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TU1206-WG1-001

OUT OF SIGHT OUT OF MIND?

Considering the subsurface in urban planning - State of the art

TU1206 COST Sub-Urban WG1 Report

Michiel J. van der Meulen, S. Diarmad G. Campbell, David J. Lawrence,
Rubén C. Lois González, Ignace P.A.M. van Campenhout

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Authors: Michiel J. van der Meulen, S. Diarmad G. Campbell, David J. Lawrence,
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Version	Version 1, March 2016
Authors	Michiel J. van der Meulen[1], Ingelöv Eriksson[2] S. Diarmad G. Campbell[3], David J. Lawrence[3], Rubén C. Lois González[4], Ignace P.A.M. van Campenhout[5] [1] Workgroup leader | TNO Geological Survey of the Netherlands, Princetonlaan 6, 3584 CB Utrecht, The Netherlands [2] Workgroup deputy leader | Avdeling for Geodata, Plan- og bygningsetaten, Oslo Kommune, Norway [3] British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, United Kingdom [4] University of Santiago de Compostela, Department of Geography, Praza da Universidade 1, 15782 Santiago de Compostela, Spain [5] Gemeentewerken Rotterdam, Europoint III, Galvanistraat 15, 3029 AD Rotterdam, The Netherlands
Contributors	**A Coruña**: Beatriz Moar Ulloa | **Bergen**: Anna Seither, Guri Ganerød, Hans de Beer, Torbjørn Melle, Ingelöv Eriksson **Dublin**: Beatriz Mozo Lopez, Michael Sheehy, Taly Hunter Williams **Glasgow**: Katie Whitbread, Gillian Dick **Hamburg**: Renate Taugs, Lothar Moosmann, Nikolaus Classen, Paul Meyer | **Helsinki**: Ossi Ikävalko, Ilkka Satola, Raila Hoivanen | **Ljubljana**: Mitja Janža, Ivan Stanič, Petra Jamšek Rupnik, Miloš Bavec | **Nantes**: Fabrice Rodriguez, Cécile Le Guern, Béatrice Béchet, Yves Gouriten | **Novi Sad**: Đurđica Stojanović | **Odense**: Gert Laursen, Susie Mielby **Oslo**: Ingelöv Eriksson, Johan Borchgrevink, Marte Muan Sæther, Hans Kristian Daviknes, Stavros Adamou, Live Andresen **Rotterdam**: Ignace van Campenhout, Jeroen Schokker

Organisations	BGS British Geological Survey | BRGM Bureau de Recherches Géologiques et Minières | City of Hamburg City of Helsinki | City of Rotterdam | GeoZS Geological Survey of Slovenia | GEUS Geological Survey of Denmark and Greenland | Glasgow City Council | GSI Geological Survey of Ireland | GTK Geological Survey of Finland Hamburg Water | IFSTTAR Institut français des sciences et technologies des transports, de l'aménagement et des réseaux | IRSTV Institut de Recherche en Sciences et Techniques de la Ville | Municipality of A Coruña | Nantes Métropole | NGU Geological Survey of Norway | Odense Municipality | Oslo Municipality | TNO Geological Survey of the Netherlands | University of Novi Sad
Online resources	For supplementary material see: www.Sub-Urban.eu/
Project website	www.cost.eu/COST_Actions/tud/TU1206/

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Abstract

The subsurface is an important constituent of the physical environment of cities. We live on top of it; building and construction have to deal with the structure and properties of the subsurface, and occasionally with the hazards it presents. Cities not only expand outward and upward, but also downward. More and more, subsurface space is used to relieve the increasingly crowded and congested urban surface, especially for networks (metros, tunnels, cables, sewage, drainage), storage (warehouses, cellars, parking lots, thermal energy), and exotic applications such as shelter and protection (nuclear bunkers, bank vaults, underground passageways in cities with harsh climates). The more use we make of subsurface space, the more surface space we free for the one function that cannot do without daylight and fresh air: living.

Its ability to record is a function of the subsurface that is particularly relevant to the urban domain. Just as rocks in general are records of conditions and events in the geological past, the urban subsurface can be seen as a physical record of the history of cities. Buried cultural heritage needs our protection, whether by preventing its degradation in situ, or by careful excavation before building and construction take place. However, it also reflects industrial legacies and their impacts in the form of polluted soils or unstable mine shafts.

From the above, the importance of knowing the ground beneath cities may seem self-evident, but the urban subsurface is in fact still largely ‘out of sight, out of mind’. It does not present a daily concern to city planners and managers, and when it does, there is often trouble. COST Action TU1206 Sub-Urban therefore sets out to explore, promote and improve the use of the urban subsurface. It aims to help identify options for cities to grow and develop more sustainably that are currently overlooked, and to increase the predictability of ground conditions that are now considered unforeseeable. For these purposes, this report offers a review of the state of the art, which describes the interactions between urban and subsurface domains in generic terms, with special reference to the acquisition of subsurface data, their interpretation into useful subsurface models, and the transferability of data and models to planning documents.

Keywords

City; urban planning; urban geology; subsurface; A Coruña; Bergen; Dublin; Glasgow; Hamburg; Helsinki; Ljubljana; Nantes; Novi Sad; Odense; Oslo; Rotterdam; Europe

Full reports

The present report summarises and analyses the following city case studies (available online at www.Sub-Urban.eu/):

City	Report
A Coruña	B. Moar Ulloa, 2015. A Coruña. Municipality of A Coruña, TU1206-WG1-002, 26 pp.
Bergen	A. Seither, G.V. Ganerød, H. de Beer, T. Melle, I. Eriksson, 2015. Case Study of Bergen. NGU Geological Survey of Norway (Trondheim) & Oslo Municipality, TU1206-WG1-003, 43 pp.
Dublin	B. Mozo Lopez, M. Sheehy, T. Hunter Williams, 2014. Subsurface and urban planning in the City of Dublin. Geological Survey of Ireland (Dublin), TU1206-WG1-004, 21 pp.
Glasgow	K. Whitbread, G. Dick, 2014. The subsurface and urban planning in the City of Glasgow. BGS British Geological Survey (Edinburgh) & Glasgow City Council, TU1206-WG1-005, 21 pp.
Hamburg	R. Taugs, L. Moosmann, N. Classen, P. Meyer, 2014. Case Study of Hamburg, theme: Groundwater monitoring and modelling of the urban groundwater system of Hamburg, Ministry of Urban Development and the Environment & Hamburg Water (Hamburg), TU1206-WG1-006, 24 pp.
Helsinki	O. Ikävalko, I. Satola, R., Hoivanen, 2015. The subsurface planning and construction in the City of Helsinki. GTK Geological Survey of Finland (Espoo) & City of Helsinki, TU1206-WG1-007, 16 pp.
Ljubljana	M. Janža, I. Stanič, P. Jamšek Rupnik, M. Bavec, 2015. City description of Ljubljana. GeoZS Geological Survey of Slovenia and City of Ljubljana (Ljubljana), TU1206-WG1-008, 6 pp.
Nantes	F. Rodriguez, C. Le Guern, B. Béchet, Y. Gouriten, 2014. Case study – Nantes. IFSTTAR Institut français des sciences et technologies des transports, de l'aménagement et des réseaux (Bouguenais), BRGM Bureau de Recherches Géologiques et Minières (Nantes), IRSTV Institut de Recherche en Sciences et Techniques de la Ville (Nantes), Nantes Métropole, TU1206-WG1-009, 11 pp.
Novi Sad	Đ. Stojanović, 2015. Novi Sad - Challenges for making state of the art. University of Novi Sad, TU1206-WG1-010, 3 pp.

Odense Gert Laursen, Susie Mielby, 2014. Odense – A city getting wetter? Municipality of Odense & GEUS Geological Survey of Denmark and Greenland (Odense), TU1206-WG1-011, 28 pp.

Oslo Ingelöv Eriksson, Johan Borchgrevink, Marte Muan Sæther, Hans Kristian Daviknes, Stavros Adamou, Live Andresen, 2014. State of the art report for Oslo municipality. Oslo Municipality, TU1206-WG1-012, 29 pp.

Rotterdam Ignace van Campenhout, Jeroen Schokker, 2015. Rotterdam - between Cables and Carboniferous. City development and its subsurface. City of Rotterdam and TNO Geological Survey of the Netherlands (Utrecht), TU1206-WG1-013, 85 pp.

1. Introduction

Project Sub-Urban

COST[1] Action TU1206 Sub-Urban[2] explores management of the urban subsurface and the use of subsurface information in urban planning. For that purpose, the project's Working Group 1 has assessed the state of the art, and presented the results in a series of comprehensive city reports for A Coruña, Bergen, Dublin, Glasgow, Hamburg, Helsinki, Ljubljana, Nantes, Novi Sad, Odense, Oslo and Rotterdam. Each individual report takes both an urban planning and a subsurface perspective, and was jointly prepared by planning and geoscience experts. The present report summarises these reports, draws some general conclusions on the subject, and offers a view on the way forward.

Technical experts often speculate or philosophise about the needs of planners and policy makers they wish to serve, who in their turn speculate about or are unaware of technical (im)possibilities. The Sub-Urban COST Action has arranged for interaction between the two, allowing all participants to keep to their trade, and to bring in what each does best. Even though (potential) providers and users of urban subsurface information do of course consult with each other, Sub-Urban has enabled a level of exposure between the two that is rare, both in duration and depth. A first general lesson learnt from the whole exercise is that the interaction achieved in this way has been very useful and productive.

Organisation of Work package 1

Working Group 1 started in April 2013 and rapidly expanded to the twelve cities that are represented in this report. A series of meetings and workshops were organised at which project participants, i.e. city representatives, subsurface experts and planning scientists, discussed subsurface-related challenges and opportunities, building a general awareness of the challenges that cities are facing, and sharing approaches and solutions. Working group 1 encouraged all city representatives to write a State-of-the-Art report. The most important content of each report have been extracted into the summary report. The full reports are available through the Sub-Urban web page.

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[1] COST is the longest-running European framework supporting transnational cooperation among researchers, engineers and scholars across Europe. It is a unique means for them to jointly develop their own ideas and new initiatives across all fields in science and technology, including social sciences and humanities, through pan-European networking of nationally funded research activities. See http://www.cost.eu/

[2] http://www.cost.eu/COST_Actions/tud/TU1206/

What is a city?

Cities are microcosms. Each city we studied inevitably represents a unique combination of governance, history, traditions, and environment, including geological setting. We also refer, on a more practical level, to the fact that city planners and managers do not often consult in depth with their peers in other cities, let alone abroad, even though they are all basically solving similar problems in different settings. The city council/municipality representatives who are taking part in Sub-Urban have found the interaction amongst themselves inspiring and useful. The purpose of the project is to extend this to a wider community of urban stakeholders, both within the councils of cities that have already participated and towards new cities.

> "*A city is a large and permanent human settlement. Although there is no agreement on how a city is distinguished from a town in general English language meanings, many cities have a particular administrative, legal, or historical status based on local law. Cities generally have complex systems for sanitation, utilities, land usage, housing, and transportation. The concentration of development greatly facilitates interaction between people and businesses, benefiting both parties in the process, but it also presents challenges to managing urban growth.*"

What is urban planning?

> "*Regional/spatial planning gives geographical expression to the economic, social, cultural and ecological policies of society. It is at the same time a scientific discipline, an administrative technique and a policy developed as an interdisciplinary and comprehensive approach directed towards a balanced regional development and physical organisation of space according to an overall strategy*" (European Regional/Spatial Planning Charter, adopted in 1983 by the Council of Europe Conference of Ministers responsible for spatial/regional planning, CEMAT)
>
> "*Urban planning is a technical and political process concerned with the use of land, protection and use of the environment, public welfare, and the design of the urban environment, including air, water, and the infrastructure passing into and out of urban areas such as transportation, communications, and distribution networks. Urban Planning is also referred to as urban and regional, regional, town, city, rural planning or some combination in various areas worldwide..*"
> (Wikipedia, accessed on 1 April 2016)

An urban planner is trained to process and analyse various types of information concerning an urban area and present it to the public and politicians. The urban planner needs to respect national and European laws as well possible local restrictions and guidelines that set the framework for the urban planning in his or her municipality or region. Planning systems vary per country, but are generally characterised by a hierarchy. At the highest level, there will be a master plan, which defines the overall zonation (housing, commercial, industrial) and infrastructure, covering the entire city, being based on a long-term vision for its development. The master plan sets boundary conditions for subordinate plans, down to the level of detailed zoning plans for individual urban sectors.

Why consider the urban subsurface?

Cities are where they are for a reason. You will find them near water and arable lands, at military or logistically strategic points, or near mineral resources. After their establishment, world history and their own dynamics made cities what they are today, determining whether they are: small or large, powerful or peripheral, cosmopolitan or isolated, prosperous or poor. Over time, an initial advantage may have become irrelevant, or even changed into a disadvantage. A stronghold is now a tourist attraction. The river that was once a source of drinking water and food, is now primarily a transport pathway and perhaps a source of flood risk. The mine that once brought prosperity now brings instability. Many, if not most of the reasons for cities being where they are actually relate to past and ongoing geological processes, which determine landscape and the presence of resources. The subsurface is the product of these processes, and represents a hidden but integral part of the urban environment.

Zooming in, the most practical importance of the subsurface is in the fact that a city is built on top of it. **Building and construction** have to deal with the structure and properties of the subsurface: the subsurface may determine what can or needs to be constructed, and where, and basically sets boundary conditions for design. The subsurface not only presents stability for constructions (or a lack of it), it also presents space. Intensification of urban land use and mobility leads cities to not only build up and out, but also down. More and more, subsurface space is used to relieve the increasingly crowded and congested urban surface, especially for **networks** (metros, tunnels, cables, sewage, drainage), **storage** (warehouses, cellars, parking lots, thermal energy), and exotic applications such **shelter and protection** (nuclear bunkers, bank vaults, underground passageways in cities with harsh climates). The more use we make of subsurface space, the more surface space is freed for the one function that cannot do without daylight and fresh air: **living**.

