



TU1206-WG1-003

Bergen

TU1206 COST Sub-Urban WG1 Report

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GEOLOGICAL
SURVEY OF
NORWAY
- NGU -



CITY OF
BERGEN



Plan- og bygningsetaten, Oslo kommune
Planning and Building Services, City of Oslo, Norway

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Summary

In this report the case studies for Bergen city, western Norway, are described. We are presenting facts about the city, the administration and the role of responsibility in the municipality with respect to planning and decision making. Furtheron the physical geography and geology of Bergen city area is described, providing the basis for the problems addressed in the case study of Bryggen in Bergen (ca. 2000-2015) and the newly started case study of the medieval city of Bergen, including Vågsbunnen and its appurtenant issues.

Here, the main emphasis is on describing the background of the ongoing sub-urban project in Bergen and the success story of Bryggen in Bergen. The issues to address in the future work are numerous. Laws and regulations will be evaluated during and because of this work. The aim is to build knowledge about the subsurface, to emphasise its role in urban planning and to develop a communication of data that is accessible for all parties who play a role in planning the urban area.

1. City description

Bergen is the second largest city in Norway. Oslo is the capital. Bergen, with its appurtenant municipality, is located at the western coast of Norway in Hordaland county. The city is surrounded by "the seven mountains" and is called the "capital of western Norway". Bergen city has its boundaries to the fjord and the North Sea to the west-northwest and to mountainous area to the east-southeast (Figure 1).

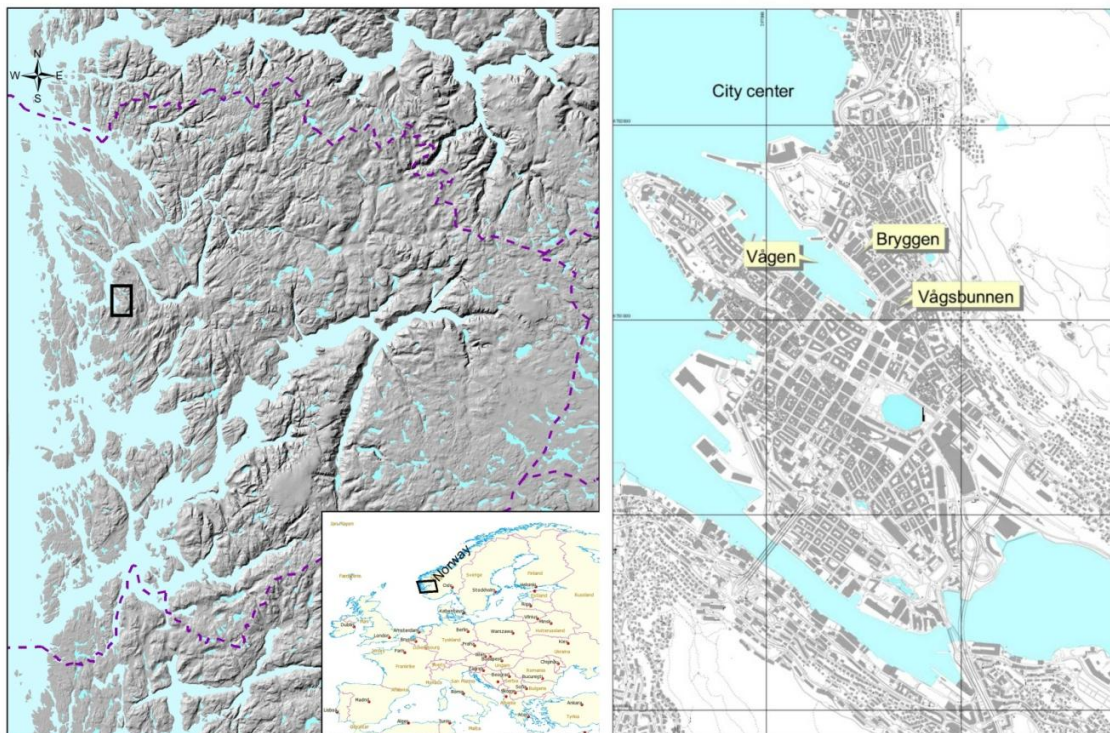


Figure 1: Location of the city of Bergen in western Norway and Hordaland county.

Bergen was founded in 1070 AD. Today it is a city in a dynamically developing region with a growing population and an international centre for aquaculture, shipping, offshore petroleum industry and subsea technology. Bergen is also the second largest educational centre in Norway, with the University of Bergen, the Norwegian School of Economics, the Bergen University College and many other smaller educational institutions. The city is famous for "Bryggen", a wharf from the Hanseatic League (1702) that is on the UNESCO's World Heritage List.

The topography in Bergen varies within short distances, from lowland a few meters above sea level to mountains reaching up to 400 to 643 m above sea level. The city is known for its wet climate, with an annual precipitation of 2250 mm, on average 213 rainy days a year, and an average air temperature of 7.6°C, which is high compared to other places in Norway.

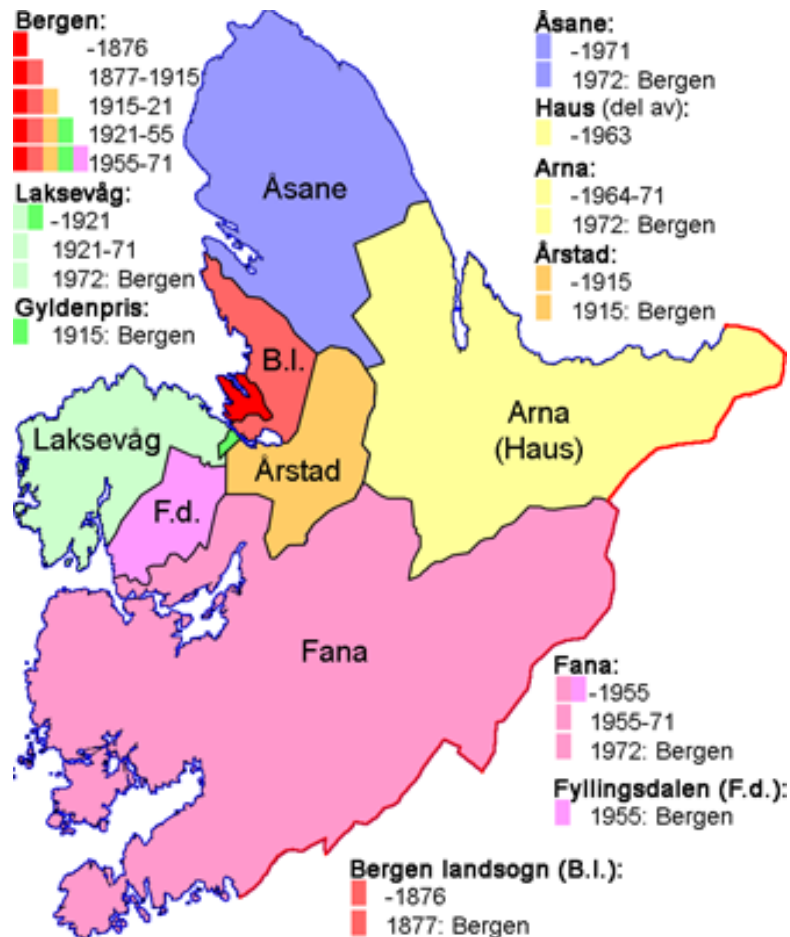


Figure 2: The city of Bergen consists of the districts Bergenhus with the city centre plus Årstad, Fyllingsdalen, Laksevåg, Åsane, Arna, Fana and Ytrebygda. The city centre has developed in size since 1876, until then the districts were independent municipalities (wikipedia.org).

1.1 Description of Bergenhus and Nordnes

From the year 1070 AD Bergen town gradually developed around *Vågen* ("the bay"), a natural, well-sheltered and ice-free harbour that proved to be an ideal location for commanding trade along the coast. From the end of the thirteenth century Bergen was one of Northern Europe's most important ports and one of the Hanseatic League's most important towns.

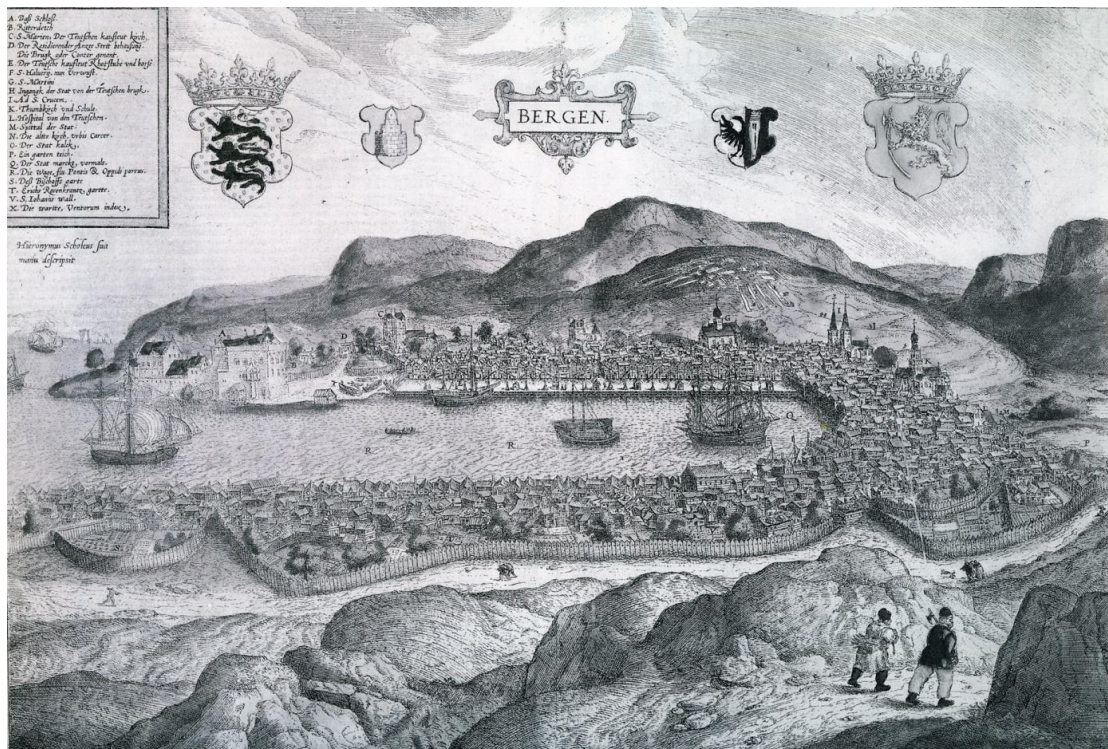


Figure 3: A drawn picture of Bergen city centre from around 1850 where the centre is located around the Vågen bay area (by Hieronymus Scholæus, 1850).

The town thrived and settlement gradually expanded towards southeast to form the Vågsbunnen. The area was originally dissected by a narrow inlet, which became gradually filled. Bryggen and Vågsbunnen gradually expanded up to 140 m seawards by filling a range of materials such as wood and household rubbish into timber “boxes” in the seawater at the quay front. Settlement spread further along the bay’s south-western shore, the area known today as *Strandsiden* (Figure 4).

Throughout history, Bergen has experienced many disastrous fires. The current timber buildings at Bryggen and Vågsbunnen were erected after a major fire in 1702, but generally on the old sites and frequently on the old foundation walls as well. Due to its outstanding testimony to past traditions, Bryggen became designated as a World Heritage Site in 1979.

