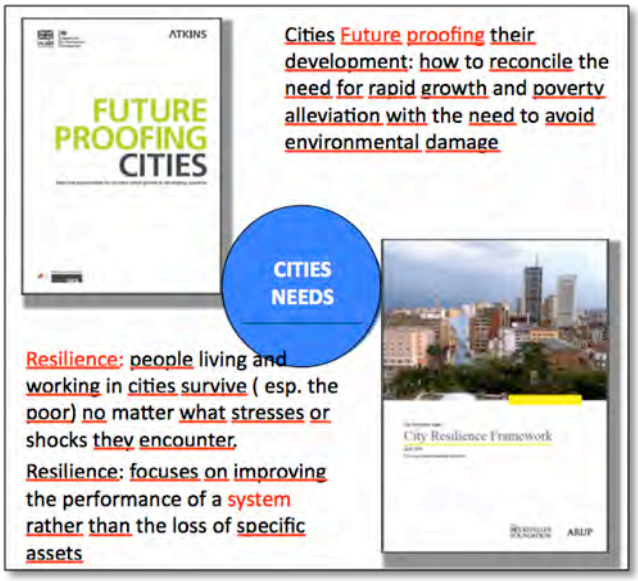


Fig 7.10.1b City Resilience Framework and Future Proofing Cities: two examples of **programs that define the urgent city needs.**
Source: Stadsontwikkeling Rotterdam

7.11 **Concluding remark**

Fig 7.11.1 Under construction!
Source: Stadsontwikkeling Rotterdam

Since the start in 2007, see Chapter 7.9.1, Rotterdam has made significant progress in making urban planners and decision makers aware of the possibilities and impossibilities of its subsurface. However, there is still a long road to go; “under construction” is the motto!

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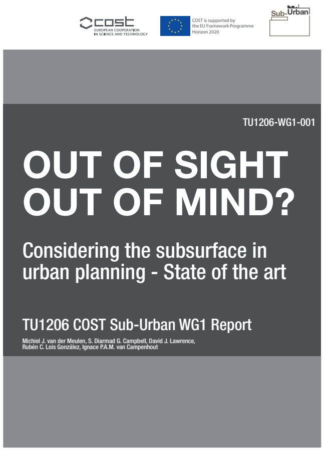
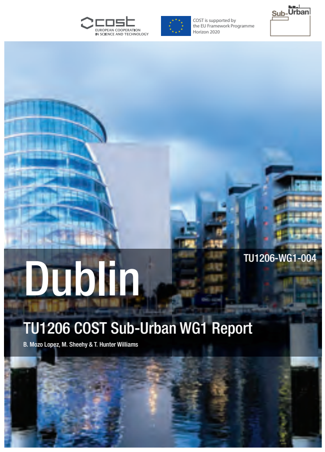
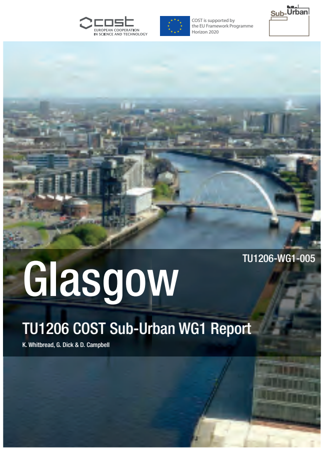
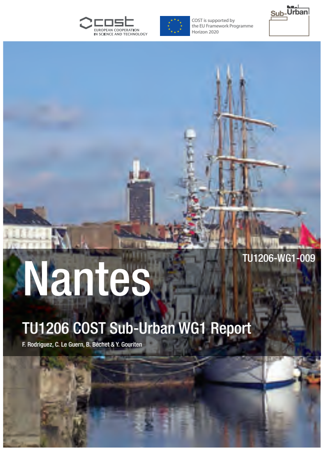
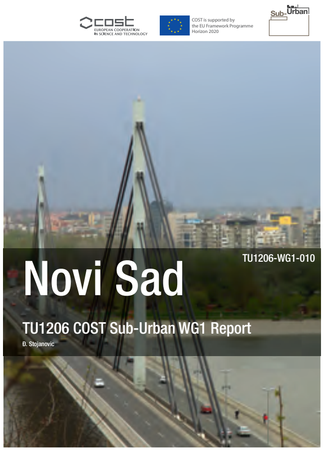
COST is supported by the EU Framework Programme Horizon 2020

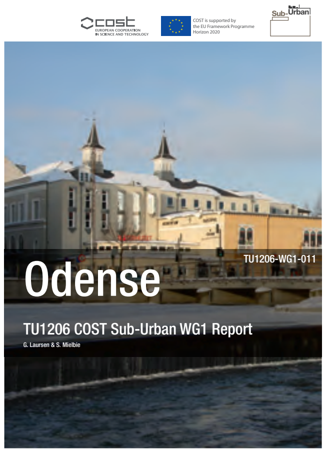












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