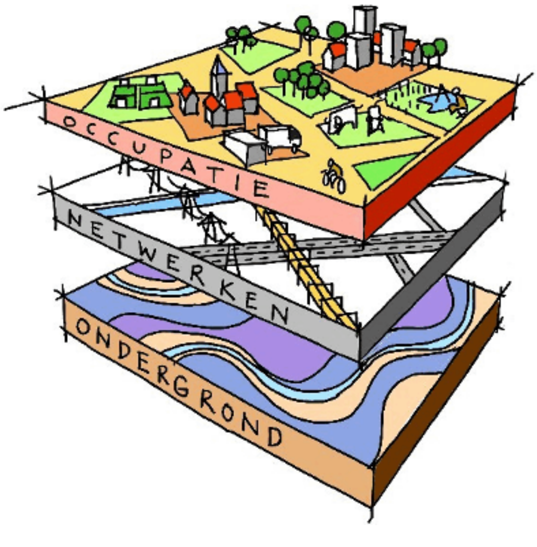
The subsurface holds **resources**. Groundwater requires protection from urban pollution, and its exploitation and management – even when this occurs outside the city proper – may affect urban ground conditions, causing problems such as subsidence and deterioration of foundations. Building materials are typically quarried close to urban areas, restricting land use and creating stability problems when cities grow over sites that once yielded their resources. Hydrocarbon production may cause regional subsidence and seismicity, having a sphere of influence that is typically larger than individual cities. Mining, an industry that has been on decline in Europe for decades, evolved from a source employment to a source of concern, as abandoned shafts have caused subsidence and sinkholes in and near former mining towns.

Its ability to **record** is a function of the subsurface that is particularly relevant to the urban domain. Just as rocks in general are records of conditions and events in the geological past, the urban subsurface can be seen as a physical, non-documentary archive of urban history. Buried **cultural heritage** needs our protection, whether by preventing its degradation in situ, or by careful excavation before building takes place. Unfortunately, though, the subsurface will also preserve the evidence of **industrial legacies** in the form of polluted soils or unstable mine shafts.

… so why don't we?

If the importance of considering the subsurface in urban planning is as self-evident as suggested above, why did we feel it was necessary to create a project to make this very point? Most importantly, the subsurface is still largely **out of sight, out of mind**. It does not present a daily concern to city planners or the city's inhabitants. General awareness of the subsurface below cities typically only exists where either great opportunities are presented, think of boomtowns like Kimberly (diamond mining) and Dawson (Klondike gold rush), or great risks, for example in San Francisco (the San Andreas Fault) and Naples (the Vesuvius volcano). However, in the much more prevalent less spectacular cases, beneficial subsurface conditions are taken for granted, and the subsurface is only considered when adverse conditions manifest themselves, in which case they often referred to as unforeseen. **So the subsurface usually means nothing or trouble**.

In the past, the typical response of a geoscience professional hearing about such trouble was, 'I could have told them, if they had just asked me.' Even when accurate, there is an element of self-serving in offering such wisdom in hindsight, which we feel should be replaced by a sense of an opportunity missed. We see rapid advances in the applied earth sciences and geo-information management, which we hope will ultimately make the term 'unforeseen ground conditions' something of the past.



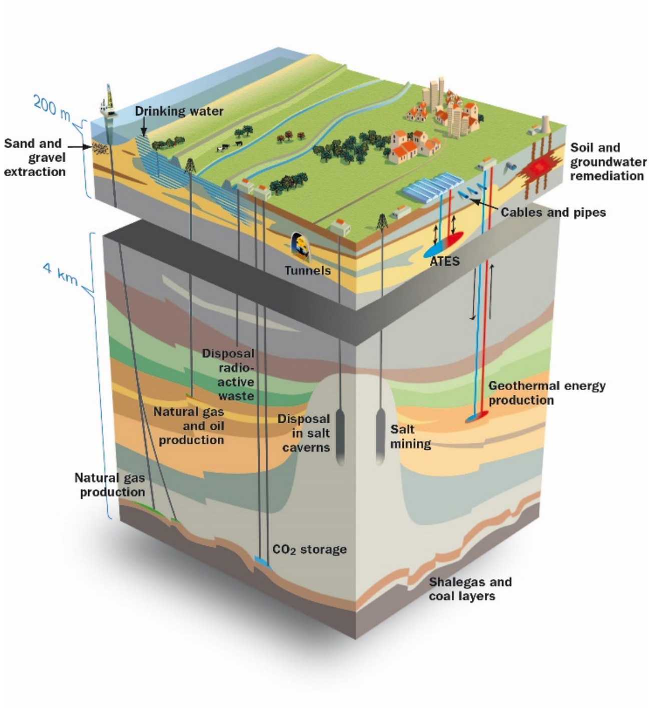
The layer approach, a Dutch spatial planning concept that distinguishes between three layers, conceptual rather than physical, each having its own combination of properties, functions and dynamics. Buildings, and other primary land use functions are in the **occupation layer**. In terms of residence time and change, these functions are more dynamic than the transport infrastructure and utilities networks that connect them, and are put in the **network layer**. The subsurface layer is the least dynamic, not only because of the long life of underground constructions such as tunnels and mines, but also because geological processes such as deformation and groundwater flow are distinctly slower than superficial environmental processes we are more used to. Its representation may not be very sophisticated, but the fact that it is represented presents an advantage to Dutch spatial planning.

What do we know?

Traditionally, the subsurface is seen primarily as a source of energy, minerals and water, and what we know of it is largely related to their exploration. Yet while cities obviously rely on such resources, their production is not an urban activity: the installations and facilities are usually found outside cities, and licensing and associated policy making are mostly the prerogative of regional or national authorities. Cities do however have to deal with the **side effects** of mining activities; if not with those of an ongoing operation, then perhaps with the **aftereffects** of past ones. One can think of settings such as where subsidence occurs due to the abstraction of water or hydrocarbons, or sinkholes are caused by the collapse of mines that were once outside town, but have later been 'overrun' while the city grew.

Altogether, urban subsurface use is primarily a matter of knowing what one builds on and making optimal use of the additional urban space it offers. So, if one wants to know what the subsurface is like for urban planning purposes, who should one turn to? The traditional custodians of subsurface data and information are **geological surveys**. However, the geological map, which has been their prime output since the 19th century, doesn't usually show city geology. Cities will mostly not have been surveyed and are simply shown as 'built up'. But this situation is changing in two important ways. Firstly, geological surveys have started to work with third-party data, and are now starting to tap into and make sense of, the vast amounts of subsurface data that are acquired in cities, for instance in the preparation of building and construction projects. Secondly, there is a shift from **2D to 3D** information products: a geological map is a representation of what geology is at or near the surface, but in cities you will want to know what lies beneath as well.

Example of the stacking of functions and services of the subsurface. As a rule of thumb, in the deep surface we make money; in the shallow subsurface we avoid costs. This implies that the main financial benefits of using and managing the urban subsurface is in **avoiding costs**. In a broader sense, urban subsurface allows cities significantly to improve **quality of life** (see text for explanation).



What is the challenge?

Irrespective of the application – urban or another domain – it takes time to get to know the subsurface. On a site scale and in the shallow subsurface (less than tens of meters below the surface), it is a matter of commissioning a ground investigation project. Such projects, typically conducted by engineering agencies, are not only site-specific but also problem specific, and in principle yield a one-off result. When, however, one wants to extend subsurface knowledge to the city in its entirety, and go deeper, **a systematic rather than a project-based approach is mandated**. This is how geological surveys are used to operate, making sure that a base level of geological information is there when it is needed. This is basically a matter of answering unanswered questions, simply because if one wants a geological map or a comparable product, it can only be delivered if it is already there.

We argue that to serve the needs of city planning, systematic 3D mapping is required. This must incorporate third-party data, and it must be attuned to city needs. Geological surveys will have to accept, and get used to this new responsibility. A key challenge is in the fact that the upper layer is created or at least modified by human activity. While the extent of such layers can be mapped in 2D or 3D, their properties are unpredictably heterogeneous, not only because of the occurrence of non-natural materials that are 'deposited' by non-natural processes, but also due to constructions such as underground infrastructure and foundations. Deeper in the subsurface, undermining may cause instability. Equally challenging is the 'urban scale': the urban environment is, compared to the scale at which subsurface geology is typically resolvable, a very detailed one and the expectations as to the resolution of subsurface model information are high.

2. The state of the art in twelve cities across Europe

Introduction

The below selection of cities represents the first batch of case studies in COST Action Sub-Urban. Ensuing work packages will include more city cases, which will be included in a next version of this report, should it add to our understanding of the state of the art.

Map showing the cities studied in COST Action TU1206, Work Package 1 (Inventories of existing methods, practices and case studies)

Cities are presented in alphabetic order, introducing the city as such, urban geology, available information about the subsurface and planning. For a full account we refer to the following reports (available at www.Sub-Urban.eu/).

City	Report
A Coruña	B. Moar Ulloa, 2015. A Coruña. Municipality of A Coruña, 26 pp.
Bergen	A. Seither, G.V. Ganerød, H. de Beer, T. Melle, I. Eriksson, 2015. Case Study of Bergen. NGU Geological Survey of Norway (Trondheim) & Oslo Municipality, 43 pp.
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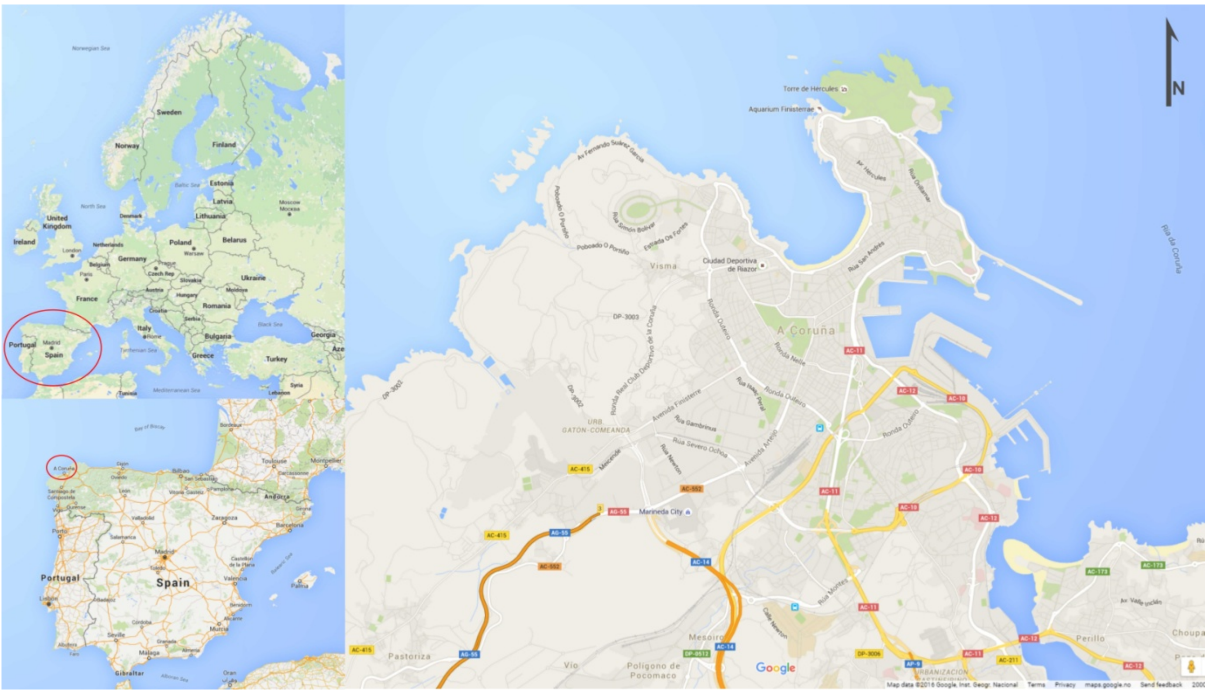
A Coruña



The city

A Coruña, with a population of 244,388 (2007), in an area of 36.8 km^2 is one of the main cities of Galicia, in the Northwest of Spain. With a coastal location on a peninsula and an isthmus, A Coruña is the main urban agglomeration in the North of Galicia, and is a key point in the Atlantic axis, which runs along the Galician coast into Portuguese lands. The location of the municipal area, at the end of a natural peninsula, which multiplies the perimeter of the coastline, is unusual. The municipality is situated on a rock base, and the main problem presented is the proximity of the sea.

Urban geology

Particular geological factors that influence the city are the groundwater level, the proximity of the sea water, the existence of ancient dry valleys whose formers rivers are now canalized, which must be restructured, and the settlement of Pescadería, one of the towns quarters, on a dune.

Relevant information

Geological data are contained in the maps of Spain's National Institute for Geology and Mining (IGMN).

Planning context

Planning of the municipal area of A Coruña is based on the existing General Town Planning (PGOM), approved in 2013. This addresses problems related to transport and communication infrastructure, by proposing the replacement of the current radial transport network by a mesh-like model. There is no specific consideration within the PGOM of geological issues.

Legislation does not require specific consideration of the geology during the drafting of general planning (planning of the entire municipal surface). Geological and subsurface data from IGMN are utilised only at the planning stage of specific urban works and building projects, for which geotechnical studies are carried out (for foundation and other design purposes).

Another important issue, associated with the subsurface is the existence of archaeological remains. This requires precautions to be taken, and archaeological investigations to be undertaken, in some areas prior to construction or earthmoving. Such areas are particularly focussed in the old town, fish market, and Castro de Elviña (place where a Roman castro is located).

Bergen

The city Bergen, the second largest city in Norway, has a population of 272,600 people (401,181 within the wider Metropolitan area) within an area of c. 450 km^2 of which 94 km^2 is urban. The remainder is a forested recreational area (nature area) protected against urban development. The city is coastal and the landscape is strongly influenced by glaciation. The small city centre lies in a flat valley bottom, and the city as a whole is surrounded by high mountains.

Urban geology The city lies partly on bedrock and partly on sediments, the topmost of which are man-made and can be up to 8 m thick. These overlie glacial and marine sediments comprising primarily sand (including beach deposits), gravel, (marine) clays and sand, and glacial (moraine) sand and till.

Sediments on the steeper valley sides are typically thin (< 0.5 m). The bedrock is fractured and comprises granitic gneisses, greenstone, phyllite and quartzite. Key geological challenges include: ground stability, concerns over which may prevent planned Light Rail expansion being constructed underground, and prevention of enhanced decay of organic deposits in the subsurface as a result of changes in groundwater pressure and level.

Relevant information

Some groundwater modelling, but little monitoring, has been undertaken. Groundwater flow is mostly controlled by the topography, with flow from the mountains, through the sediments and into the harbour. During developments, lowering of the groundwater level has adversely affected the city's cultural heritage, in terms of both standing monuments and archaeological remains. Therefore, projects have been initiated to investigate the relationship between groundwater, new developments, damage to historic buildings and terrain by subsidence and degradation of archaeological remains, as a precursor to long-term monitoring. The City Council of Bergen has initiated a temporary prohibition on all measures that may cause a change in the groundwater level within the whole Medieval city centre.