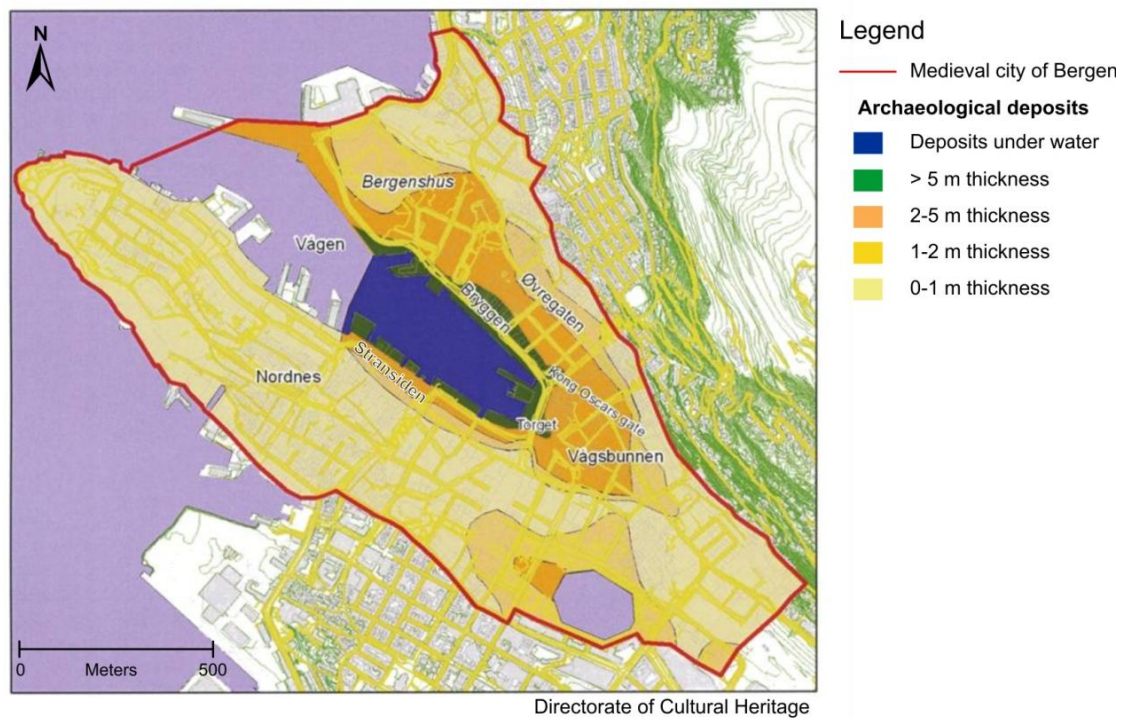


Figure 4: The boundary of the medieval city of Bergen (Source: The Monitoring Manual, Directorate of Cultural Heritage).

A large part of the settlement in the Vågsbunnen area is founded upon several meters of cultural deposits that are vulnerable for degradation and subsidence. During upgrading of the road system and rehabilitation of buildings in the district Vågsbunnen, significant subsidence connected to artificially low groundwater levels have been observed. There is increased awareness in the city administration related to measures that may alter the groundwater level and the impact this may have in terms of damage to cultural heritage above and below ground, as well as subsidence that may further damage buildings, structures, cables, roads and pavements.

A municipal pilot project has been initiated to map existing groundwater pumps. This has led to restrictions on the right to implement measures in the ground that can alter the groundwater table. Therefore, the city needs a comprehensive understanding of the subsurface to ensure a more sustainable and cost-effective management of urban spaces, including tools, procedures and methods to better integrate urban geological knowledge in land management.

1.2 Key city data

- Surface area: 465.56 km², urban area: 94.03 km² (metropolitan area: 2.755 km²)
- The increase in population is 11.0% per 10 years \approx 1.1%/year
- Number of inhabitants/population: 272 600 (5th May 2014)
- City: 271067
- Urban: 238098 (2012)
- Metropolitan area: 401181

Density / land use intensity

- The population density in the city of Bergen is 566 inhabitants per km²
- Total number of housing: 131096 registered buildings in the city of Bergen
- Transport infrastructure : busses, train, light rail

1.3 Subsurface land use

The subsurface in Bergen is increasingly used for many purposes, such as:

- Infrastructure tunnels
- Interest of national security
- Air raid shelters
- Parking facilities
- Water storage
- Water treatment centre
- Sewage tunnels
- Drinking water transportation
- Storage
- Pipes
- Cables
- Industrial purposes, such as waste management
- Working and living space (houses, offices, shopping centres)
- Ground stabilization (filling)
- Raw material extraction (gravel, stone, sand)
- Ground source heat (closed loop systems)

Table 1: Wells in Bergen municipality (NGU, 2013).

Total	Wells in bedrock	Wells in deposits	Wells for water supply	Wells for heat source
1136	1082	54	334	737

1.4 Infrastructure

1.4.1 Transportation system

The transport infrastructure in Hordaland county is based on roads, railway and shipping. The city of Bergen has a railway connection with Oslo via the Bergensbanen built in 1907 over a mountain plateau with a height of 1222 m above sea level, which has strong winter storms from December to April. The main European and County roads that connect Bergen to other cities are E39 to Trondheim in the north and Stavanger in the south, E16 to Oslo in the east and county roads Rv580 and Rv555 lead to the Bergen airport at Flesland southwest of the city centre. Bergen city centre is the transportation hub, either on open roads or in tunnels. In recent years most of the large roads are laid in tunnels, placing large traffic junctions near the city centre.

Cargo to the city is transported on railway, by ship and on road by trucks. The Bergen harbour is located north-northwest of the city centre, just outside Vågen. The transport from the harbour to the railway is by road, through parts of the city centre.

The Light Rail is an initiative to enhance public transport and the distance from the city centre to Nesttun to the south was opened in 2010, with an extension to Lagunen in 2013. The next extension will be to the Airport at Flesland. A continuation of the Light Rail, north of the city centre to Åsane, is planned. Currently, impact assessments for alternative routes through the historic city are being carried out. This northward route will provide public transport through the suburbs Sandviken, Norwegian School of Business and Management (NHH) and Åsane. The Bergen City Council decided in February 2012 that an extension of Light Rail to Vågsbotn (Bryggen) should be investigated. A range of alternative routes are assessed. The main concern is whether the Light Rail should be constructed above ground or below ground through the historic city centre. Concerns with subsurface construction are primarily related to subsidence and permeability of the ground and groundwater table and flow, as well as to the related risks for disintegration of archaeological, built heritage and ground stability.

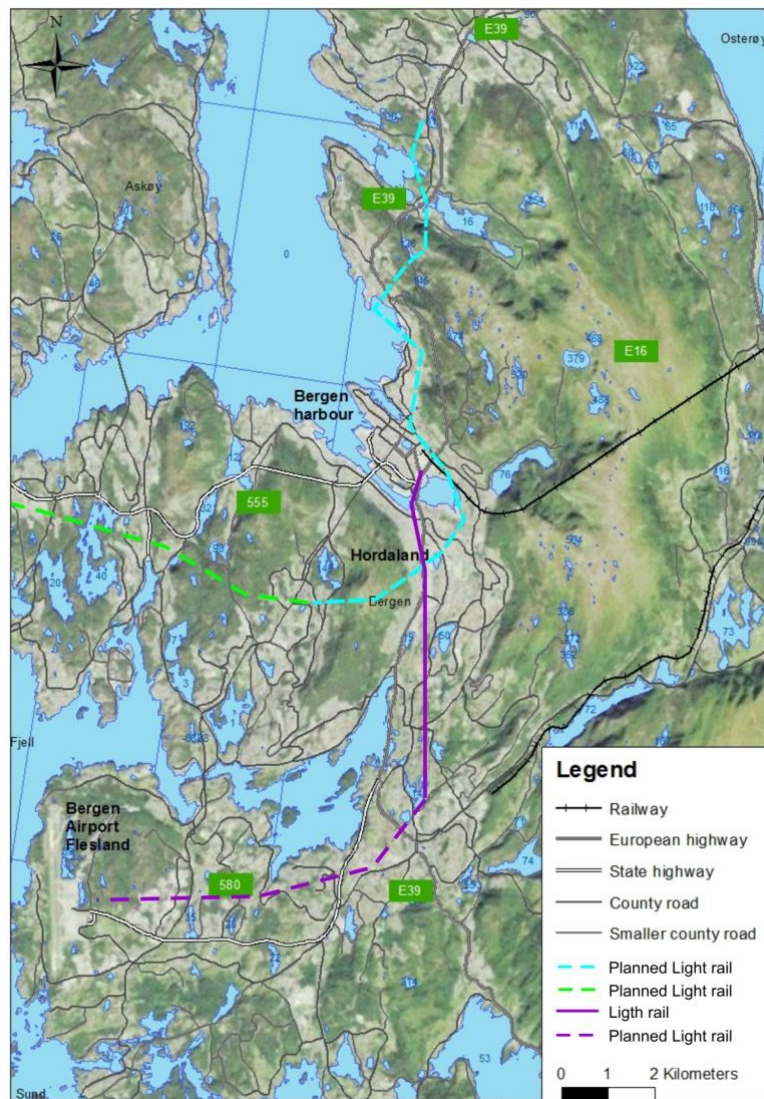


Figure 5: Infrastructure in the Bergen area, including European, State and County roads, railway, shipping and Light rail.

In accordance with the Planning and Building Act § 9 (2008) a planning program for our project is being established. The planning program adds the formal framework for planning work and related processes. The program has been circulated and approved by the City Council in summer 2012.

An impact assessment as a basis for planed routes is ongoing, which will be the basis, underpinning the recommendation of the choice of route. The impact assessment is a corridor study with a level of detail similar to that required for plan work. For several locations detailed studies have been necessary to check if the various solutions are feasible. After the route has been adopted by the City Council, the final detailing and plan design is done in a separate process through a zoning work. This will be the formal plan documents for the construction of the light rail to Åsane.

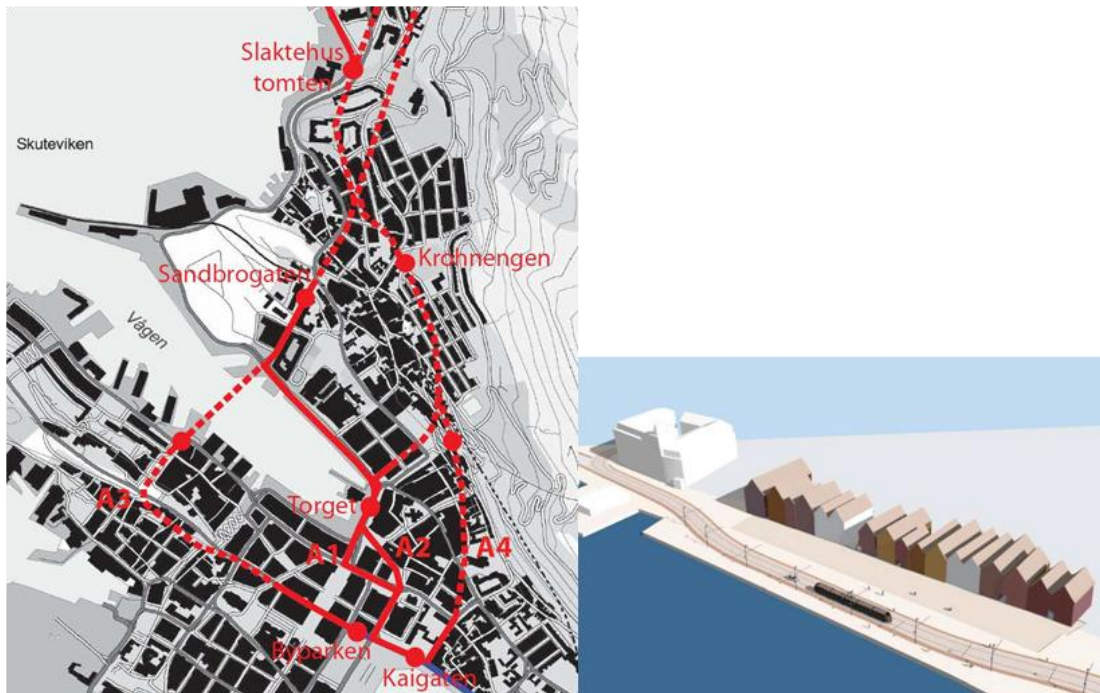


Figure 6: Map of alternative paths for the Light Rail in the city centre and Vågen (left). One of the alternatives runs directly in front of the facade of Bryggen (right). The Light Rail will replace the existing traffic, with pedestrian boardwalks on either side of the railroad (Source: Bybanen.no).