The National Database for Ground Investigations in Norway is drawing together a vast amount of data, scattered amongst owners and users. Challenges related to ownership and free flow of subsurface data remain.

Planning context

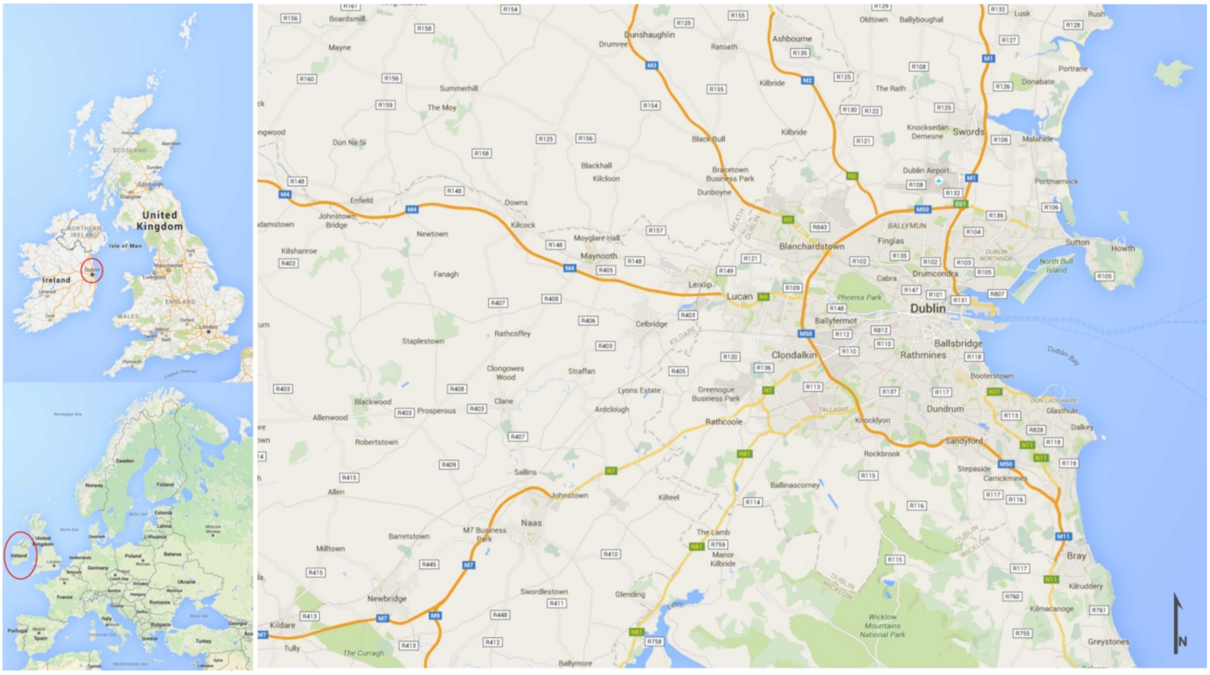
Subsurface use is increasing: for drainage, sewerage and water supply; tunnels for transport, military purposes; working and living space; energy wells and extraction of resources (sand, gravel and aggregates). Consideration is being given to the planned Light Rail expansion being (partly) underground. A project intended to improve the knowledge and management of the city's subsurface has recently been initiated.

There is a legal framework for protecting existing subsurface structures, as well as the planning and construction of new ones. Planning is map-based but the law also allows for future 3D planning.

Ownership of land extends beneath the surface, and landowners are free to use the ground beneath their property. There is no fixed limit to how far down this right of ownership goes; case law emphasises "reasonable use" but energy wells for example are not currently subject to approval. Buffers between underground constructions are not established.

Legal requirements to maintain groundwater pressure and level are vague. However, a key strength in Bergen is the strong cooperation between the heritage authorities and planning authorities at municipal level. National legislation that automatically protects in-situ subsurface archaeological heritage, and the fact that parts of the city centre are designated as a UNESCO World Heritage Site are key drivers for this cooperation. This is helping to prevent changes in groundwater level and pressure which might adversely affect building in the Medieval city centre.

Dublin



The city

Dublin, capital of Ireland, has a population of 527,612 (2011). It is part of Dublin County which has an area of 920 km², and is located on Ireland's eastern coastal margin. Dublin is situated at the mouth of the River Liffey. It is bordered by a low mountain range to the south and surrounded by flat farmland to the north and west.

Urban geology

Glacial Till (Boulder Clay) has a widespread distribution across central Dublin. It ranges in thickness from a few metres to upwards of 20 m. Terrace gravels are found along the River Liffey and are overlain by recent alluvial deposits. These glacial and postglacial deposits obscure the bedrock. The bedrock topography is dominated by a major buried channel that runs into Dublin Bay, filled with postglacial intertidal and estuarine sediments overlying a basal glacial till. Man-made deposits cover much of the city centre and are present in areas of reclaimed tidal land. The bedrock geology of County Dublin is very varied. Lower Palaeozoic metasedimentary and volcanic rocks are mainly found in the north and south of Co. Dublin while the central zone is underlain by rocks of Carboniferous age. Emplacement of granite into the southern Lower Palaeozoic rocks occurred in the Devonian. The bedrock of the Dublin urban region is mainly composed of bedded dark limestones and shales known as 'Calp'.

Systematic geochemical mapping of soils in the greater Dublin urban area indicate that concentrations of the heavy metals lead, copper, zinc and mercury are strongly influenced by human activities and are elevated in the docklands, inner city and heavy industry areas. Other challenges include ground instability and coastal inundation.

Groundwater resources in Dublin are limited by both naturally modest aquifer potential, and from man-made impacts on water quantity and quality, although small industrial, municipal and private abstractions within the city centre and suburbs are known. The existing public drinking water supplies for the Dublin region are derived predominantly from surface water.

Relevant information

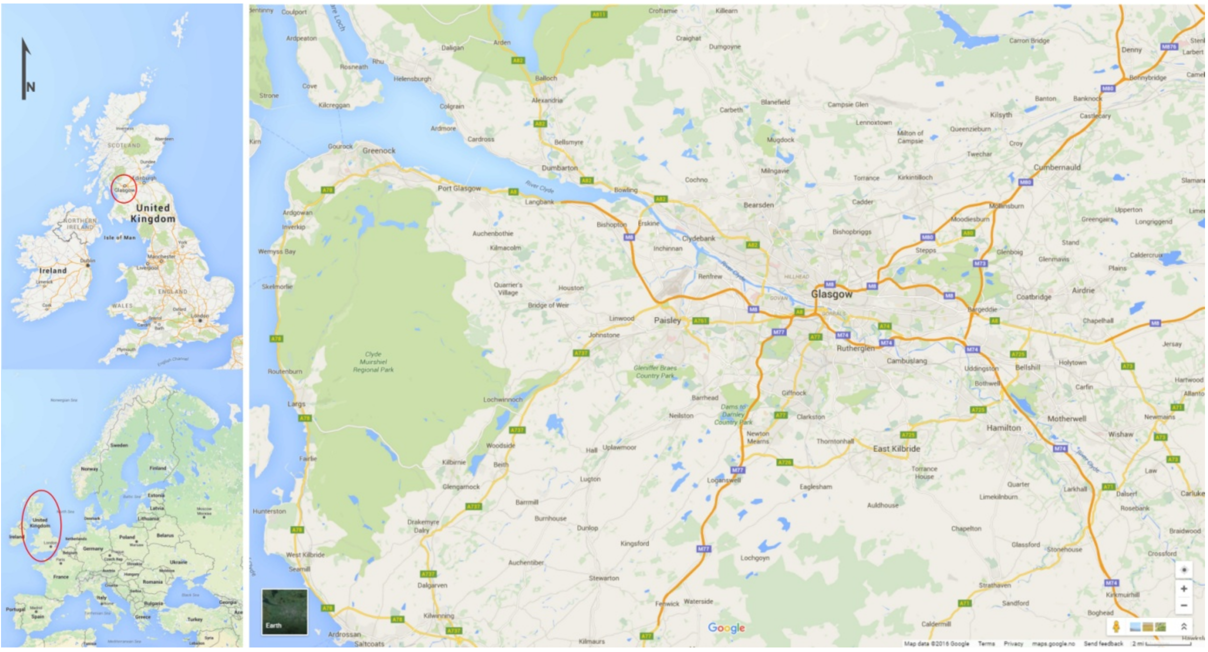
The Geological Survey of Ireland has collected data in Dublin City Centre for many years and holds the National Geotechnical Borehole Database. The GeoUrban project created a web-enabled, free access, 2D/3D/4D geo-environmental GIS for Ireland's largest urban zone. The project outputs provide a geological framework that will facilitate informed planning and infrastructural decision making in the Greater Dublin region, including forward looking scenarios. 2D & 3D modelling of the subsurface in the urban centres of Dublin allows new insights into the nature and distribution of the geological units that underpin some of Ireland's most important infrastructure.

A systematic geochemical survey of shallow soil quality (1065 samples) has also been undertaken across Dublin. The Dublin SURGE (Urban Geochemistry) Project has established geochemical baselines of metals and organic chemicals in the soils. These data, which are publically available, are relevant to human health, land-use planning and urban regeneration in Dublin, and identify and quantify human impact on the urban soils through comparison with an adjacent rural soil baseline geochemistry.

Planning context

The Dublin City Development Plan sets out development policies and objectives to create a sustainable and vibrant city at the heart of the Greater Dublin Region over the next 6 years. The day to day granting of planning and development licences is governed by this framework and Irish planning legislation. Dublin City Council commissions many infrastructure and domestic building projects, most of which are obliged to carry out detailed geological investigations prior to siting and construction works.

Glasgow



The city

Glasgow, Scotland's largest city, has a population of nearly 600,000 people, in an area of c. 176 km^2. Within the Greater Glasgow area, covering 370 km^2, the population is nearly 1.2 million. The city occupies the low-lying valley of the River Clyde, at the head of the Clyde estuary, and was formerly a major sea port and industrial centre.

Urban geology

Glacial Till (Boulder Clay) has a widespread distribution across central Dublin. It ranges in thickness from a few metres to upwards of 20 m. Terrace gravels are found along the River Liffey and are overlain by recent alluvial deposits. These glacial and postglacial deposits obscure the bedrock. The bedrock topography is dominated by a major buried channel that runs into Dublin Bay, filled with postglacial intertidal and estuarine sediments overlying a basal glacial till. Man-made deposits cover much of the city centre and are present in areas of reclaimed tidal land. The bedrock geology of County Dublin is very varied. Lower Palaeozoic metasedimentary and volcanic rocks are mainly found in the north and south of Co. Dublin while the central zone is underlain by rocks of Carboniferous age. Emplacement of granite into the southern Lower Palaeozoic rocks occurred in the Devonian. The bedrock of the Dublin urban region is mainly composed of bedded dark limestones and shales known as 'Calp'.

Much of the Glasgow area is underlain by sediments, locally up to 80 m thick. Widespread man-made deposits, associated with former industry and construction, occur at the ground surface and are locally over 10 m thick. Underlying sediments include river and lake deposits of sand, silt and clay with some peat, extensive marine deposits of silt and clay, and widespread glacial deposits of till (diamicton) and sand and gravel. The presence of rounded hills of glacial till (drumlins), sculpted by the past glaciers, has influenced urban development throughout central Glasgow.

The bedrock underlying the glacial and postglacial sediments comprises sandstone, siltstone, mudstone, limestone, coal, ironstone and seat-earth. The rocks are extensively faulted. Coal and ironstone were extensively mined within the city; sandstone and limestone were extracted locally, and there are many cuttings for roads,and railrailways . Volcanic and other igneous rocks are also common, forming local hills and underlying high ground to the north and south-west of the city.

Some modelling of groundwater level and flow has been undertaken across Glasgow and a pilot groundwater monitoring network has been established. Groundwater is shallow (c. 3 m deep) and shallow aquifers are vulnerable to (heavy metal) contamination from soils and surface water sources affected by past industry (e.g. chromium), and from mining. Groundwater flooding is a hazard locally.

Key challenges include the effects of running sand, compressible ground and shrink-swell clay on construction works; land dereliction and contaminated groundwater; ground instability and subsidence arising from collapse of shallow mine workings (within 30 m of rockhead) and deep mine shafts.

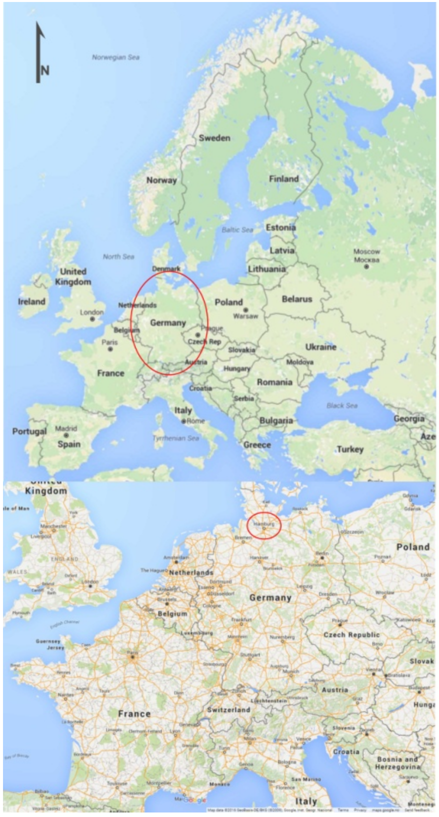
Relevant information

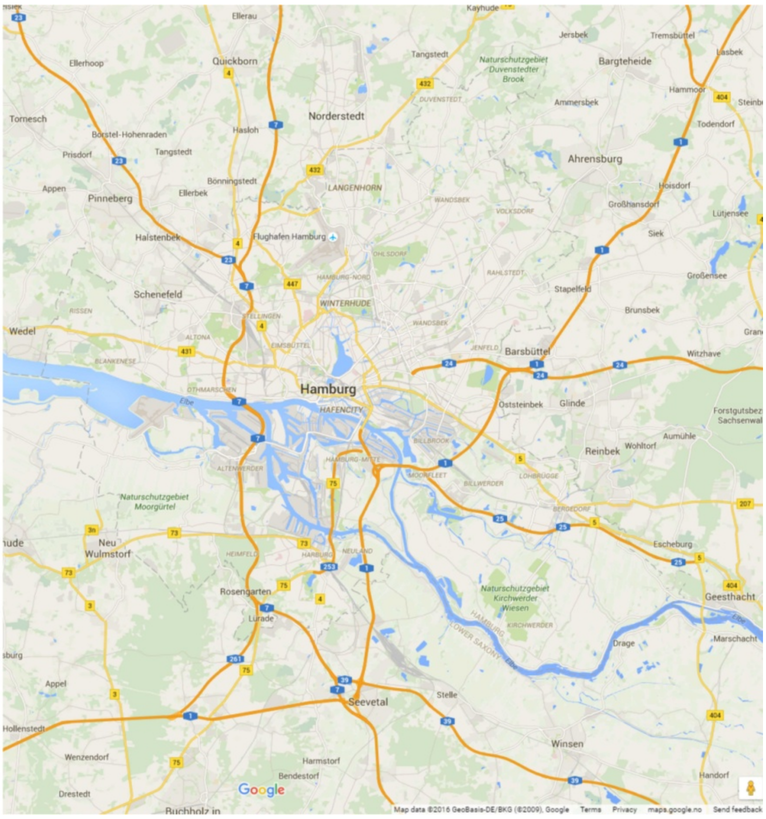
The BGS has produced digital maps of the regions sediments and bedrock and manages a database of borehole records donated by private companies including over 40,000 records for Glasgow. Through the Clyde Urban Super Project (CUSP), the BGS has developed comprehensive 3D subsurface models of the sediments and bedrock (Figure A), and undertaken geochemical surveys (soil, waters and sediments), and monitoring and modelling of groundwater in the city. The subsurface models are freely available through a knowledge exchange partnership called ASK (Accessing Subsurface Knowledge). Geochemical surveys of soils and stream sediments across the wider catchment of the River Clyde have also been conducted. Geochemical data relating to over 50 inorganic elements characterize sediment, water and soil quality across Glasgow and the Clyde catchment from 2000 stream and river sediment samples; 1800 stream and river water samples; 1460 samples from rural soils and 2450 samples from urban soils (Figure B). A purpose-designed pilot groundwater monitoring network has also been established by BGS for a former industrial area in central Glasgow, to monitor groundwater level and quality.

Planning context

Historically, the primary use of the subsurface was for the extraction of coal and stone. Current and proposed future uses include tunnels for transport (metro, rail and road), sewage and other infrastructure; water distribution; pipes and cables; and SuDs and energy wells, especially in regeneration areas. Glasgow City Council is taking a leading role in the UK in developing a strategic local planning framework that: accounts for the subsurface and its management; addresses the legacy of industry and mining; and provides opportunities to identify and develop future energy resources. In the absence of national legislation related to the subsurface, developments in the use of subsurface data and spatial planning policy for Glasgow are being achieved through knowledge exchange, voluntary agreements, and use of contractual obligations to encourage private contractors to share data in exchange for access to 3D subsurface information provided by BGS. The inclusion of geology and the subsurface in the new Development Plan for Glasgow (under consultation) reflects the growing awareness of policymakers of the importance of the subsurface. Steps are now being taken by Glasgow City Council to develop subsurface planning guidance, the first of its type in the UK, and to develop a subsurface planning regime for the city, based in part on the 3D modelling carried out by BGS.

Hamburg





The city

The Free and Hanseatic City of Hamburg is one of the 16 states of the federation and the second largest city in Germany with its 1.7 million inhabitants and an area of 755 km^2. In this sense, Hamburg is a city as well as a state. Hamburg is located in the northern German lowlands in the lower reaches of the Elbe River. The port of Hamburg is situated 120 kilometres from the North Sea and has an area of 72 km^2. About 50 % of the city area is made up of waterbodies, green areas and forests, cultivated areas and grassland. The current topography has been formed during three glaciations. The broad glacial valley of the Elbe separates the Geest area of Harburg Hills in the south from moraine Geest area in the north. The landscape of Hamburg is dominated by the current division of the river Elbe with its low-lying marsh areas and adjacent Geest areas.

Urban geology

Hamburg and its surrounding areas are covered with Quaternary sediments (sand, silt, clay, till). Pleistocene buried (or tunnel) valleys cut more than 400 m deep into the underlying Neogene strata, which consist of Miocene clay, silt and sand layers. Holocene sediments (as clay soil, organic silt, peat) are found in the Elbe river valley.

Three deep seated salt structures cause special problems – as salinization of freshwater resources or sinkholes. Due to the long industrialization history more than 4,000 contaminated sites (soil and/or groundwater contamination) are known in Hamburg.

Due to complete reliance on groundwater for public water supply it is necessary for Hamburg to implement extensive urban groundwater monitoring to ensure groundwater resources are protected. It was recognized several years ago that the network was unnecessarily large, not all sites were yielding valuable data, the network was not targeted and therefore it was too expensive to maintain. Following a complete review of the monitoring stations in the context of the urban groundwater system it was possible to rationalize the network, reducing it from over 4000 potential boreholes down to 646 monitoring stations. High resolution 3D geology is providing a reliable base for groundwater modelling. Coherency across the groundwater monitoring network, hydro-stratigraphy and geological model has facilitated the development of a unified groundwater model for Hamburg.

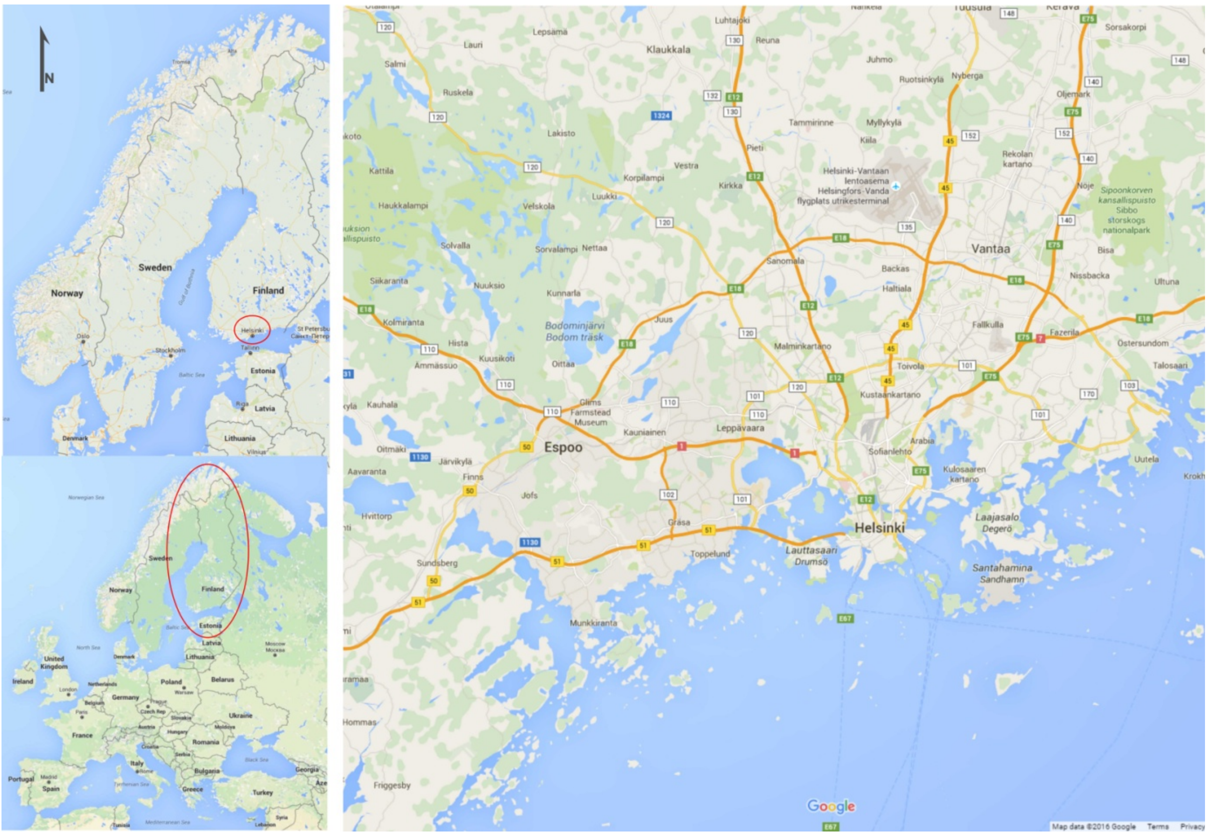
Relevant information

The Geological Survey as a part of the Ministry of Environment and Energy (BUE-since 01.07.15) receives geological data from official boreholes and private boreholes. Once validated, borehole data are stored within the Geological Survey borehole database and becomes instantly available within other live-linked data portals internally and externally via the BUE and internet website. It is a legal requirement that borehole data is submitted to BUE Hamburg for any new borehole drilled, and that standardised lithological and borehole coding is used by contractors and drillers.

Planning context

Responsibilities for geoscientific research and on issues of nature and resource protection are a matter of the federal states and their specific authorities such as the Geological Survey of Hamburg. Hamburg has developed a unified groundwater model for the metropolitan region of Hamburg. A great number of geological and hydrological data has been the basis of the model. It can be applied for a variety of issues concerning the water supply of the City (and also for geothermal applications). The model will be mainly used by the Ministry of Environment and Energy and the state owned public water supply Company. The already established workflow will be further developed.

Helsinki



The city	The City of Helsinki, capital of Finland has a population of about 1,000,000. It consists of metropolitan area including a smaller urban Capital Region and commuter towns within an area of 716 km^2. Situated in the southern part of Finland, on the northern coast of the Gulf of Finland, the City of Helsinki is located on the course of a peninsula and 315 islands. In the typical landscape the hills with bedrock outcrops alternate with valleys filled with clay sediments.
Urban geology	Quaternary deposits in southern Finland consist of a thin till (1-15 m) sometimes overlain by glaciofluvial sand deposits. These are overlain by soft clay sediments everywhere in the study area. The ancient 'shield' bedrock and consists of gneisses and granitic rocks. It is a very stable area where earthquakes, tectonic movements and natural movements of the ground are unusual. The bedrock surface is generally quite flat, but has zones where it is deeply eroded (10 – 30 m). Challenges: The soft and flat clay areas can cause very difficult conditions for construction because of the depth of the bearing layer for piles and easily settling surface. Bedrock makes a very hard, well bearing and stable basis for construction of foundations but on has also its difficulties in making flat areas for building.

The groundwater table in the Helsinki area is typically very close to the surface. Lowering of the groundwater level (typically by leaking of water to bedrock tunnels below) has caused much damage to buildings and structures founded on bearing soil or wooden piles, especially in old town areas. Since 1977 the city's Geotechnical Division and Building Inspection Department have monitored the city centre's groundwater situation. 700 tubes are monitored monthly in the city centre.

Relevant information

Geotechnical investigation data have been collected for 30 – 40 years in digital databases. Data is saved in standard national digital format (INFRA) delivered to users with a map based information service which is not public and intended only for professional planners.

Underground land use totals 9.5 million m^3; More than 400 premises; 220 km of technical maintenance tunnels, 60 km of which are multi-utility tunnels used by a number of operators; raw water tunnels 24 km; Wastewater treatment is carried out centrally at a large underground plant.

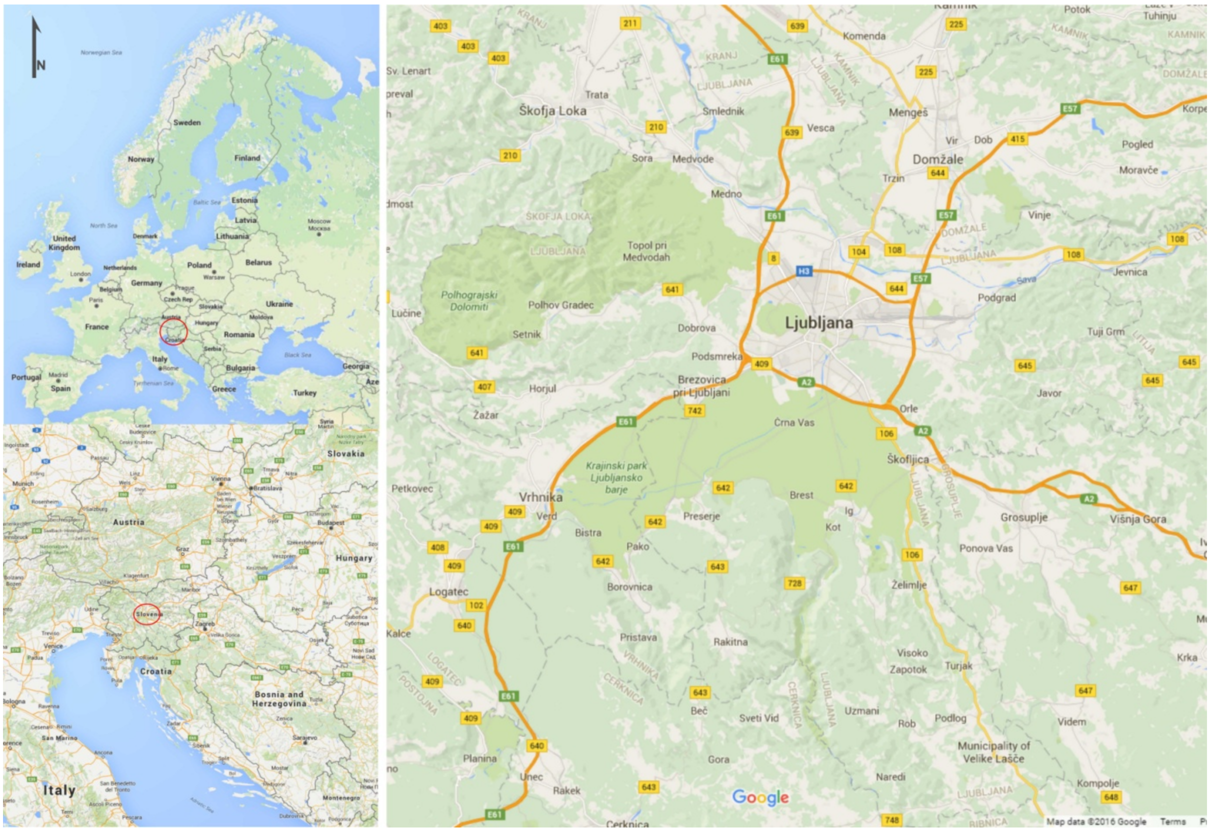
Planning context

The Land Use and Building Act (2000) shows three types of development plan: the regional plan, the master plan at the citywide or district level, and the detailed plan for sites. The City of Helsinki's 2002 master plan covers the entire city. It is essentially a land-use zoning map and guides the detailed planning stage. Only the detailed plan has the legal sanction to establish development on a site or to change the land-use designation. The Helsinki Underground Master Plan has been drafted to safeguard the continued utilization of its bedrock resources in connection with construction and other significant commercial projects. It controls the locations, space allocations and mutual compatibilities of the newest, largest and most important underground rock caves, facilities and traffic tunnels. It also safeguards the permanency and functionality of facilities already constructed. Already built facilities are listed and classified. The Plan is binding on property owners and public officials. The plan also serves as a guide when preparing aboveground zoning plans. Besides the space allocations indicated in the town plan map, other construction is allowed as long as it does not conflict with the main underground functions indicated in the master plan.