1.4.2 Water and wastewater

97% of Bergen's population obtain their drinking water through the public water supply. The municipal water supply consists of five water treatment plants; Jordalsvatnet, Svartediket, Sædalen, Kismul, and Espeland. These plants deliver water to a fellow distributive system and present a backup for each other. The distribution network consists of 900 km of water pipes, 62 dams, 30 elevated reservoirs, and a vast number of tanks and other installations. According to Norway's framework for water management (Drikkevannsforskriften), the responsibility for a safe and reliable water supply lies with the owner of the water plant. In the case of Bergen, this is the municipal Agency for Water and Sewerage Works (Vann- og avløpsetaten).

The water distribution system varies greatly in age and quality. About 20 km of pipes are more than 100 years old, but the major portion is from the period 1971 to 2000. Most pipes are made of cast iron (Figure 7).

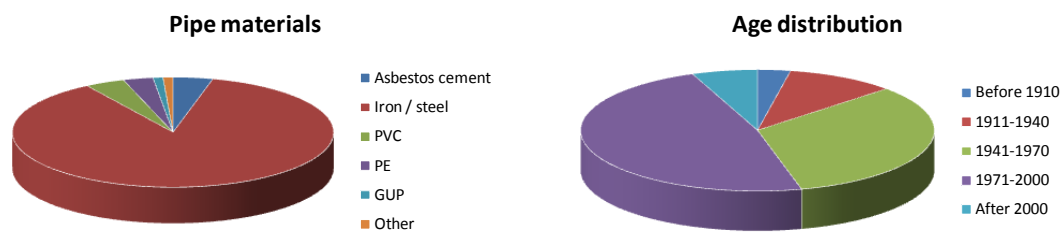


Figure 7: Pipe materials (left) and age (right) of Bergen's water supply system. Data from Bergen municipality (Source: Agency for Water and Sewerage Works, Bergen municipality).

Before 1860, wastewater was collected in narrow, open ditches that directly led into the harbour. New hygiene regulations initiated the installation of simple pipes and the wastewater system gradually expanded. Simultaneously, the fjord turned more and more into a sewer. In order to limit the contamination, it was decided to restructure Bergen's current (1976) wastewater system. As a part of this plan, several purification plants were installed.

A main challenge of today's system is that rainwater collected from roofs, streets and parking lots is directed into the same pipes as the wastewater from households. Rainwater and wastewater use one and the same pipe system (Figure 8). The highly diluted wastewater is cleaned in treatment plants, which reach capacity when processing the large volumes of water. Considering that it rains 2250 mm per year on average, a common pipe system is not an optimal solution. The strategic plan for wastewater and the aquatic environment for 1997 to 2007 states that the common pipe system in the old parts of the town should be kept, and recommends to gradually introduce separated systems and water retention / infiltration facilities where it seems reasonable.

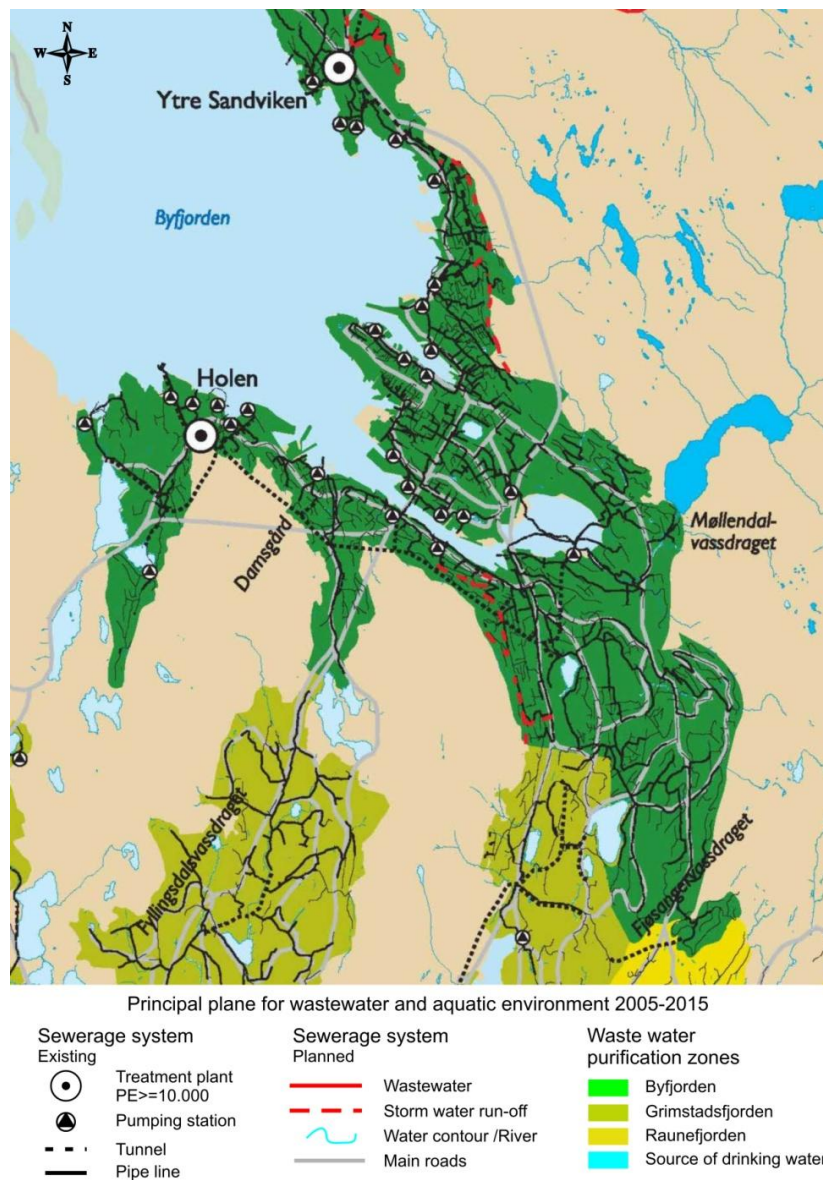


Figure 8: Map of Bergen's wastewater system (Source: Bergen municipal "city duty"(bydrift)).

2 Geology and physical geographical setting

The landscape of Bergen is dominated by the high mountains located around the city (Figure 9). The city centre is relatively small with the developed areas clinging to the hill side. The centre is on a flat valley bottom situated a few meters above sea level, with hills striking in a NNW-SSE direction on both sides.

Due to the steep topography there is plenty of surface water and during heavy rain periods it frequently happens that the overfilled drainage system overflows.

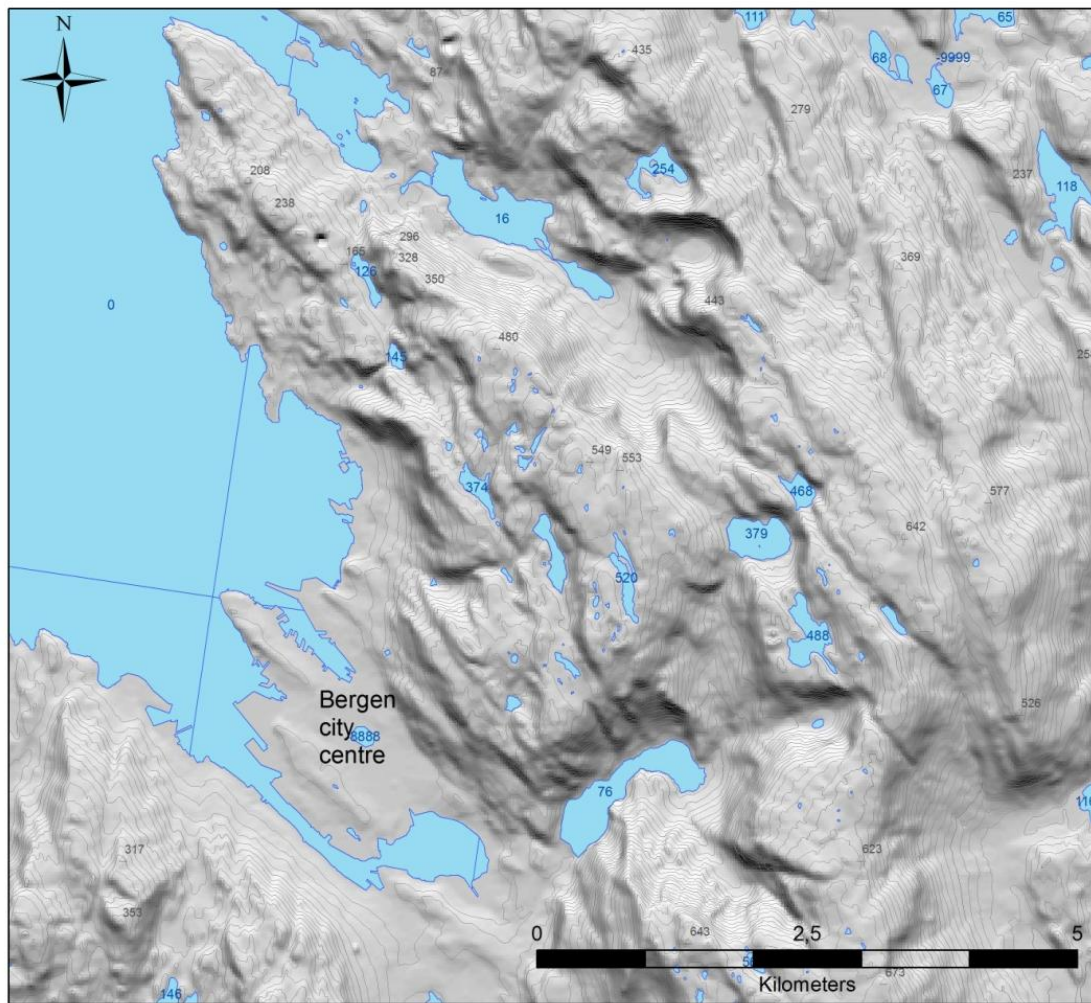


Figure 9: Topography of the Bergen area.

The overburden is thin in the hillsides where the bedrock is exposed. The bedrock is characteristic for the Bergen Arcs, which are part of the Middle Allochthon and related to the Caledonian orogeny, squeezed into an arc to the left between Precambrian basement rock (Figure 10). The Precambrian bedrock is predominantly granitic gneisses while the Caledonian arcs consist of greenstone, phyllite and quartzite.