In law, the owner of a property has control over the underground part of the property, though the vertical extent of ownership is not specifically defined in legislation. It is interpreted as being limited to the depth where it can be technically utilised (in practice 6 m from the lowest point of the building lot). Anyone constructing facilities underground must obtain agreement on the right to use the underground construction site. Right of ownership can be established either through voluntary transactions, agreements or redemption based on legislation.

Helsinki is well suited to rock construction because its bedrock is hard and located near the ground surface. Helsinki is the first city in the world to have developed and take into use an underground master plan. The use of rock construction in municipal facilities has brought the possibility to replace above-ground structures with corresponding underground ones and thereby released the valuable above land to use in more important activities.

Ljubljana



The city

Ljubljana is the capital and largest city of Slovenia, population 282,994 (2012) with an area of 10,000 m^2. It has a central geographic location within Slovenia. The city has a hilly, marshy and aquatic natural hinterland that was historically less attractive for construction and urban development. Green areas from the hinterland extend into the historical city centre via green wedges and riparian corridors giving Ljubljana its distinctly green identity. Most of Ljubljana is built on fluvial or lake sediments where the surface is horizontal to gently sloping. The northernmost parts are built near the Sava River that has cut several terraces up to 5 m high. Parts built on hard rock are elevated above the plain for up to about 100 m. They are dissected by numerous streams and gullies and have slopes that can reach up to 50°.

Urban geology

The Ljubljana Basin is located in the transition zone between three active fault systems. The uppermost 50-100 cm of soil in the basin is anthropogenic due to agricultural activity. In the city itself the underground construction and archaeological remains reach down to several meters and so the soil in the city is entirely anthropogenically reworked.

The northern part of Ljubljana is mostly built on gravel and only partly on hard rock in the hills. Except on the slopes, these areas provide stable geotechnical conditions. The southern part of Ljubljana is built on lake and marsh sediments (clays, sands, peat, gittya) that are prone to compaction. Quarrying took place historically in small pits at numerous places where gravel is present in the basin. In the gravely parts of the basin the archaeological findings are confined to the upper tens of centimetres. In the Ljubljana Marsh area, the several metres of sediments may cover pre-Roman and Roman remains.

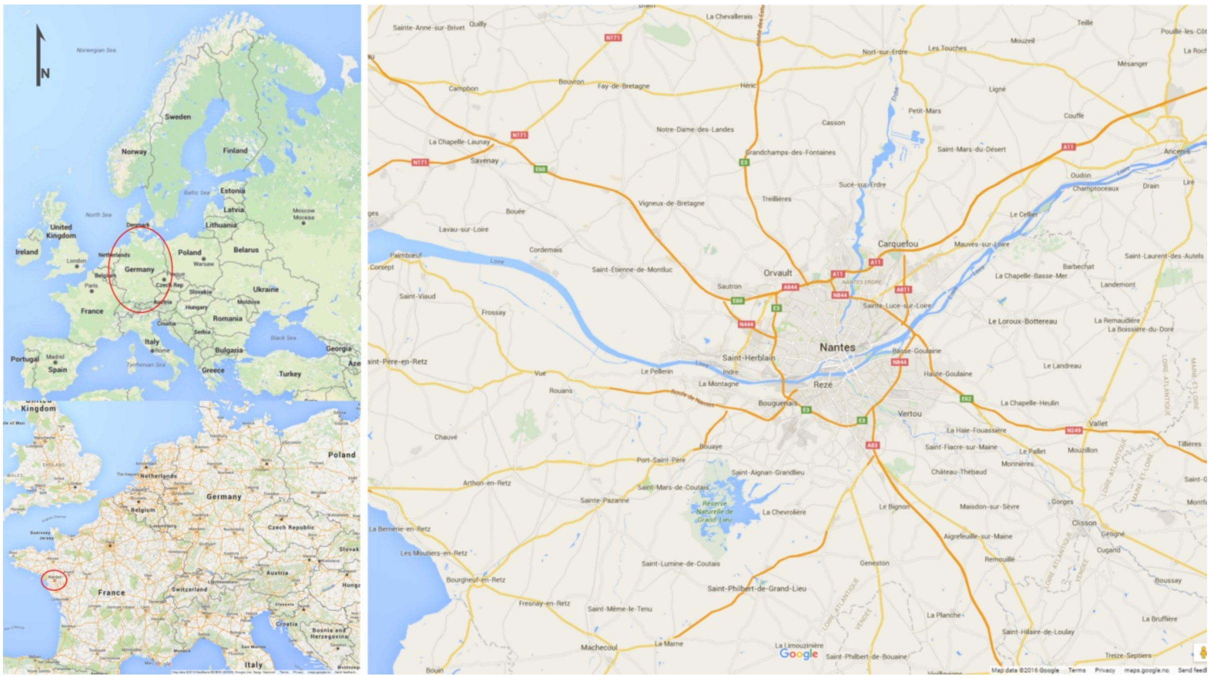
Key geological challenges: Active faults present potential seismic hazard for the densely populated area. Constructions on slopes have to take into account the potential for soil creeping on soft rocks.

The sediments of Ljubljansko polje and Barje (Marsh) store important quantities of groundwater which is main resource, exploited for the public water supply of the city Ljubljana mostly without any treatment. The catchments of water fields are protected with drinking water protection zones. The implementation of protection zones has a preventive role and reduces the risk of pollution of the groundwater. But it also affects urban development of the city.

Relevant information and Planning context

The city’s main development objectives are defined in the Municipal Spatial Plan (2010). City development is directed mainly at regeneration and renewal of existing developed areas and is also committed to resolving issues concerning safeguarding and development of green and open spaces. The most important objectives are to safeguard and manage the five green wedges in the city that link the city centre to the hinterland. These key macro-spatial component sections of the urban space also house the main subterranean aquifers in the city territory. Two major rivers pass through the territory of the municipality therefore emphasis is also on waterside features as a special element of the urban system.

Nantes



The city

Nantes, France's sixth largest city has a population of 284,970, within an area of 65 km^2. The larger Nantes Métropole conurbation occupies an area of 523 km^2, and has a population of c.600,000, projected to rise to 700,000 by 2030. The city is situated on the Loire River, at its confluence with the Erdre and the Sèvre, close to the apex of the estuary. The Nantes metropolitan area has a gentle morphology, and encompasses plateaus on either side of the Loire, which are notched by small valleys.

Urban geology

The city overlies man-made deposits; some in the city centre, infill arms of the River Loire, under a planned expansion of the transport network, and the Ile de Nantes (in mid-Loire) has been raised in height for development by man-made deposits. Beneath these deposits, there are alluvial deposits of the Loire and other rivers, and sedimentary deposits including sand, loam and loess.

The bedrock is mainly composed of ancient igneous and metamorphic rocks including granite, gneiss and mica schists. There are bedrock and sedimentary aquifers; the Loire alluvium supplies Nantes' drinking water. The groundwater level is generally shallow (<5 m below surface).

Key geological challenges include subsidence and soil compaction, especially in the city centre where old buildings may be damaged; the need to pile buildings along the River Loire, above compressible alluvium; the relatively shallow groundwater level, requiring drainage and pumping to enable subsurface construction (e.g. car parks); local contamination.

Use of geothermal resources is under consideration in Nantes.

Relevant information

Data on soil and groundwater quality are available from monitoring of test sites within the city. The Institut de Recherche en Sciences et Techniques de la Ville (*Research Institute for Sciences and Technology in Urban Areas)* has provided data on: characterization and pollution of soils, including (trace) metals in allotment soils and its biophytoremediation; anthropogenic impacts on groundwater, including monitoring inorganic and organic subsurface plumes from landfill sites, and infiltration of water and transfer of pollutants; the impact of rainwater management (SuDS trenches, swales and retention basins) on soils (including trapping of pollutants); and soil-sewer interactions, and their effect on the water budget. In situ remediation strategies are under development.

Planning context

Subsurface uses include: car parks, buried infrastructure including pipes for water and heat distribution, sewerage, cables; sustainable drainage (SuDS) for flood alleviation recharge of aquifers, and improvement of water quality in the River Loire. Major developments will include expansion of subsurface networks related for examples to the development of the Iles de Nantes.

A focus of planning in Nantes is on limiting urban sprawl. With respect to the urban subsurface, key elements are: the restoration of existing waste tips; the management of soils, soil quality; and addressing contaminated land. There is also proactive protection of archaeological heritage, involving provision for excavation prior to developments. Protection and maintenance of buried infrastructure is also a planning priority.

Novi Sad

The city

Novi Sad, Serbia's second largest city, has a population of 341,625 (in 2011). The city covers an area of c.700 km², with an average population density of 526 inhabitants per km². The city itself covers just over 100 km², and its metropolitan area extends across a further 600 km².

Urban geology

The city lies at a prominent S-shaped meander of the River Danube, with the prominent Petrovaradin rock on one side, where the river is only 350 m wide, making a good crossing point. The rock, an intrusive dolerite (diabase) of Triassic-Jurassic age, was an excellent defensive location; the present fortress complex was constructed in the 17th century. Most of the city lies on the left bank, on a fluvial terrace part of an extensive alluvial and agricultural plain, up to 10 km in width which overlies Pliocene sedimentary strata. The rest of the city lies on right bank, and the east-west trending, Fruska Gora Mountain area, a fault-bounded horst (Jurassic, Cretaceous and younger rocks), the northern part of which is characterized by large, apparently inactive, landslides.

Relevant information

Made ground, used to raise the ground level (up to 3 m) because of the risk of flooding, is locally relatively thick in the urban area. This led to further problems (basement flooding and disruption of natural drainage). For these reasons, observation of groundwater levels started in 1953. Problems associated with shallow groundwater levels and flooding in the alluvial plain led to the construction of the Danube-Tisa-Danube Canal for flood control, water supply, waste water drainage and navigation. The canal marks the northern edge of wider city center.

There is no integrated database of subsurface data, but extensive geotechnical/hydrogeological data are available from various engineering and construction projects (bridge foundations, drainage schemes, flood defenses, canal, etc.). Groundwater data collected since 1953 demonstrates depth to groundwater: 0-2.5 m on the alluvial plain varying with the Danube's level, and groundwater flooding; 0-4 m in the alluvial terrace; up to 8 m in the loess terrace; standing water locally.

Recently, the city municipality and urban planers from the public enterprise JP Urbanizam have completed the IPA project CROSSWATER_IPA CBC HU-SRB, financially supported by EU. As a result of the cooperation on the project, the city municipality has defined positions for piezometers for monitoring groundwater level in the city and implemented them. Thus, the groundwater level data are included into the comprehensive municipality GIS database. The collected data are also available to the public.

Novi Sad is a transport hub (road, railway, waterways) and bridges across the Danube (2 road and one rail) are key infrastructure which may in part be developed underground. Novi Sad has since 1965 relied on groundwater for its drinking water.

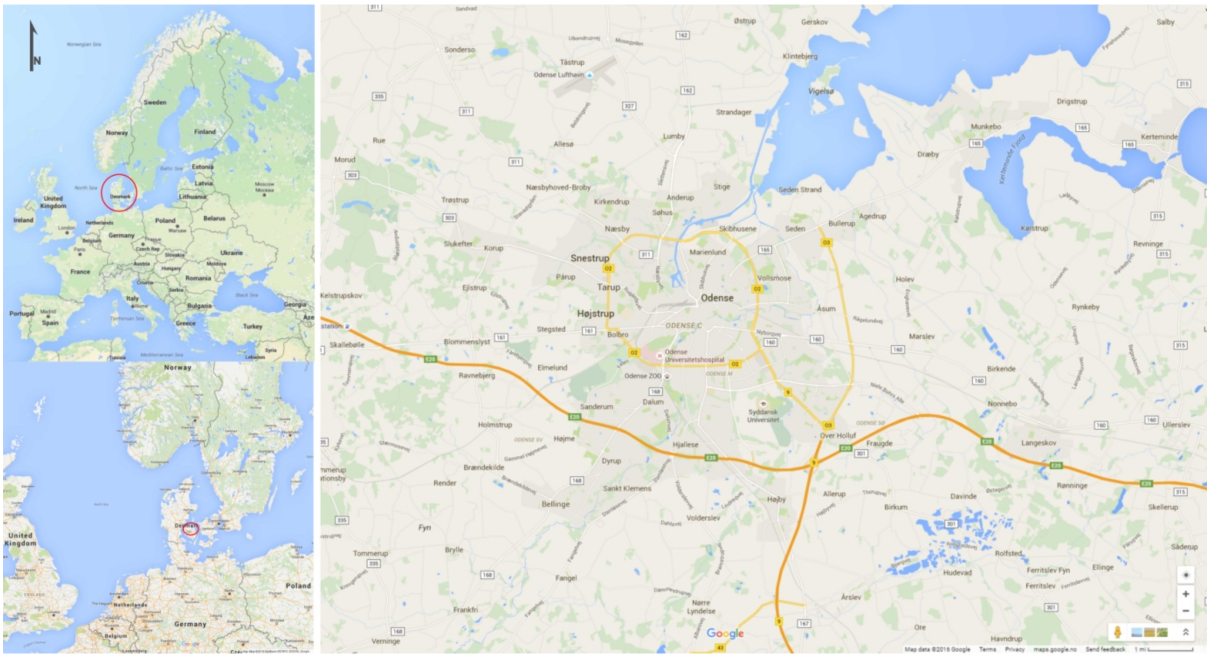
An extensive network (c.16 km in length) of historic tunnels occurs on four levels in the rock beneath the Fortress. Otherwise subsurface use has been limited historically by high groundwater levels. Novi Sad's water supply relies on groundwater from shallow aquifers (c. 20 m deep) and feeds the extensive supply network. The sewerage system discharges directly into the Danube.

A new combined bridge across the Danube is planned and linked to an existing 354 m long tunnel in jointed dolerite under Petrovaradin Fortress. A regional landfill is planned, and its impact on groundwater, and drinking water supply will be assessed. Geotechnical and hydrogeological investig-ations are planned, with four wells to monitor groundwater quality / level, and mitigation measures and environmental protection as necessary.