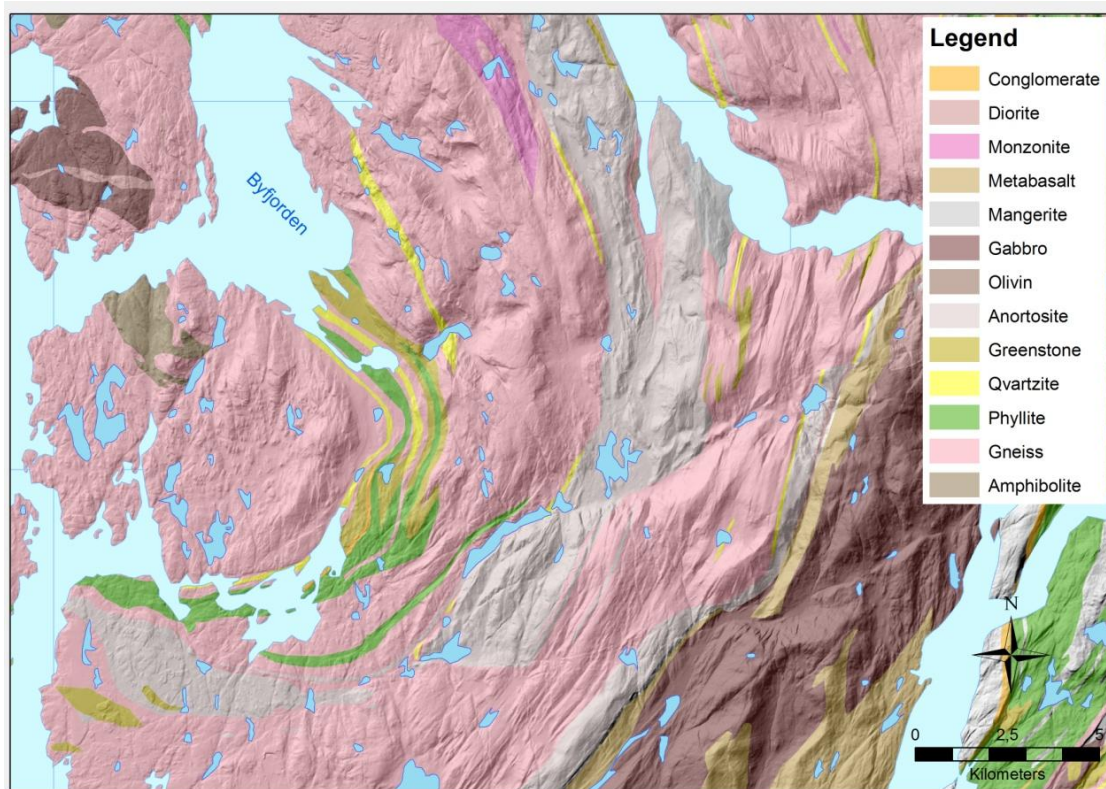


Figure 10: Geological map of Bergen area with the minor Bergen Arc. The granitic gneiss to dioritic (pinkish) bedrock is part of the Western Gneiss region and is of Precambrian age. The phyllite (green), Greenstone (brownish green) and quartzite (yellow) are younger and related to the Caledonian orogeny (Source: Geological Survey of Norway).

The overburden consists of sediments of Quaternary age and dominantly moraines (Figure 11). The city centre is not mapped with respect to deposits, mainly due to extensive anthropogenic cover. The map displayed in Figure 11 shows the upper marine limit with a blue line and the area that has been covered by the ocean during and after the last glacial maximum at about 9600 years ago (Younger Dryas), and Bergen city centre was below upper marine limit. Therefore, large deposits of clay, marine clay and beach deposits, can be expected in the city centre and in the Vågen; the bay area.

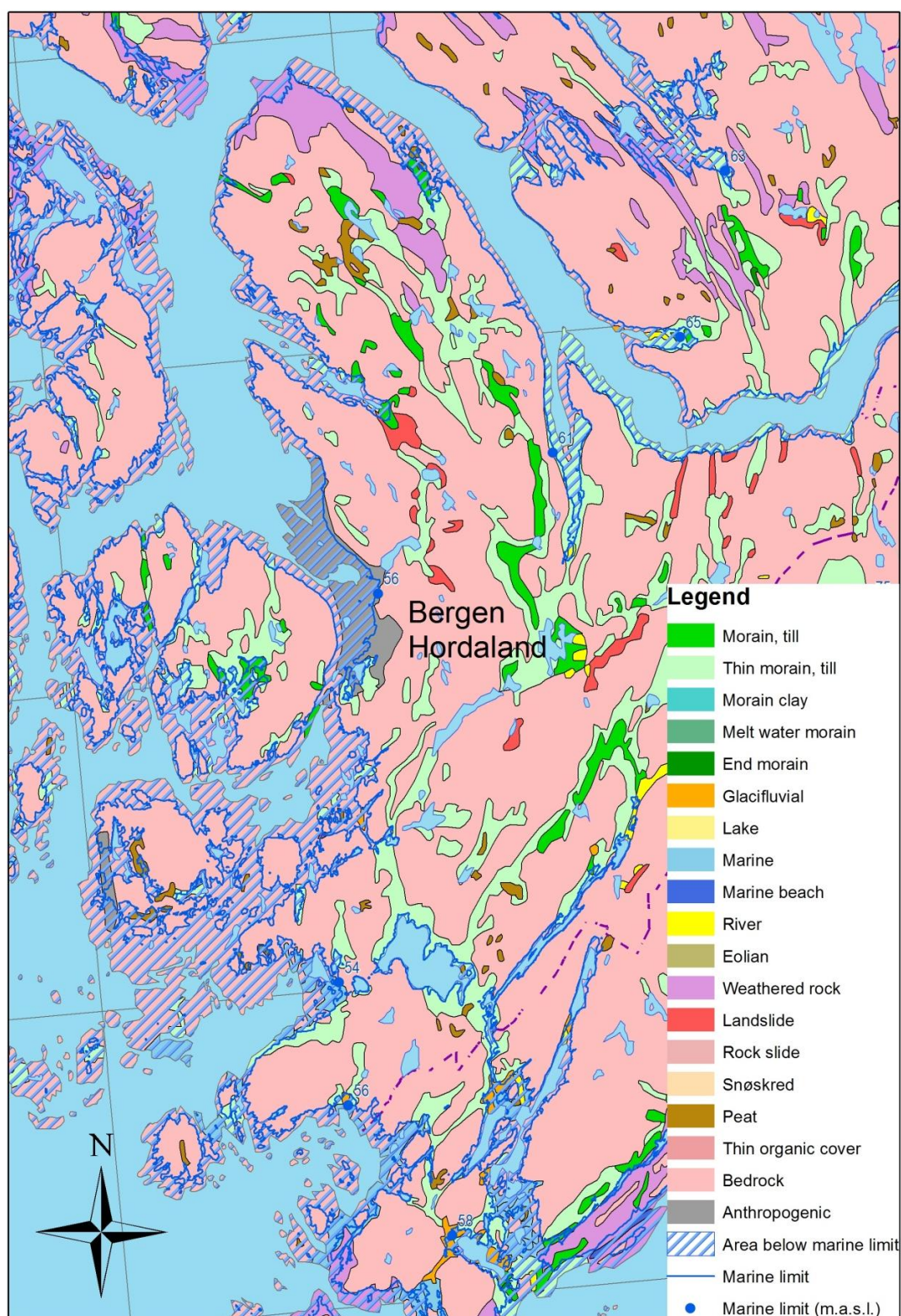


Figure 11: Quaternary deposits in Bergen municipality. Bergen city is not mapped due to urban development and poor exposure and therefore indicated as unspecified anthropogenic deposits (Source: Geological Survey of Norway).

2.1 The urban subsurface

The steep hill sides with thin overburden in combination with the climate make Bergen a wet city. Due to the high average air temperature, the vigorous vegetation consists of species that are known from milder climate zones. The sediments below the anthropogenic masses are most likely of Quaternary age and consist of glacial sediments; primarily sand, gravel, (marine) clays and glacial moraines.

The map displayed in Figure 12 shows roughly the depth to bedrock in the Bergen area, where pink colour is exposed bedrock, light green is cover less than 0.5 m thick, and olive green colour is cover more than 0.5 m thick. There are deep bedrock wells (mostly ground source heat) and shallow wells (groundwater monitoring and investigation) in the overburden that contain information about depth to bedrock and overburden sediments.

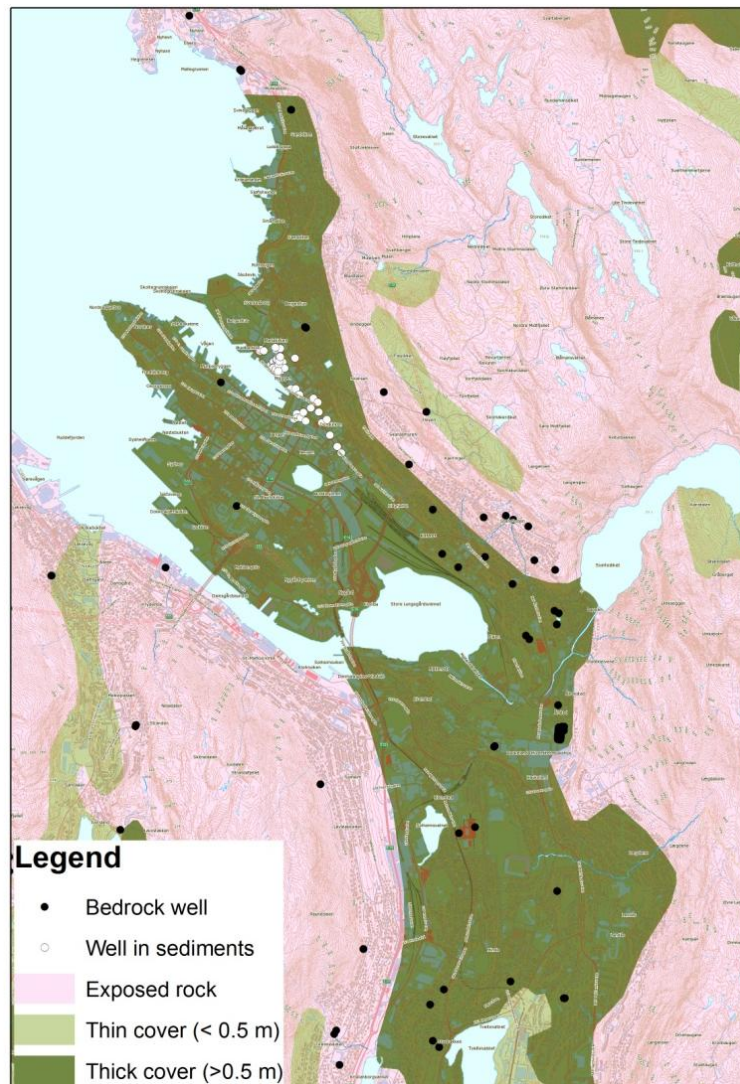


Figure 12: Depth to bedrock and position of wells (Source: Geological Survey of Norway).

The subsurface at the World Heritage Site Bryggen has been subject to detailed ground investigations and can be regarded as a representative stratigraphic sequence for the whole of the Medieval centre of Bergen. The bedrock is covered by a sequence of superficial deposits (Figure 12 to Figure 15). The deepest natural deposit is glacial till. The till is covered by marine sand from the former sea bottom. The uppermost layer is comprised of modern filling materials. The layer that makes Bryggen's subsurface and the subsurface of the Medieval centre of Bergen special, are the cultural deposits in-between the sand and the filling material. This layer is up to 8 m thick, highly organic and is automatically protected by the Cultural Heritage Act. The spatial extension of the cultural deposits is indicated in Figure 13.

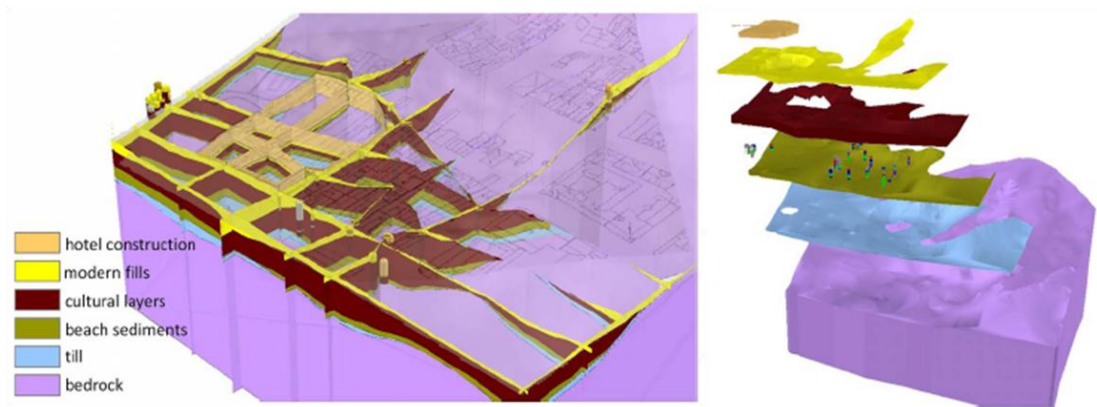


Figure 13: 3D visualization (GSI3D) of the layer sequence underneath Bryggen's timber buildings including borehole sticks. An exploded view of the 3D subsurface model is given on the right. (Source: de Beer et al., 2012a).

2.2 Regional hydrogeology

The hydrogeology in the Medieval city centre (Bryggen and Vågsbunnen) is defined by its location between a steep mountain slope to the east-northeast and the harbour to the west-southwest. The regional groundwater flow is mostly controlled by the local topography and the groundwater level can be pictured as a smoothed, simplified representation of the terrain.

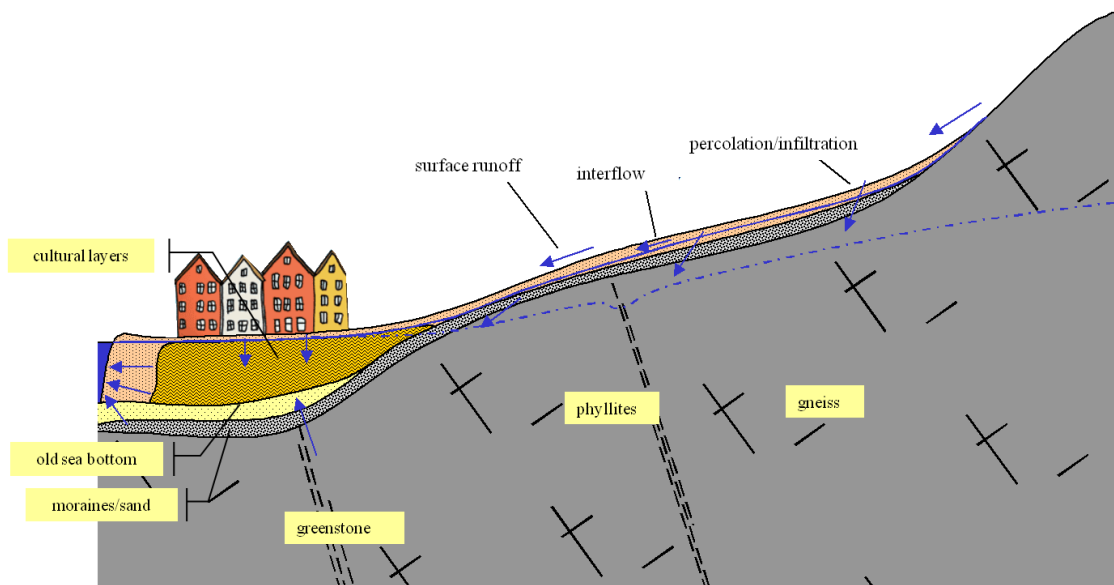


Figure 14: Conceptual hydrogeological model of Bryggen and the adjacent mountain slope (Source: J. de Beer, 2008)

There are few measurements of groundwater pressure head in the recharge area. Presumably, groundwater roughly follows the NE to SW trend of surface water, but is flowing mostly through a system of open fractures and weak, permeable bedrock zones of greenstone, phyllite and gneiss, before feeding the superficial deposits under Bryggen and Vågsbunnen. Local precipitation partly infiltrates into the subsurface and contributes to the groundwater underneath the old town.

The groundwater generally flows from the recharge area in the NE towards Bryggen and out into the harbour. This is reflected in the hydraulic head measurements in the superficial deposits below Bryggen. However, the local groundwater heads are influenced by a complex interaction of various factors (Figure 15):

- Precipitation (~ 2250 mm/year) and evaporation (~ 450 mm/year).
- Properties of the deposits: sand, clay, refills, bedrock, fracture zones, etc. and their hydraulic properties, e.g. permeability.
- Tidal variations (up to 2 m) and salt-water intrusion.
- Withdrawal or infiltration: wells, drainage systems, stormwater infiltration. Leaks through the sewer, storm- and wastewater pipes.
- Surface conditions: buildings, asphalt, cobblestones, green spaces, etc.
- Pipe and cable trenches.
- Underground installations: sheet piling of the SAS hotel, basements, tunnels.

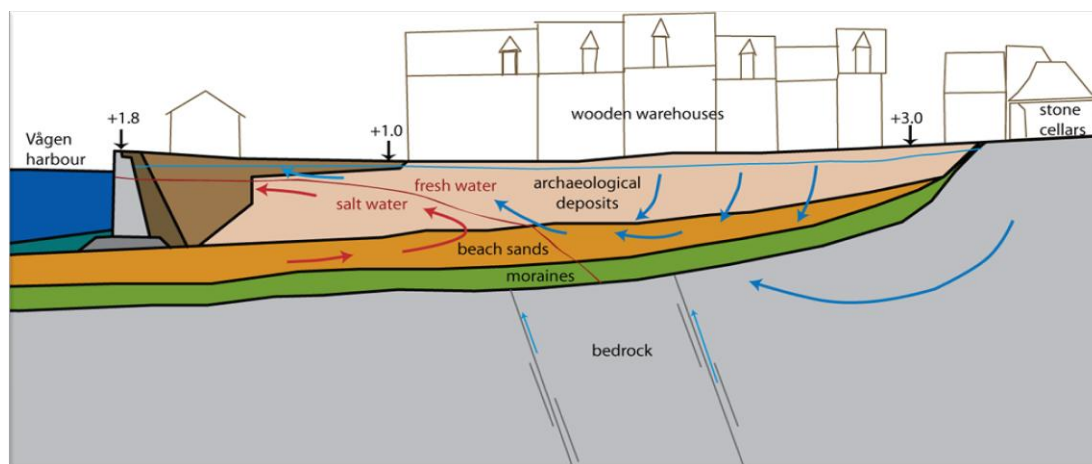


Figure 15: Cross section from the harbour (left) to the rear of Bryggen (right), giving a simple picture of the subsurface layering sequence and the local water flows (De Beer and Matthiesen, 2008).

3 Urban planning and management

The Norwegian municipalities have to make both spatial and societal plans for the development of public services and for the use of land and other natural resources. Land development plans show areas allocated to housing with the accompanying roads, water mains and sewage system, etc. As such, the municipalities are responsible for integrating and balancing cross-sectorial interests and requirements in their local planning. At the national level, The **Ministry of Environment** sets targets around which the local and regional authorities base their planning decisions, in accordance with the Planning and Buildings Act (Lovdata, 2008). The current Planning and Building Act came into force in 2009 and applies nationwide.

In cultural heritage management, the Ministry of Environment is responsible for development of policies and principal frameworks, with the **Directorate of Cultural Heritage** as the national agency. Regionally, the county council is the responsible authority, also regarding the **Cultural Heritage Act** (Lovdata 1978), while at the local level the municipalities have responsibility through the **Planning and Building Act** (Lovdata 2008). One exception is cultural deposits in medieval cities, where The Directorate for Cultural Heritage has a special role.

In general, the municipalities do not have authority according to the Cultural Heritage Act, which in general handles nationally and regionally valuable heritage, but is expected to safeguard this heritage through the Planning and Building Act. Within this framework, they may also list locally important heritage monuments and sites. If

these monuments or sites are from prior year 1537/1650, they are automatically protected (Kulturminneloven § 4; Lovdata 1978).

Norway has a long tradition as a decentralized democratic welfare state where, since the Second World War, the “communes” – municipalities – have been of vital importance in implementing the **Scandinavian Welfare Model** (Montin 2000). They have shown a strong ability to deliver locally adapted public services in an effective manner. Local governments are, however, more than instruments of central government and its political aims. They are political bodies in their own right, headed by a democratically elected council. Accountable to the local public, councils are expected to promote local interests and values and fulfil local demands (Amnå 2000).

3.1 The Planning and Building Act

The Planning and Building Act, as we see it today, is a *process* law. It outlines the model for *decision-making* about development, land-use disposition and building control. In accordance with the intentions of the act, the policy is also to be outlined in comprehensive municipal master plans and several thematic plans. These superior plans are then to act as guidelines for the executive officers in decision-making about specific developments. This approach requires a more integrational model: the relationship between the different levels must be closer, they must participate in a process, and both levels must have a pragmatic and flexible point of view.

Over the last decades, a gradual change from a strong, governmental regulation to private initiatives of the building industry could be observed. Today, the urban development of Bergen is to a great extent controlled by market economy. However, the framework is still defined by the municipalities. The building industry has to follow the municipal regulation plans and must go through strict application processes.

A number of laws, bylaws and local regulations set the legal framework for protecting existing underground structures as well as the planning and construction of new ones. The most important tool is the Norwegian Planning and Building Act (Lovdata 2008). The law was revised in 2008, a work that resulted in quite significant changes.

The Norwegian planning system has over the last decades moved from being *strong* to being *balanced*. Local municipalities would earlier not only develop municipal master plans themselves, but also carry out most of the detailed planning. Detailed plans are now mostly developed by private interests, and approved by municipal authorities (City Council).

Previously, the building controls were quite strict throughout the construction process. Responsibility for compliance with regulations are now to a much greater extent placed on the developer, while authorities carry out random controls and check reported violations of laws and regulations.

The planning system is designed to encompass underground structures, and a bylaw describes how planning in more than one level shall be shown on maps.

The law opens for planning in 3D, but so far 3D has only been used to illustrate plans and constructions. Methods for producing 3D plans are presently under development.

The Norwegian planning and building hierarchy can be described as being structured in four levels:

1. Central government land-use plan
2. Municipal master plan
3. Municipal sub-plan
4. Detail plan
5. Building project

3.1.1 Central government land-use plan

The state can develop and determine plans according to the Planning and Building Act when national interests are concerned. This is seldom used. However, when it is used it is mainly done at a detailed plan level. Some examples are the main international airport (Gardermoen Airport) and the national hospital (Rikshospitalet) in Oslo.

3.1.2 Municipal master plan

A plan developed for the entire municipality in two parts: One strategic plan which is descriptive and a land use plan, which is map based (2D) with related regulations. The plan shall be revised every four years in rhythm with change of political leadership (elections every four years).

3.1.3 Municipal sub-plan

A municipal sub-plan is a plan developed either for a geographical part of the city, or for a certain topic for the entire city. Over the later years a sub-plan has mostly been used for certain topics. Urban planning in 3D is currently under development in

Norway and has not yet been tested in full scale. Methods to store and build up a 3D plan as well as how to communicate a 3D plan with the public and decision makers needs to be investigated before a decision can be made.