Planning context

Problems related to very shallow groundwater, (groundwater) flooding, and shallow aquifer protection are particular concerns for planners. Protection of buried archaeological assets is also important. The conflicting demands of the transport hub, housing, environmental legislation and sustainable development also need to be addressed. There is though no subsurface database to link to the integrated and comprehensive above ground GIS/database available to planners. The subsurface has generally been seen as a constraint, and its use costly, in planning terms. There are intentions to use COST Sub-Urban ideas (e.g. the toolbox) to address these issues. Facilitated by an agreement between the Faculty of Technical Sciences and local municipalities, subsurface opportunities will be explored, impacts on the subsurface (especially groundwater) considered, and sources of data identified, and their integration improved.

Odense



The city

The City of Odense, population of 172000 (2014), occupies an area of about 80 km^2 within the 305 km^2 of the Municipality of Odense. Odense is located in the middle of Funen. In the Odense area the landscape is dominated by a moraine plain to the south and east, with some larger areas of alluvial deposits to the east. In the west there is a transition zone to a dead-ice landscape. In the north the Odense Fjord dominates. The infrastructure of Odense is influenced by the “The Odense Canal” that connects the old harbour in the central part of the city with the Odense Fjord (inlet) area north of the city. Odense is a flat (low) city - “the city of residential neighbourhoods”. In the urban area of Odense the river results in a marked valley through the central part of the city centre. Adjacent to the river valley are bogs, which have been drained and urbanized.

Urban geology

Odense lies on sediments of extreme variability in thickness (0-100 m). The topmost are generally thin and man-made, and overlie the dominant marine clays with important organic content, and beneath those are glacial sediments of tills, sand and gravel. In several places buried valleys have been cut into the underlying deposits sometimes as deep as the pre-quaternary deposits. These buried valleys are often filled with thick sand and gravel deposits, interbedded with tills. The higher ground is made up of moraine plains with a complex geological composition consisting of embedded alluvial deposits and tills. Organic rich deposits from paleo-bogs can be found, especially along the river valleys. The difference in elevation between the valley-floor and the higher ground is no more than 10-20 m. To the north, larger parts of Odense city is situated around 1-10 m above sea-level. To the south the terrain rises generally to about 20-25 m above sea-level.

Beneath the glacial deposits are Pre-Quaternary deposits of Cainozoic age. The upper 300 m of bedrock consists of clays, marl, limestone and chalk. In terms of bedrock, the city lies in the middle of a graben, surrounded by Precambrian basement. Marine shales and limestones form the low ground in the city centre and to the south-west, and igneous rocks form the high ground to the north and west. The top surface of the bedrock has been deeply incised during the glaciation.

Key geological challenges: Generally the subsurface of Odense is geotechnical stable, but deposits rich in organic material may pose a problem, if they are de-watered during or after construction work. In some parts of the city centre, the foundation of older buildings probably consists of wooden piles, which tend to decompose, if the groundwater table is lowered too much for longer periods of time. The small relief of the urban landscape leads to vulnerability due to flooding during rain storms and melting of snow in late winter or during spring time. The northern part, around the harbour and the inner parts of the Odense Fjord area are therefore vulnerable to sea-level rise, both as short-term events during storm flooding, and the long-term event due to climate changes.

The water supply was primarily based on local groundwater abstraction sites. Today, it is still based on groundwater, but most of the groundwater abstractions within the urbanized areas have been stopped. The effect of these changes has meant that the groundwater level within the city limits has risen dramatically over the past 25 years. In some areas the water table has risen 12 m. Today, the water level in some areas, are close to what the water level used to be in the early 1900s. The areas that are drained and urbanized are becoming increasingly waterlogged. More than 1 billion Euros has been spent within the city limit establishing large diameter sewage pipes for delaying or storing storm water during extreme rains. There is a growing interest in securing local infiltration. A multi-partner project is underway to build a detailed 3D geological and hydrogeological model to study the groundwater resources, the climate change impact on the water cycle and also covering subjects of archaeological and historical interests.

Relevant information and Planning context

Use of subsurface:

- More than 1/3rd of the buildings in Odense have a basement;
- Sewers: More than 2100 km
- District heating (and cooling in near future?);
- Communication: all sorts of electric wires and optical fibres;
- Garbage: underground waste collection systems;
- Underground infrastructure: Natural Gas pipes, wells and pipes for

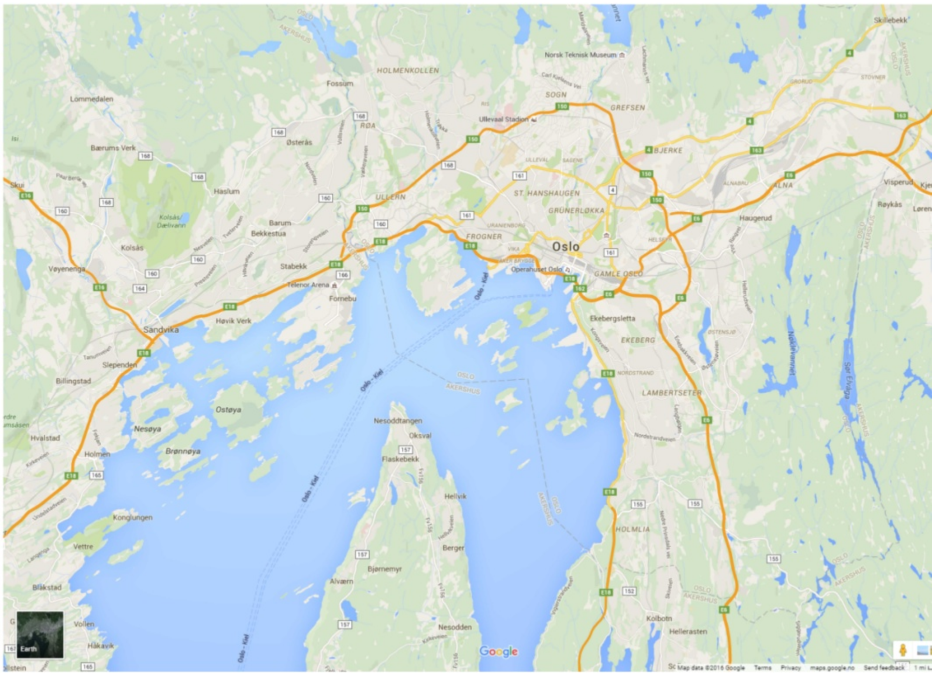
potable water (about 1500 km); wells/boreholes; ground source heating/cooling systems; storage tanks for oil/gas; artificial structures-parking lots, waste water and storm water basins; drains and Gabon's. There are plans for a big Aquifer Thermal Energy Storage (ATES) installation in the central part of the city.

The Planning Act is the most important tool for spatial planning in Denmark: it decentralizes decision-making authority and promotes public participation in the planning process based on the reformed planning legislation of the 1970's.The Planning Act does not work beneath the soil surface. Denmark does not have any special "municipality plan" or "local plan" dealing with subterranean conditions. There are a number of laws and directives dealing with the underground. "The Underground Law" aims an appropriate use of raw materials – in general it only comes into action in depths greater than 250 m below the surface, regardless of the purpose. All parts of Denmark beneath 250 m below sea level belong to the State.

When dealing with the uppermost 250 m of the underground it is important to notice that the Constitutional Law in §73 defines that the ownership of the private property shall be inviolable. The idea behind article 73 is such that the individual does not have to bear extra burdens because of interventions carried out in the interests of the public. Usually for instance, the drilling of tunnels is tolerated as long as the utilization of the private property aren't changed. In practice the involved owners of the relevant private property loses their right to drill wells or establish all sorts of foundation, by expropriation.

Water abstraction: Groundwater is not "private property" but the owner of the land has a preference to exploit/abstract the aquifer after he has been given the permission from the municipality. Usually this permission is very hard to get, especially if the private property is situated within areas already designated to supply the public with water, i.e. well field for public waterworks.

Oslo



The city

The City of Oslo, capital of Norway has a population of 625,000 people within an area of c.450 km^2 of which 150km^2 is urban. The remainder is a forested recreational area (nature area) protected against urban development. The city is coastal, and generally flat lying at the head of a fjord, and is surrounded by rocky hills on three sides. The city has expanded in part by reclaiming land incrementally into the fjord. The landscape is also strongly influenced by glaciation and there are lakes dammed by glacial moraines to the north of the city.

Urban geology

The city lies on sediments of extreme variability in thickness (0-100 m). The topmost are generally thin and man-made, and overlie the dominant marine clays with important organic content, and beneath those are glacial sediments.

In terms of bedrock, the city lies in the middle of a graben, surrounded by Precambrian basement. Marine shales and limestones form the low ground in the city centre and to the south-west, and igneous rocks form the high ground to the north and west. The top surface of the bedrock has been deeply incised during the glaciation. Key geological challenges include: subsidence; quick clay, the radon-producing alum shale.

Relevant information

There is no systematic mapping of groundwater levels in Oslo, but some monitoring is undertaken during developments, and lowering of the groundwater level has been proved at several sites.

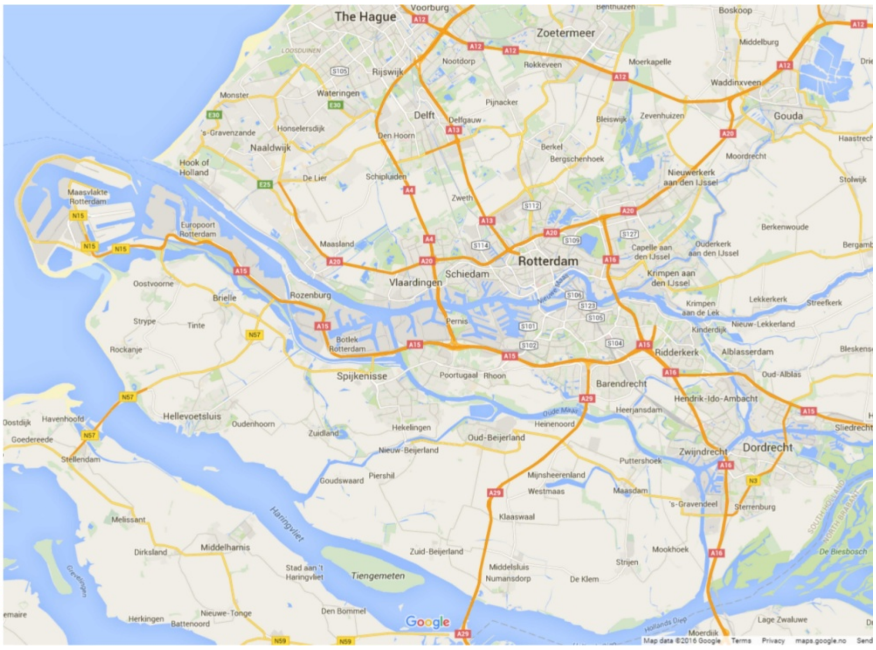
A National Database for Ground Investigations in Norway, under development, is drawing together the vast amount of data, scattered amongst owners and users.

Planning context

Subsurface use is widespread, including: tunnels for transport, sewage and other infrastructure; air raid shelters and national security interests; facilities for parking, water and other storage, and water treatment; and pipes, cables, and energy wells. Major subsurface developments include a major development area, 22km of double track railway, new metro lines and a major sewage project. These face some significant construction challenges necessitating innovative geotechnical solutions (e.g. Eufemias Gate). A current major multi-disciplinary study, The Subsurface Project, will improve knowledge and management of the city's subsurface.

There is a legal framework for protecting existing subsurface structures, as well as the planning and construction of new ones. The planning system is map based, but allows for future planning in 3D; this is under development in Oslo (and Norway), but has not yet been tested fully. Ownership of land extends beneath the surface, and landowners are free to use the ground beneath their property. There is no fixed limit to how far down this right of ownership goes; case law emphasises "reasonable use" but energy wells are not subject to approval, and there is a tradition of "first come first served". Buffers between underground constructions are not established. There are legal requirements to maintain groundwater pressure and level but these are vague, and significant problems have resulted from recent subsurface use (see Bergen for further information).

Rotterdam



The city

The City of Rotterdam, the second largest city in the Netherlands, is the largest port, and an industrial complex, in Europe. Its peak population of 731,000, was in 1984, but this decreased to 555,000. Currently, the population is 618,467 within an area of 320 km^2. The population of the greater Rotterdam area ("Rotterdam-Rijnmond") is c.1.3 million in an area of 860 km^2. The landscape reflects a sandy coastal barrier, interrupted by estuaries and tidal inlets. Behind the coastal barrier, the coastal plain consists of clayey tidal deposits and peat. The city is flat lying, and is divided by the river Nieuwe Maas. The center lies on the northern bank. Built mostly behind dikes, large parts of Rotterdam are below sea level. To keep the reclaimed polder areas dry, water is pumped continuously, and the surface level in most of this area is below mean sea level.

Urban geology

The upper 10-15 m of the subsurface consists of coastal and fluvial Holocene deposits with clayey shallow marine deposits to the west and fluvial sandy channel and clayey flood basin deposits, including peat, to the east. 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. Underlying Quaternary deposits beneath Rotterdam are up to c.300 m thick and comprise clayey and sandy coastal deposits varying to gravelly river deposits, and from fine-grained windblown sand to lagoonal peat. The uppermost coarse-grained deposits (the 'first sand layer') serve as the main foundation level for most buildings in Rotterdam.

In terms of ‘bedrock’, the city lies on alternating marine sand and clay (400-12000m thick), overlying in turn: shallow-marine sandstone, siltstone, claystone and marl; mainly fine-grained sediments (silt, clay) and marly deposits, with some massive sandstones; lacustrine fine-grained sediments, sandstones; and sandstones, mudstones and limestones to a depth of 4500 m.

Relevant information

Groundwater in urban polder areas is about one meter below ground level. Besides drainage by polder ditches, there is some management of groundwater levels. Building projects with underground elements usually need to lower the groundwater level by temporary groundwater extraction. This is regulated by the rules and permits of the water boards. In (deeper) polder areas seepage of deep groundwater is an issue. It occurs when the head of the deep groundwater is higher than the shallow groundwater level. In most of Rotterdam there is a separating layer of clay and peat (thickness: usually 10 to 15 m) between the deep and shallow groundwater, which limits vertical groundwater flow. In 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 past peat mining. Seepage is usually brackish, with relatively high iron and nutrients.

Problems associated with (shallow) groundwater include:

- High groundwater levels can result in damage to road constructions, water in basements etc.
- Low groundwater levels can lead to putrefaction of the wooden piles of older buildings when the wood is (periodically) above groundwater level (oxidising conditions).
- Settlement of buildings without a pile foundation. This will reduce the distance between ground and groundwater level, which can therefore lead to groundwater problems.
- Groundwater contamination by industrial/commercial activities in the past.

Key geological challenges include: control of groundwater level and quality, preservation of archaeological assets; presence of unexploded ordnance; soil Quality; sinkholes and a range of other geotechnical issues affecting construction, foundation conditions etc.

Rotterdam has a large database of soil quality of top soil layers and aquifers; the data are available in a GIS and include soil composition, chemical analyses of ground and groundwater, historical activities, excavations, soil investigations and remediation plans. There are data from c.2000 groundwater monitoring wells in Rotterdam. Most knowledge of the deeper subsurface has been obtained from wells drilled by oil companies and from seismic data.

Subsurface use is widespread, including: tunnels for transport (metro and roads), sewage and other infrastructure; pipes, cables, construction foundations and basements, preserving archaeological assets, shallow and deep geothermal energy for heating (extraction) and cooling (subsurface thermal storage), oil and gas extraction. Historically, peat was extracted for energy, clay for bricks, and sand and gravel for construction. Today, soils are recycled via a soil bank.

The present subsurface model consists of 4 layers:

- From 100 meters downwards, in the deep layer where oils and gas is extracted, the Mijnbouwwet (Mining Law) applies. The Ministry of Economic affairs is responsible for managing the resources, and owns the rights to oil, gas and mineral exploration and geothermal activities below 500m.
- The provinces are responsible for the activities in the water zone
- Municipalities supervise the management of shallow zones
- There is potential for CO_2 storage, and shale gas extraction.

A current major multi-disciplinary study by the Geological Survey of the Netherlands (TNO) will improve knowledge and management of the city's subsurface.

Planning context

Rotterdam has a 'balanced' planning system. In the past, urban planners did not consider the subsurface as particularly important, other than in relation to archaeology and soil pollution, in line with national and international laws. Groundwater, geotechnical properties and subsurface space are only taken into account on a project scale, although recently, the subsurface has been increasingly acknowledged more in city planning. Rotterdam has been experimenting with 3D visualization of the subsurface, but does not yet have a 3D zoning plan of the subsurface.

At national level, a Committee is currently engaged in creating an integrated structural vision for the subsurface. Instead of the 'first come, first served' principle, subsurface uses will be assessed and prioritized, so enabling sustainability. This will align policies related to subsurface usage; the Ministry of Economic Affairs is responsible for the deep subsoil, while the shallow subsoil falls under the authority of the provinces, municipalities and the water boards.

Water boards are the responsible for (ground)water management and maintenance of related dikes and dunes, and the discharge of rain- and waste water. Groundwater is a key challenge, and has to be pumped continuously. Together with the water boards, the city of Rotterdam has developed a Water Plan; focused on implementing spatial measures todays, to protect the city in the future.

Ownership of land extends from the surface downwards, and landowners are free to use the ground beneath their property. Cable companies have the right to lay cables, but must declare their subsurface activities to the authorities. All subsurface resources (mineral resources, oil and gas) deeper than 100 m are owned by the State (although for geothermal resources the law applies only to heat extraction below 500 m). Private landowners benefit from local revenues from the subsurface in various ways.

3. Analysis and discussion

Common ground for comparisons?

Ten out of the twelve cities we studied are located at or near **the sea**. A Coruña and Nantes are situated at the Atlantic coast, and Glasgow and Dublin at / near the opposite shores of the Irish Sea. Bergen and Oslo are situated at the elevated northern rim of the North Sea, and Hamburg and Rotterdam are in the lowlands present at the southern shores of the North Sea. Odense and Helsinki are built at the shores of the Baltic sea, which separates most of Scandinavia from mainland Europe. Ljubljana and Novi Sad are the only two truly **land-locked** cities, they are positioned in the Alpine-Dinarid mountain range and the Pannonian Basin, respectively. Water is still a key element of their physical environment, both towns are located along **major rivers**: Novi Sad along the Danube, Ljubljana along the Sava, one of the larger tributaries of the Danube.

Other than water being important, our city selection shares a number of shared characteristics that primarily stem from the fact that they are European. This implies that our cities are:

> … **at least several centuries old**. Buried or superficial, all cities in our selection have cultural heritage that needs protection and exerts influence on town development. Our towns also share a number of historic events that have determined, to a varying extent, their development, including for instance unification in the EU, the Cold War and its aftermath, two World Wars, and the Industrial Age.
>
> … **redeveloping** rather than (strongly) developing. Population and economic growth rates in Europe are both in the order of about 1%. At such low overall growth rates, the focus in urban development is on maintenance and improvement, presenting a marked contrast with the spectacular urban growth seen in for instance Brazil and China.
>
> … **post-industrial**. Most, if not all European cities have seen more heavy industry in the past than they do at present. As already argued above, industrial legacies present great redevelopment challenges.
>
> … presently under a fair to strong **planning control**. EU regulations on, for instance, environmental and public health, require a level of control on life in the city and on how a city develops. This introduces common ground for all our cities, eleven of which are already in the EU, and one in a country that aspires to become member state. Beyond that, cultural differences prevail, e.g. between the post-communist and Scandinavian strong planning traditions, between the more liberal approaches to planning seen in southern Europe, the northwestern countries taking an intermediate position.

… **prosperous**. Even though Europe is recovering from an economic crisis, and notwithstanding the fact that the economies in northwestern Europe are stronger than the ones in the south and east, our cities are prosperous. The standard of living is fairly to very high.

Our selection does not include cities that are very poor, very big, or (geologically) very dangerous. For the purpose of exploring the extremes, as well as to provide a framework for a first assessment of the urban geology of our cities, we will first zoom out and have a look the bigger geological picture.

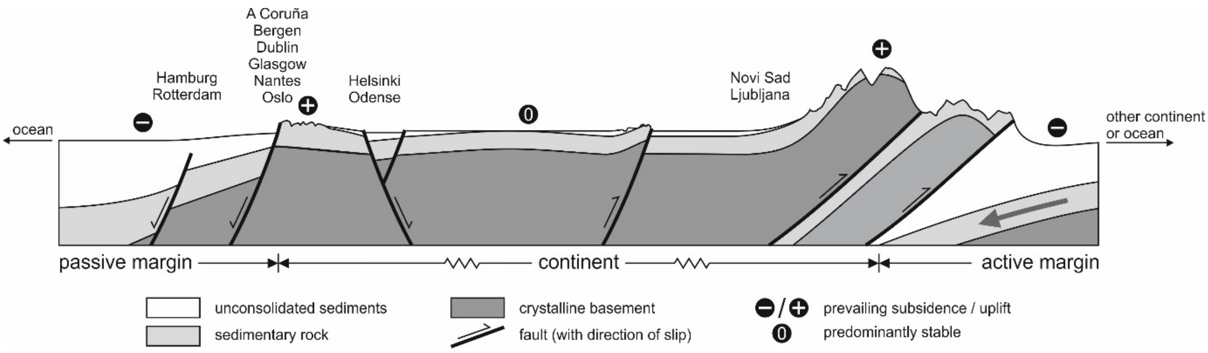
The bigger picture: tectonics

When studying urban geology, it is essential to not only consider the urban subsurface but also the larger setting, simply because the scale of many geological features and conditions that affect cities is larger than that of cities. Practical examples, in the sense that they bear to geological resources and risks, include aquifers, watersheds, earthquake zones, etc., etc. At the largest scale, the primary factor that determines urban geology is tectonics, i.e. the dynamics and deformation of the Earth's crust. The fundamental entities of tectonics are tectonic **plates**; their motion causes deformation, especially along plate boundaries. Tectonics control:

- the distribution of **continents** and **oceans**,
- **subsidence** and **uplift**, and thereby large-scale topography, the presence of basins and mountains, drainage patterns, sedimentation and erosion,
- **seismicity** and **volcanism**,
- the distribution of many **resources** (including hydrocarbon, metals, geothermal heat, etc.).

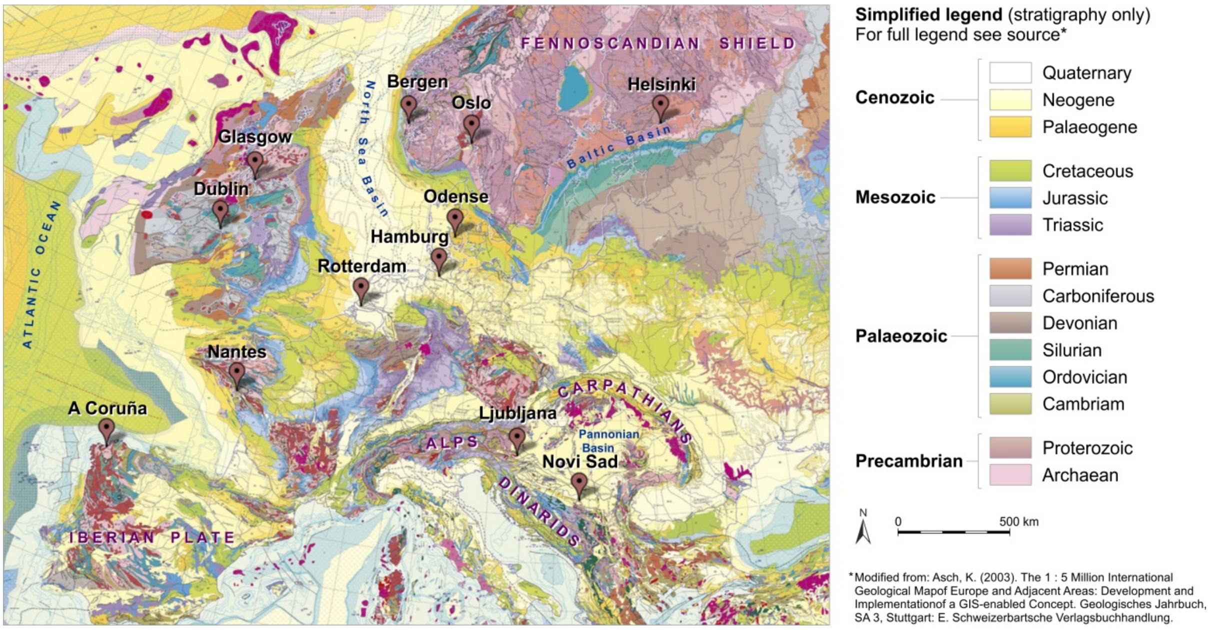
Continents, the vast landmasses on top of which most of the World's population live, correspond to plates or segments of plates having a thick ('continental') crust. An **ocean** is a body of water which sits on a plate or a sector of a plate having a thin ('oceanic') crust. The margins of continents can, but do not necessarily coincide with plate boundaries. It is the case where a continent overrides a neighbouring plate (**subduction**); here the continental margin is called an **active margin**. The process of convergence can persist until the continental part of the neighbouring plate reaches the subduction zone, and **continental collision** occurs. Mountain building takes place both during the subduction and collision stages of the evolution of active margins, as well sedimentary basin formation. Melting of subducting rock causes volcanism (**volcanic arc**), typically behind the mountain range on the overriding plate.

As the Earth does neither contract, nor expand, consumption of oceanic crust along active margins is globally balanced by the creation of new oceanic crust along spreading ridges that exist between plates that are moving away from each other, for example along Mid-Atlantic ridge between the Americas in the west and Europe and Africa on the east. A **passive margin** is a contact between a continent and an ocean belonging to the same plate, i.e., where no subduction takes place. Passive and active refer to tectonic activity, there is a pronounced difference in risk and hazard profiles when comparing both types of margins. Our study area, central to western Europe, has an active margin in the south, the Mediterranean area, and passive margins towards the North and East, at the Atlantic coast.



Schematic cross-section view of the main geological settings for cities, and the grouping of the cities (see text for explanation).

The westernmost cities in our selection, A Coruña, Dublin, Glasgow, Nantes and Bergen, are situated (geologically) near the Atlantic passive margin. The fact old rocks (Mesozoic to Palaeozoic) are exposed, is partly due to the fact that the relative buoyancy of the oceanic plate slightly lifts the continental margin. In the north, this is enhanced by rebound of the crust after it became unloaded of the thick ice sheets of the last Ice Age. The geological map below clearly shows that this pattern is not uniform, the Atlantic margin is cut by basins such as the Bay of Biscay and North Sea, at or near which shores Rotterdam, Hamburg and Oslo are located. The North Sea Basin is an extensional structure, where subsidence is caused by stretching an thinning of the European crust. The Baltic sea was created by glacial processes rather than by extensional tectonics; Helsinki occupies the most intra-**continental position** among our selection of cities.



The twelve cities that were studied in Sub-Urban WP1 in their geological context, see text for explanation.

The Mediterranean area is situated in the zone of convergence between the African and European continents. While continental collision in the western and eastern Mediterranean has put an end to convergence, remnant portions of oceanic crust that are present in between, i.e. below the Mediterranean Sea, still ‘attempt’ to subduct. This has resulted in a complex mosaic of basins, interlaced by extremely curved mountain ranges. As evidenced by the presence of active volcanic arcs, he most **active sectors** of the Mediterranean area include the Calabrian and Hellenic Arcs in southern Italy and southern Greece, respectively. Ljubljana and Novi Sad are positioned in a more quiet sector.

Besides extensional (divergent) and compressional (convergent), there is a third type of tectonics that brings an urban geological setting that is not represented in selection of cities, but which does occur in Europe. The North Anatolian Fault accommodates an westward motion of Turkey relative to Europe and the Black Sea remnant ocean. Earthquakes along such fault, a **strike-slip** fault, can be just as disastrous as the ones that are caused by head-on convergence, as demonstrated by the similar and well-known San Andreas Fault. So, the largest European city, Istanbul, sits on a structure that presents a great geohazard to its population.

Zooming in: topography, water, subsurface

While tectonics governs the overall urban geological setting, what we experience and deal with are its second and third order features: how deep is rock head, what are the water system characteristics, do we face earthquakes, what about ground conditions and overall stability, etc. At that level, it is useful to make the following (geological) distinctions: whether or not the city is positioned in a sedimentary basin environment, and if not, whether it is situated in a mountainous or more gentle topography.