3.1.4 Detail plan

A detailed plan is a legally binding land use plan for a relatively limited area, normally in scale 1:1000. According to the 2008 law there are two types of detail plans: One where plans are being worked out by the planning authorities and where the aim is to ensure public interests (may also cover privately owned areas), and one type where plans are developed to govern specific buildings and constructions. Detailed plans will in principle have to comply with superior plans. Normally they will expand on superior plans in terms of level of accuracy, and include underground issues like pipelines and cables, car park facilities, etc. Detailed plans are approved by the city council.

3.1.5 Building project

The planning and building law lists a range of building projects and construction measures that needs to be met through a process of application before approval. The list is detailed and further explained in bylaws. The effect of this is that almost everything that needs digging in the ground, moving of rock or soil, and/or implies constructing something on or underground needs be approved by the municipality before it can be carried out.

There are two challenges connected to this:

- If there is an application for a construction that is expected to be in conflict with a future (underground) measure like for instance a future metro tunnel which is not yet planned to an extent where it is governed by law binding land use plans, there is no legal base to refuse it.
- There are measures that are not subject to application and approval, although better control would be beneficial for the municipal management of the city. A typical example is drilling of energy or groundwater wells.

3.2 Particular challenges affecting subsurface planning

Ownership to land goes below the surface, and landowners are free to use the underground beneath their property. This means that other parties may occupy and utilize the subsurface underneath the depth that the owner may use himself, without

the need for the owner's permission, i.e. tunnels. There is no fixed limit to how far down this right of ownership reaches, and there have been trials in court where it is referred to "reasonable use" and phrases of similar nature. As long as this has meant basements and other constructions directly connected to buildings on the ground, the lack of accuracy in laws has represented few problems, but particularly with the accelerating number of private energy wells drilled (presently some 100 – 150 per year), being drilled to depths between 100 and 300 meters, this issue becomes more important.

This vaguely defined limit of ownership worked rather well as long as it was applied to conventional constructions, such as basements. However, the rapid development of technology has led to new options for utilization of the ground, the depth that is "reasonable to use" has increased considerably, and the legal system did not incorporate these developments yet. The most concerning issue are private energy wells. Until now, drilling private energy wells is not regulated and it is not obligatory to apply ahead. However, the driller has to report the well to the well database at the NGU. There is likely a significant deviation between wells being drilled and wells being reported to the database. The lack of a permission procedure for well construction leads to an unknown, but likely high underregistration of particularly energy wells. Alone in Stavanger, around 6 new wells are drilled each day and they commonly reach down 100-300 m. This means in practice that city planners who want to utilize the subsurface in the city to a larger extent (e.g. tunnels), have to deal with an underground containing an unknown number of installations with unknown depths and positions.

There is a long tradition for constructing road and railway tunnels in Norway. Though such tunnels often run through projections of private land, this has rarely caused problems as they often go so deep that it has been considered "no man's land" (ground where the land owner has no interest in using it for himself).

There is also a "first come first served tradition", meaning that if somebody wants to bring a new underground construction close to an existing, for instance a road tunnel, the road owner will have a strong position in keeping the newcomer at a distance, even if there is not a defined buffer round the road tunnel established by an approved plan.

The right of ownership also applies to the groundwater and its limits as well as who are responsible for it are equally vaguely defined. One particular challenge in this field is that measures affecting the groundwater level and pressure on one property may cause considerable (subsidence) damage to constructions on a neighbouring property. The Neighbouring Act and the Planning and Building Act do prohibit

activities on one property that cause harm to a neighbouring property, but the indirect role of groundwater is not mentioned specifically. This makes it difficult to prove juridical causal relationships if damage occurs.

Protection of ground water levels is somewhat insufficient in Norwegian legislation, though it is a common problem in several Norwegian cities, that construction works frequently influence the ground water levels and pressure, causing damage to neighbouring constructions, often older buildings of preservation value. In a detailed plan for parts of central Bergen that is presently under work, it is for the first time in Norway proposed in detailed plan regulations to control ground water levels. The outcome of the approval process can be of general importance to this issue.

3.3 National subsurface databases, organizations and standards

3.3.1 National Database for Ground Investigations in Norway (NADAG)

A large amount of data from ground investigations such as geotechnical drilling, bedrock drilling and ground water wells exists in Norway. In spite of the huge amount of data, these are not easy to access as they are located at different data owners and users. A national database for ground investigations will, for the first time, give an overview over existing drill data for all of Norway. This will make the data easier to access, and re-use will lead to considerable savings for society. Within cities, in particular, the utilization of the subsurface is growing, and the need for 3D knowledge about ground conditions is increasing.

The project Developing the National Database for Ground Investigations (NADAG) was started in 2012 as a cooperation between the Geological Survey of Norway (NGU) and three other governmental departments (the Norwegian Public Roads Administration (NPRA), the Norwegian Water Resources and Energy Directorate (NVE), and the Railway Services (JBV)), and aims to collect and make public available data important for the society. The development of the database is controlled by conceptual and standardized data models, and will be adjusted according to the needs of the various users. NADAG will contain various amounts of data, dependent on what is available – ranging from only metadata (location, drill type, drill depth, company, date, report no., etc.) to full reports and raw data. NADAG will firstly be filled by data from geotechnical investigations. The primary objective for NADAG in the future is to be able to show all ground investigations in Norway through a web application.

3.3.2 Granada

The national groundwater database (GRANADA) provides information on wells and springs in soils and rock, groundwater quality monitoring of groundwater and reports of groundwater investigations (<http://geo.ngu.no/kart/granada/>). The database is available as a map service on the Internet. It is hosted by the Geological Survey of Norway (NGU).

3.3.3 Cooperation board for wires in the ground

"Cooperation board for wires in the ground" (Samarbeidsforum for ledninger i grunnen) was established in 2013 and is a forum for relevant industry associations and government agencies with an interest in the coordination of pipes, cables and other infrastructure in the ground. This includes power, water, sewage, electronic communications , heating , gas and caverns (Plan- og bygningsloven, 1985).

The board shall fulfill the following purposes:

- Mutual exchange of information on topics of common interest and discussion of current challenges in Norway.
- Keep abreast of international developments.
- Contribute to developing new relevant knowledge, propose solutions and initiate projects that can help to solve issues.
- Be proactive and a discussion partner for the development of regulations, standards and agreements for cooperation.
- Promote greater coordination through information campaigns, by conducting seminars, workshops and the like, and lectures on relevant courses and conferences.

National SOSI standard

SOSI is a much used geospatial vector data format used predominantly for the exchange of geographical information in Norway. SOSI is short for **Samordnet Opplegg for Stedfestet Informasjon** (literally "Coordinated Approach for Spatial Information", but more commonly expanded in English to **Systematic Organization of Spatial Information**). The standard includes standardized definitions for geometry and topology, data quality, coordinate systems, attributes and metadata (SOSI-Standard, 2013).

There are several standards for underground objects, such as geology, soil, petroleum, pollution, geochemistry, pipes and cables (under development).

3.4 Bergen City administration

The City Council consists of 67 elected members and has a parliamentary model of government. The City Council elects the City Government, an executive body, which answers to the City Council. The Office of City Antiquarians main role is as an advisor to other offices within the municipality, and as a provider of information and knowledge on cultural heritage to the general public. Bergen is situated in Hordaland County, and it is the county authority that is responsible for the Cultural Heritage Act, and also may object to local plans.

In addition to cultural heritage administration at the local and regional level, the national level also plays an important role. As Table 2 (see below) indicates the Ministry of Environment has a general perspective (as the planning authority at the national level), and The Directorate for Cultural Heritage has a sector perspective. In the same way the elected city and county councils apply a general perspective at the local/regional level – and The Cultural Management Heritage Office in the city has a sector perspective.

Table 2: Partners and participants in cultural heritage administration (based on Nyseth and Bjørnå, 2007).

	Local/regional level	National level
General perspective	City council / County council	Ministry of Environment
Sector perspective	The Cultural Heritage Management Office	The Directorate for Cultural Heritage

3.4.1 Cooperation within the municipalities and with the private sector

There is comprehensive and constructive cooperation between heritage authorities and planning authorities at the municipal level in Bergen. Due to differences in administrative organisation, the contact and communication between them varies. There are formalised regular meetings at the executive level to facilitate and agree upon important strategies and particular measures across sectors. This is partly due to the fact that cultural heritage issues and urban planning sort under the same department; the Department for Urban Development, Climate and Environment, headed by an Agency Director. This department also handles large infrastructural developments in the city, such as new water and sewage systems, waste management and electric/heating systems, which has facilitated and necessitated

cross-sectorial cooperation. The city has also experienced several extreme events, for instance due to climate change (e.g., flooding), that have necessitated cooperation.

The cooperation between national, regional and local authorities in Bergen seems to be relatively clear and the roles and responsibilities agreed upon, even if there are examples of some minor disagreements in particular cases. However, these disagreements seem to be as much based on conflicts about professional competence rather than on roles and responsibilities. One particular challenge with respect to knowledge exchange is the fact that private entrepreneurs or real estate developers engage consultant companies to do various ground measures, surveys and sample testing, and keeping the results private. This is knowledge of high value to the public administration when handling cases regarding the particular site, and in building knowledge in these fields in general.

Another challenge related to this field is how to handle uncertainty. Today, there is a lack of knowledge on the effects of changes in ground water level on adjacent sites, for instance when building or establishing foundations on clay. In today's development projects, there are no legal requirements demanding that the developer has to give affirmation to the authorization offices that the new building will not cause damages to adjacent properties. The local cultural heritage administrations have therefore initiated projects that will investigate the relationship between ground water, new developments and settling damages on adjacent historic buildings by establishing baseline studies and long time series. These projects are important first steps in order to gain deeper knowledge on this issue, and to establish long-term monitoring of possible effects to be able to suggest mitigation strategies. An example of such a project is the Bryggen Project (2011-2015, www.prosjektbryggen.no).

3.5 Management of subsurface data in Bergen

There is no integral systematic management of all subsurface data within the city of Bergen. Information on subsurface infrastructure is managed by the office for GeoData, residing under the Planning and Building section. The office maintains GIS systems with spatial information of all public infrastructure. Information of private installations in the subsurface is not included and resides in private ownership. For much existing, older infrastructure, the depth information is not digitally included, but only as contextual information (metadata), if at all available. In later years, this has been significantly improved, and all modern infrastructure such as pipelines,

tunnels etc. are digitally stored in full 3D. The city of Bergen does not yet use full 3D planning systems for subsurface infrastructure.

Information on ground conditions such as geotechnical and environmental drillings resides for the largest part with the private companies that have carried out the ground investigations. For public-funded investigations, the city may have required the deliverance of subsurface data digitally, but in most cases only paper (or pdf) reports are available. Energy wells and groundwater monitoring wells are reported to the Geological Survey of Norway (NGU) and are available for the public. The future aim is that all underground information shall be registered in NADAG (Chapter 3.3).

3.6 Legal tools for handling cultural heritage in Bergen

The medieval part of Bergen is particularly vulnerable to changes in groundwater pressure, as this leads to enhanced decay of protected organic deposits in the subsurface and to settling damages of the timber houses above. It is necessary to have a legal framework to manage both preservation and development of such an area.



Figure 16: Lowered groundwater pressure has caused compaction and loss of archaeological deposits underneath Bryggen and the historical buildings have become severely damaged (Foto: J. De Beer).