When situated in a sedimentary basin, which doesn't necessarily implies that the area is submerged, cities will be built on unconsolidated **sediments** in a **wet environment**. Wet may refer to the proximity of the sea or a lake, of rivers that drain the hinterland and bring water and sediment to the basin, and to groundwater that is present in the pore space of sediments. Deeper in sedimentary basins that are geologically old enough, hydrocarbon resources may occur, the exploitation of which may present opportunities and risks to the built environment.

In a sedimentary environment in a tectonically quiet passive-margin or continental setting, water, **subsidence** and adverse **ground conditions** typically present the biggest geological challenges. A sedimentary basin setting along an active margin is far more hazardous, as tsunamis, liquefaction and landslides may occur, and seismic waves can actually be amplified in sedimentary basins, depending on their infilling.

When situated in a mountainous area, a city is surrounded by the rocks it is built on. However hard and firm these rocks may seem, a mountain topography is **inherently instable**: important instability-related geohazards include landslides, flash floods, debris slides and rock falls. Tectonic activity aggravates the situation: earthquakes do not only present a risk in their own right, but they may also trigger any instability-related event. Mineralisations that are associated with mountain building (magmatism and deformation) can produce mineral resources, the exploitation of which may interfere or be part of urban development.

In the context of our study, the **continental domain** can be first characterised by the absence of the tectonics found at plate boundaries. Intra-plate deformation does occur (e.g. the Rhine graben), and continents may bear the witness of geologically older deformation (the topography of which may present instability risks). However, generally one can think of flat to peniplane morphologies, having a relatively thin cover of sediments or drift. Particularly relevant to habitation is proximity to rivers or other bodies of water, where major continental cities such as Prague, Budapest, Vienna occur, and in case of our selection of cities, Helsinki.

While continental and passive margin settings are the mildest in terms of geohazards, geological 'freak accidents' and **far field effects** of distant disasters can still present extreme geohazards. One important example of this is the Eifel volcanic province in Germany, which is known to have produced massive explosive eruptions in the past and is probably still active. The presence of these volcanoes is unrelated to the plate-tectonic framework described above, it is thought to be deeper-seated, in the Earth's mantle. Another example would be a massive landslide in a Scandinavian fjord, which could trigger a tsunami that is just as disastrous as the ones seen in the Pacific.

Back in town: qui bono?

The resources and hazards that are presented by geology can be very large, not only physically and spatially, but also societally and economically. If so, their exploitation (in case of resources) or mitigation (in case of hazards) needs **to be organised**. We therefore argue that the balance between public and private control is an important variable that can be used for the characterisation and ranking of urban subsurface planning approaches. So who benefits?

Public control implies that **collective needs** are met, and that various interests are weighed (e.g. economic benefits versus safety). While private control certainly does not preclude societally beneficial decision making, it is inherently more focussed on the **immediate interests**, in planning context for example those of land owners. Public institutions are arguably better suited to accumulate data, information and knowledge, amongst which about the subsurface.

Scandinavian countries have strong public sectors, leading to the generally excellent public facilities and utilities but, in the context of subsurface planning, private rights are strong as well. The rights of land owners, for example, extend into the subsurface, and activities they might undertake (e.g. ground source heating) are not regulated to the same extent as in other participant cities. Oslo specifically reports a lack of public control over the subsurface to be an **obstacle** to urban planning. Odense faces a **lack of information**, because of private ownership of much of the city's subsurface data. A Coruña was faced with a spectacular thirteen-story underground parking lot, which was conceived largely outside the municipal planning framework, because of the **freedom** land owners have to develop their property (and its subsurface).

Probably the worst combinations of planning approaches and geological conditions exist where weak governance and great hazards or opportunities coincide. Uncontrolled urban sprawling in for instance seismically active or land-slide prone regions could obviously have disastrous consequences. But so could unregulated or badly supervised mining activities, bringing great environmental and safety risks. Examples of this (still) occur all over the world, and also in Europe. Note that a city is not only the result of good current planning practices and activities, but also (or more so) by past ones at a much lower level of risk awareness.

We argue that the **best possible situation** is a city that has maximised the benefits and possibilities related to the subsurface (in terms of resources) and minimised risks (geohazards). We argue that such state can be achieved by **informed planning and decision making**, for which purpose four general conditions must be met:

1) There is a general level of **awareness** of subsurface and geological issues, not only in the professional communities involved (planning and geoscience), but also politically and among the general public. Awareness is a precondition, which eventually translates to a mandate to planning and geoscience professionals to co-operate.
2) There is an understanding among planning and geoscience professionals, and they share a common professional language:
    a) Planning experts are able to **articulate** what they need (data, information, expertise), and **understand** what is out there – and what is not.
    b) Geoscience experts are able to **understand** what is needed and **articulate** what is available or developable.
3) There are systems in place that **capture** relevant subsurface data and information, so that baseline needs are met in each urban planning and development stage.
4) Planning and geoscience experts have a **joint vision** on how to develop their practices, addressing needs that cannot be met as yet, and they are able to pull **investment** budgets in order for their vision to materialise.

Best practice examples

All cities participating in Sub-Urban WP1 at least to some extent represent good practice examples of considering the subsurface in urban planning; the mere fact that they chose to join points to some level of awareness of subsurface issues and opportunities. But clearly, as demonstrated by the city reports and their summaries in chapter 2, they is a large variation. In **Novi Sad** and **Dublin** awareness is emerging, which presents the advantageous possibility of a clean slate. A good starting point might be a master plan for the subsurface, similar to the approach presented by **Helsinki**, which stands out as an example of vision and ambition on the city level. As a matter of fact, not only Novi Sad and Dublin but all twelve cities consider themselves to be pioneering, which implies that none of our cities have all elements in place that allow them to plan (with) the subsurface at the level aspired by the Sub-Urban city representatives. This is why our the state-of-the-art examples can only be fragmentary: rather than cities that have it all figured out, we present elements and building blocks.

For **Rotterdam**, it was argued that, over the last decades, people have actually forgotten about the subsurface – awareness is low. Their municipality's public engagement efforts (city tours, serious gaming) stand out as examples of **awareness raising**. Within their organisation, the **traffic light maps** that in-house engineering agency produced have been very effective as a means to **transfer information** about the subsurface to planners. Another example in this field is presented by **Glasgow**, where the City Council and the British Geological Survey have established a network (ASK) that facilitates **sharing** of (and thereby **access** to) data and information.

Free availability of urban subsurface data may be inspired by a different domain. **A Coruña** participates in the **Smart City** network, which puts much emphasis on open data and data sharing. Their participation in the Sub-Urban project actually piggybacks on Smart City activities undertaken by the municipality. Rotterdam is located in a country that traditionally promotes **free data**. The Geological Survey of the Netherlands puts all its data and information out for free, something which will be further institutionalised by a new law on geological information. Not only the situation as such may serve as an example, but also the **funding model** that comes with it. Free data does of course never actually come free of costs, it is provided free of charge by an organisation that is paid to do so.

We consider **Hamburg**, having its own geological survey which is embedded in the city's government, to be a best practice example of urban subsurface data and information management. Having a small area of operation, being fully dedicated to the (peri)urban domain, and backed by about a million taxpayers, the information they put out is both plentiful and very much fit-for-purpose, perhaps more so than in case of cities that are primarily serviced by national geological surveys.

And finally, there are of course, practical examples of specific subsurface use. **A Coruña** and **Helsinki** present the clearest examples of making use of underground space, although under completely different planning regimes. **Odense**, **Ljubljana** and **Nantes** are examples of cities having a strong grip on **urban groundwater** management. In Odense, the main overarching challenge are rising groundwater levels after a reduction of abstraction. Compared to that, Nantes and Ljubljana operate in a more steady-state situation, their monitoring and monitoring efforts demonstrate **good stewardship** of their groundwater systems.

As an industrial revolution icon, **Glasgow** is by necessity experienced in dealing with **industrial legacies**, which are expressed in soil and water quality, as well as in instability risks associated with former mines. **Oslo** and **Bergen** are particularly noteworthy for their efforts to preserve their archaeological heritage. As much of it is wooden, it is vulnerable to groundwater lowering, because the aeration and settling this brings about.

… and one no-practice example

While the present report emphasises good practice, the underlying city studies also mention gaps and limitations, one of which seems to be so generally acknowledged that it cannot go unmentioned here. The shallowest urban subsurface, referring to the zone of human interaction, more or less represents a physical separation between the subsurface and the world of urban planners, which focusses on the surface and above. Unfortunately, it also represents sort of a no man's land. It is out of the comfort zone of urban planners for the mere reason that it is below-ground ('**out of sight, out of mind**'), as well as that of geoscientists: it is the subsurface, which is OK, but it is artificialized beyond their understanding. The exploration and characterisation of made ground presents a joint opportunity to further subsurface planning.

Baseline city needs

Beyond good practice and gaps, the city reports also reveal baseline city needs when it comes to considering the subsurface in urban planning. At the highest level, these are summarised above, as (pre)conditions for informed decision making. This bears to understanding and communication between the planning and geoscience communities. To this, we add timing as a crucial element. Not only does information need to be fit-for-purpose in order for to be digestible for planners, it also needs to be available **early** in the planning process. As argued above, unless you are talking about new ground investigation or exploration efforts, geological data, maps and/or subsurface models need to be readily available, at least in part, when required in the planning process, given the efforts necessary to build the databases and to create information products. **Timeliness and readiness** imply that considering the subsurface in planning urban requires all parties involved to be **forward looking**.

4. Conclusions

What does the state of the art add up to?

We have studied how twelve European cities, in order to define the state of the art in considering the subsurface in urban planning. We have presented the state of the art as a set of good practice examples, individual reports can be consulted for full accounts. The city examples allow us to draw the following general conclusions:

1) Good practice examples can only be defined for elements or aspects of urban planning. None of our cities have got it all figured out; all cities consider their efforts in the subsurface domain to be **pioneering** (i.e. between emerging and partly or newly established).
2) Good practice examples exist on the level of **vision** and **awareness** (master plans, communication); **information** (transfer of data and information, monitoring); **planning approaches** (which requires successful transfer of subsurface data and information to the planning community); and various concrete **applications** and **risks**.
3) Most of these practices we identified are in principle transferrable. Ensuing activities in COST Action Sub-Urban include a further outlining of best practices (Work Package 2), which are to be deployed in an urban planning toolset (Work Package 3).

General lesson

In addition to the concrete results, COST Action Sub-Urban is successful in creating a community of practice between the geoscience and the planning communities, involving cities, universities and institutes. To some extent, the project is already improving the conditions for urban subsurface planning, especially where communication, mutual understanding and awareness raising are concerned. For better impact, however, this will have to be extended to decision makers and the general public.

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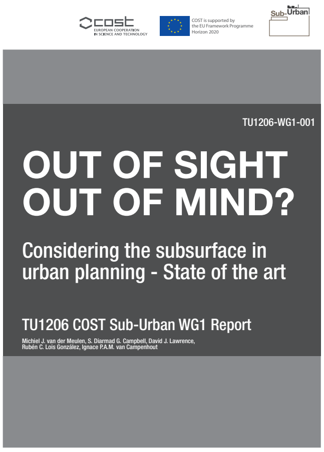

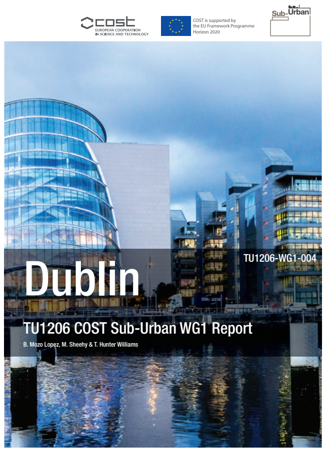

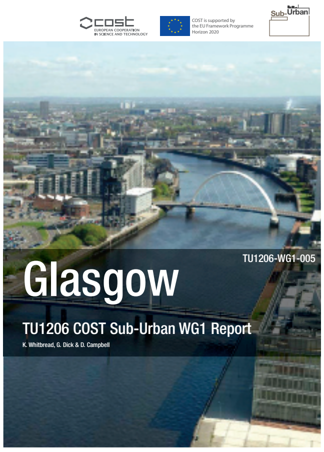

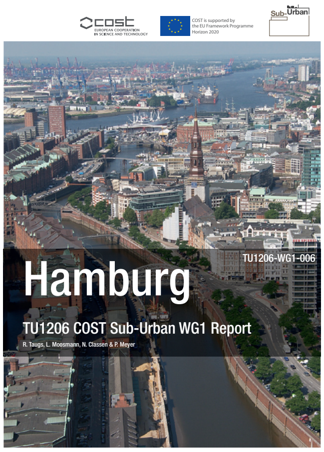

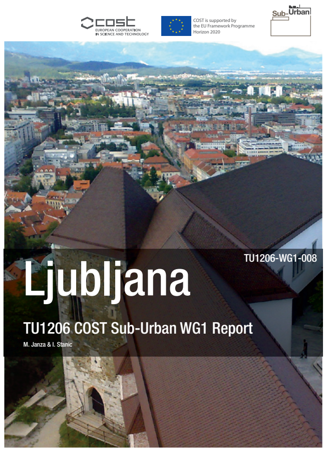

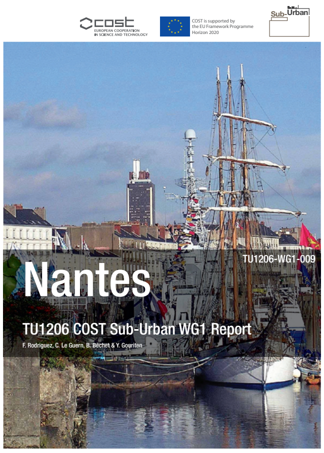

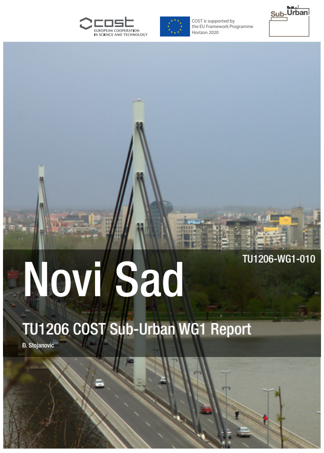

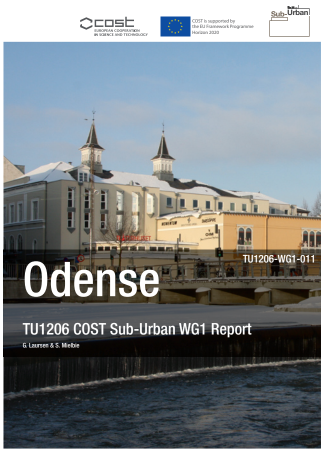

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