The present Cultural Heritage Act (Lovdata, 1978) is a result of several additions to the original text and makes it difficult to handle complex heritage values above and below the terrain surface. However, the new Planning and Buildings Act (Lovdata, 2008) introduced the instrument “*zones requiring special consideration*”. In theory, this particular instrument should make it easier to achieve a more holistic management of both archaeological and above-surface historic objects, such as buildings, parks, places, etc. However, this legal instrument is rarely used.

3.6.1 Temporary prohibition of action at Vågsbunnen

The Vågsbunnen district rests on thick organic deposits that slowly decompose. The natural groundwater level in that area is relatively high, which mechanically stabilizes the masses and protects the deposits from enhanced decay by keeping them anoxic. However, the groundwater level is not constant, but varies with season, precipitation, and tides. Additionally, human activities such as pumping affect the local groundwater level considerably. Strong variations in the groundwater level caused the intrusion of atmospheric oxygen which has enhanced the decay of the organic remains and has caused substantial subsidence and settling damages.

The municipalities have become aware of these issues and reacted with a rather unique initiative. In February 2013, the City Council of Bergen announced a temporary prohibition on all measures that may cause a change in the groundwater level within the whole Medieval city centre (Figure 17).

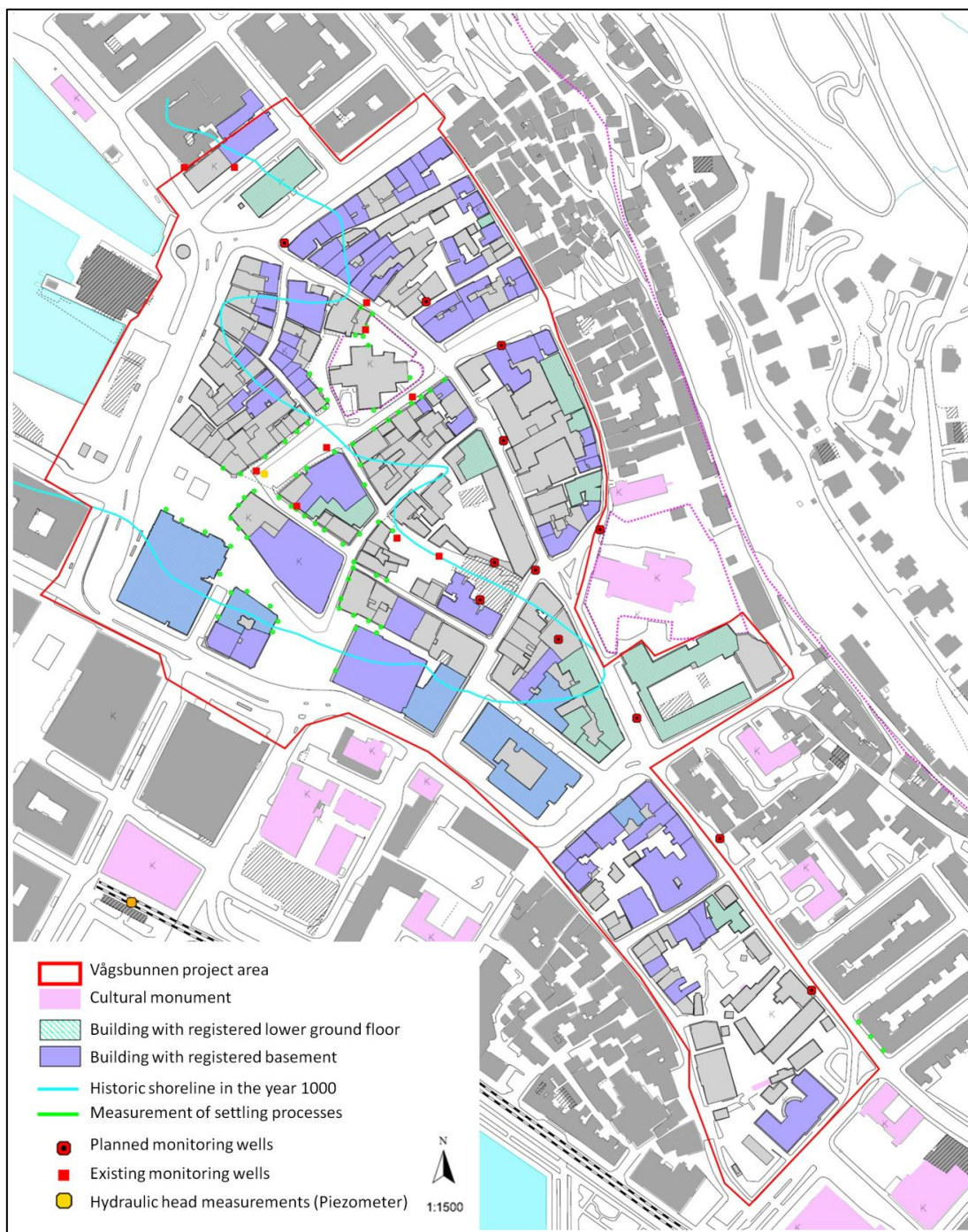


Figure 17: Map of Vågsbunnen showing the project area and information on cultural heritage. The temporary inhibition of action applies to the whole area of Vågsbunnen (Forprosjekt Vågsbunnen 2011 Ref nr: 27 535, Bergen municipality).

4 Project description of Bryggen in Bergen

Project Bryggen is a long-term initiative to restore and safeguard the endangered World Heritage Site Bryggen in Bergen. The project started up in year 2000 and is a collaboration between the Directorate for Cultural Heritage, Hordaland County, the Bergen municipality as well as local landowners. The project is financed with public funding. Various sub-projects to understand the settling and to map preservation conditions have been carried out. Recent settling and groundwater data show, that the conducted measures to counteract decay and settling were successful. The groundwater was raised to a sufficiently high level which stabilized the ground underneath Bryggen. A few places even show a moderate uplift (De Beer and Seither, *in prep.*).

Since the year 2002, an intensive monitoring scheme has shown damaging settling rates of the protected timber buildings above, caused by deterioration of underlying cultural deposits (De Beer and Matthiesen, 2008). Monitoring focuses on both chemistry and quantity of groundwater and soil moisture content in the saturated and unsaturated zone. Continuous logging of groundwater level, oxygen and soil moisture content and chemical analyses of water and soil samples are key elements. The monitoring includes registration of movement rates for buildings and soil surface, field measurements and archaeological recording in small excavations, as well as studies of archaeological and modern materials in the subsoil. The results have given good insight into the preservation conditions, with focus on deterioration rates. Groundwater monitoring and chemical analyses reveal a dynamic flow regime under the thick, organic cultural deposits of the site. The flow regime is controlled by interaction of tidal fluctuations, urban drainage systems, natural and urban stratigraphy and bedrock hydraulic features. The documented preservation conditions within the cultural deposits as well as oxygen and moisture-content fluctuations in the unsaturated zone have a significant correlation with the different groundwater flow dynamics found throughout the site. It is demonstrated that groundwater and soil-moisture monitoring, combined with 3D transient modeling, are potentially effective routines to improve the understanding of preservation conditions in complex archaeological surroundings and, therefore, protection of archaeological deposits *in situ* (De Beer and Matthiesen, 2008).

4.1 Archaeological remains: a treasure and a hassle

It has long been noticed, that several of the famous wooden houses in the medieval town have tilted, but the extent of the problem has only been realized during the last decades. Comparison of measurements from the 1950s with a survey carried out from 2001 to 2003 revealed alarming settling rates of up to 8 mm/year in the Bryggen area. The reason for this is hidden underneath the surface.



Figure 18. Scenary of a narrow ally between the Bryggen tenements. Tilting of the buildings is due to subsidence in the subsurface (photo: Hans de Beer).

Below the famous wooden buildings of Bryggen lie cultural deposits that cover the entire span of Bryggen's history. Systematic excavations (Figure 19) conducted from 1955 to 1968 revealed, that cultural deposits at Bryggen can exceed 8 m in thickness, with 10 or more separate building phases on top of each other. Figure 22 gives an overview about the thickness of the cultural deposits at Bryggen as calculated from a 3D subsurface framework model.

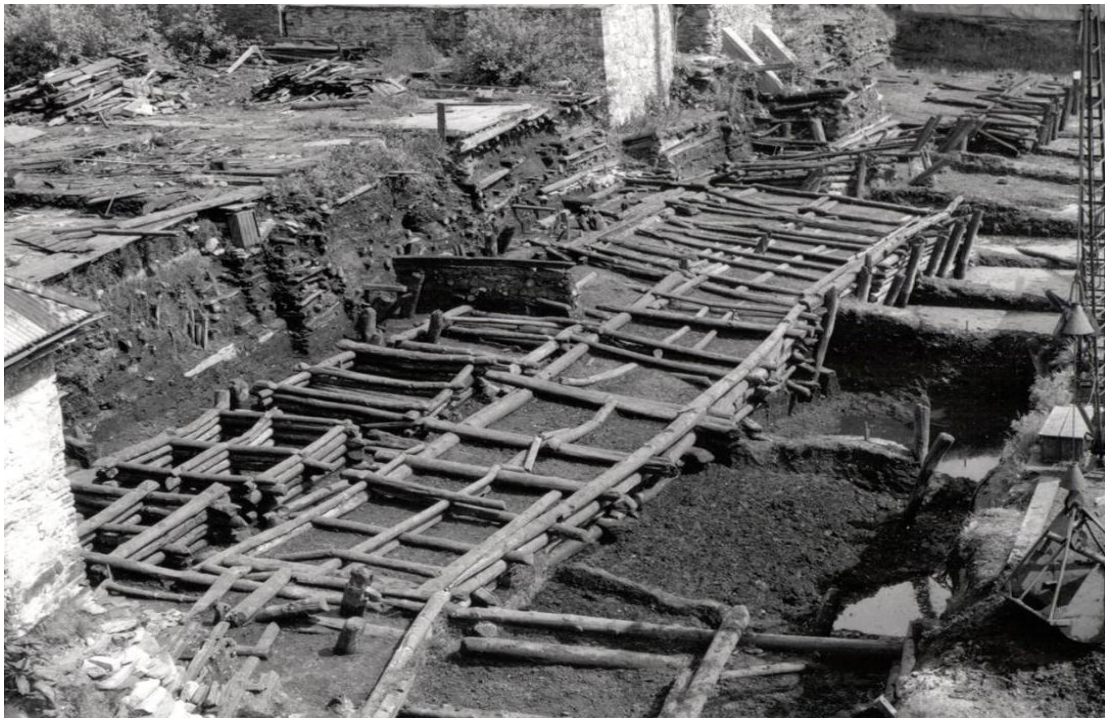


Figure 19: Massive wooden structures discovered during archaeological excavations in 1955-68 (Photo: Asbjørn Herteig, © Bergen museum, middelaldersamlingen)

In 1979 the building site was excavated and a wall of sheet piling was constructed around the building pit. The foundation consists of building aggregates and new buildings with an underground parking garage were constructed (Figure 20).



Figure 20: The construction site in 1979, with "impermeable" sheet piling around the pit where the cultural layers are dug out and replaced with an "impermeable" cover and building aggregate (Photo: Riksantikvaren / Directorate for Cultural Heritage).

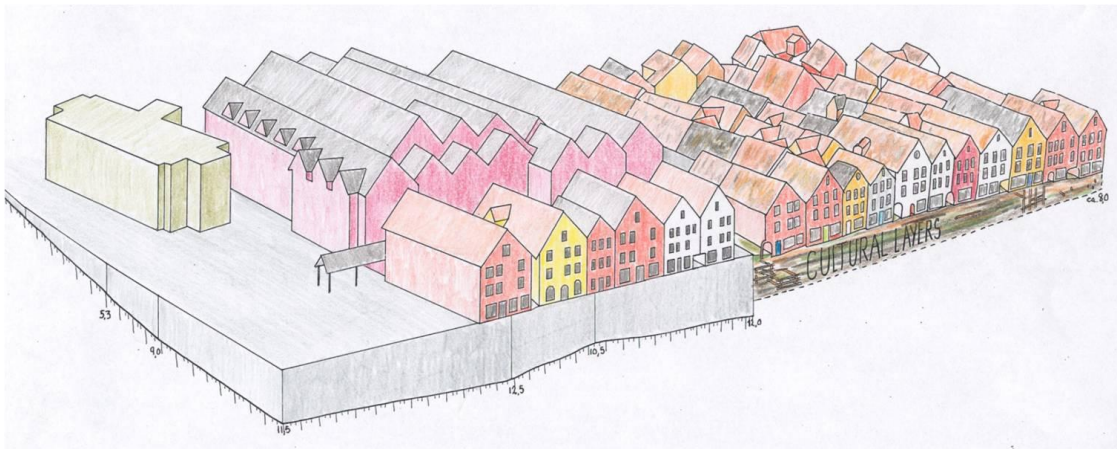


Figure 21. Sketch of old and new buildings side by side at Bryggen. The old buildings are placed upon cultural layers while the new buildings are set upon a basin of building aggregates within walls of sheet piles. This new construction (1979) altered the groundwater flow, due to barriers and leakage in the sheet pile and pumping of water in the underground parking garage. The front facade of the new building is kept in the same style as the old Bryggen tenements to preserve the atmosphere of the medieval city (Riksantikvaren / Directorate for Cultural Heritage).

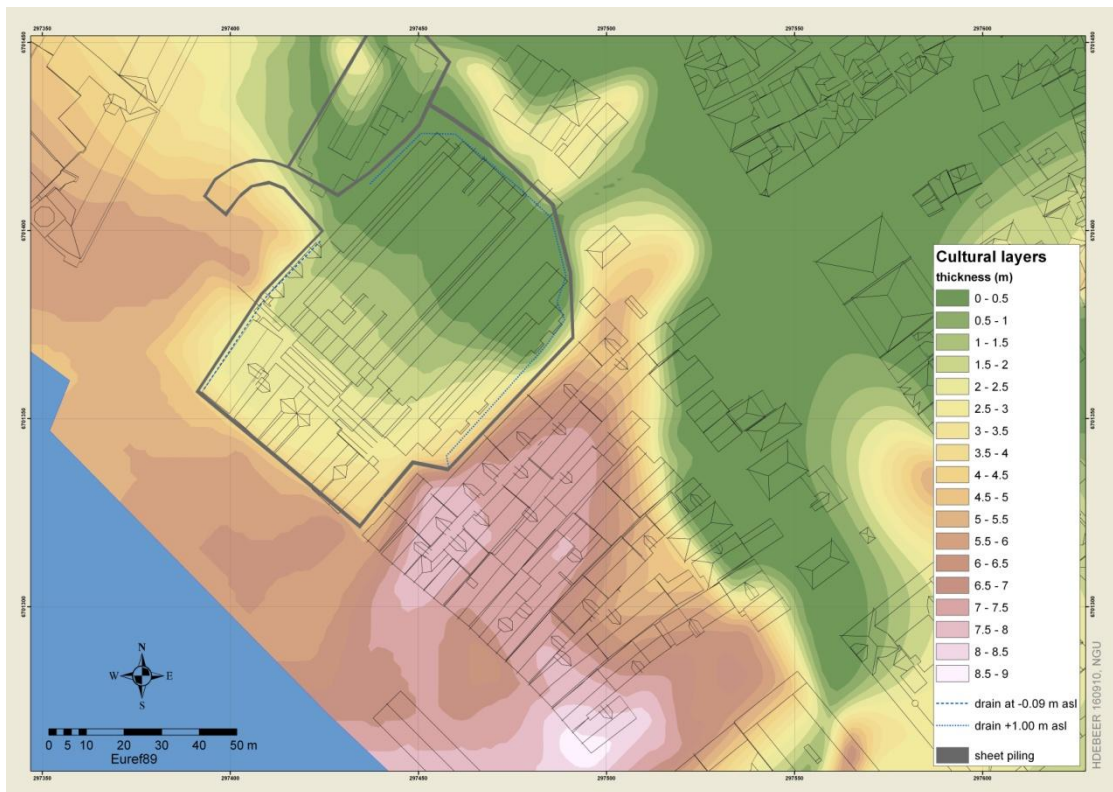


Figure 22: Thickness of the cultural deposits as calculated from a 3D subsurface model (de Beer et al., 2012a).

The deposits that make up the cultural layers are wet and highly organic, with loss on ignition values varying from 10% to 70%. Drainage of water, which causes both physical settling as well as decomposition of organic materials (Figure 23), leads to subsidence of the deposits and the respective houses above. The management of the cultural remains is regulated by a variety of different laws and regulations on the local, regional and national level, as well as EU-regulations (see above). The houses, as well as the underground archaeological remains, are automatically protected by the Cultural Heritage Act. It is a major challenge to properly safeguard the medieval part of the town, without putting a ban on development.

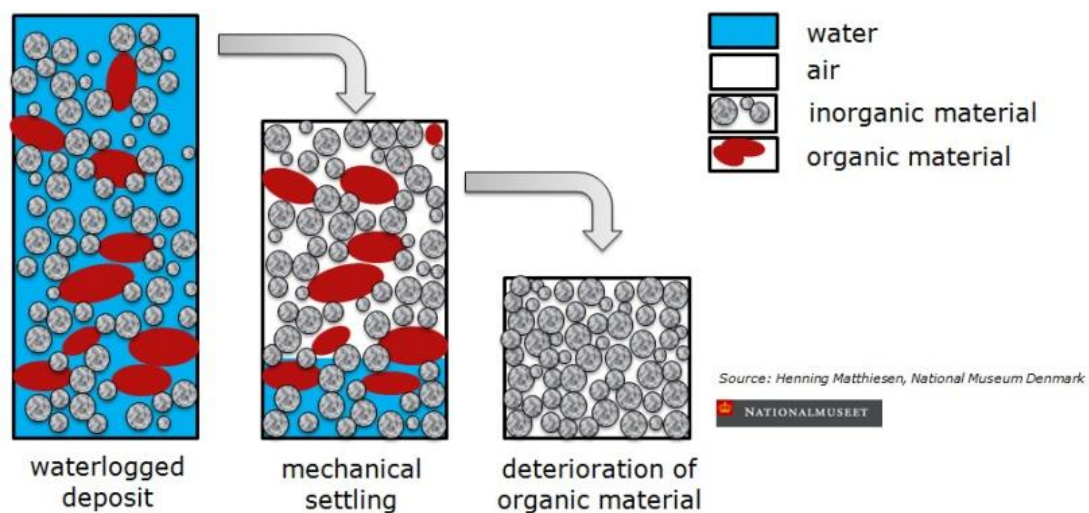


Figure 23: Preservation conditions of archaeological deposits (H. Matthiesen, National Museum Denmark).

4.2 Investigations

According to the Valetta Treaty in 1992, in situ preservation of archaeological resources is preferred to their excavation and presentation in museums. However, in situ preservation requires environmental conditions that are and remain in a stable state which does not cause significant decay of the protected objects.

In order to investigate the details of settling and to map preservation conditions of the deposits, an extensive monitoring programme of both the saturated and the unsaturated zone was initiated in 2001. It included small excavations, various soil and water analyses, continuous logging of piezometric head, and high precision settling measurements. The preservation conditions of organic materials vary considerably within the study area, ranging from excellent to very bad (Matthiesen 2007). From December 2006, the program was extended to hourly measurements in 12 of a total of 26 wells. Figure 24 shows the positions of the monitoring stations.

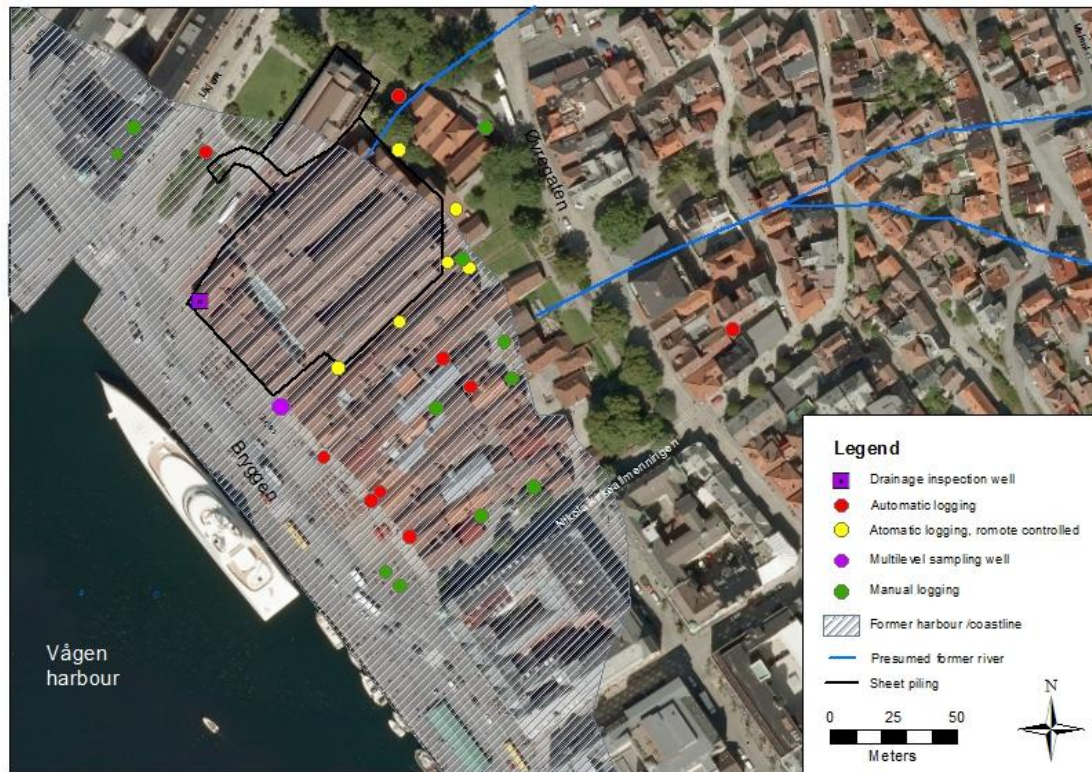


Figure 24: Orthophoto of Bryggen showing the position of monitoring wells and the location of the run-down sheet piling of the SAS hotel. The hatched area shows how much the original settlement has grown into the harbour (de Beer and Matthiesen, 2008).

4.2.1 Groundwater flow model

In order to improve the understanding of the hydrological system, to quantify the water balance and to identify the factors influencing preservation conditions, a numerical groundwater model was constructed using FeFlow[®] 5.3 (de Beer et al. 2007).

The chosen model area includes the catchment area behind Bryggen. Based on a terrain model, borehole data, known construction depths of buildings, as well as archaeological descriptions, a numerical model with 10 distinct layers was constructed. The hydraulic properties of the respective layers were initially based on literature values, borehole descriptions and grain-size analyses of soil samples. During later phases of the modeling, these parameters were changed stepwise by verification against monitoring values. The model mesh size was defined to be finer in the areas of interest, such as the sheet piling and drainage systems. Tidal variations and salt water at the harbor, daily precipitation and known drainage systems served as boundary conditions.

Figure 25 and Figure 26 show representative model results for the steady-state phreatic level within the archaeological deposits and the hydraulic head in the beach sediments below.

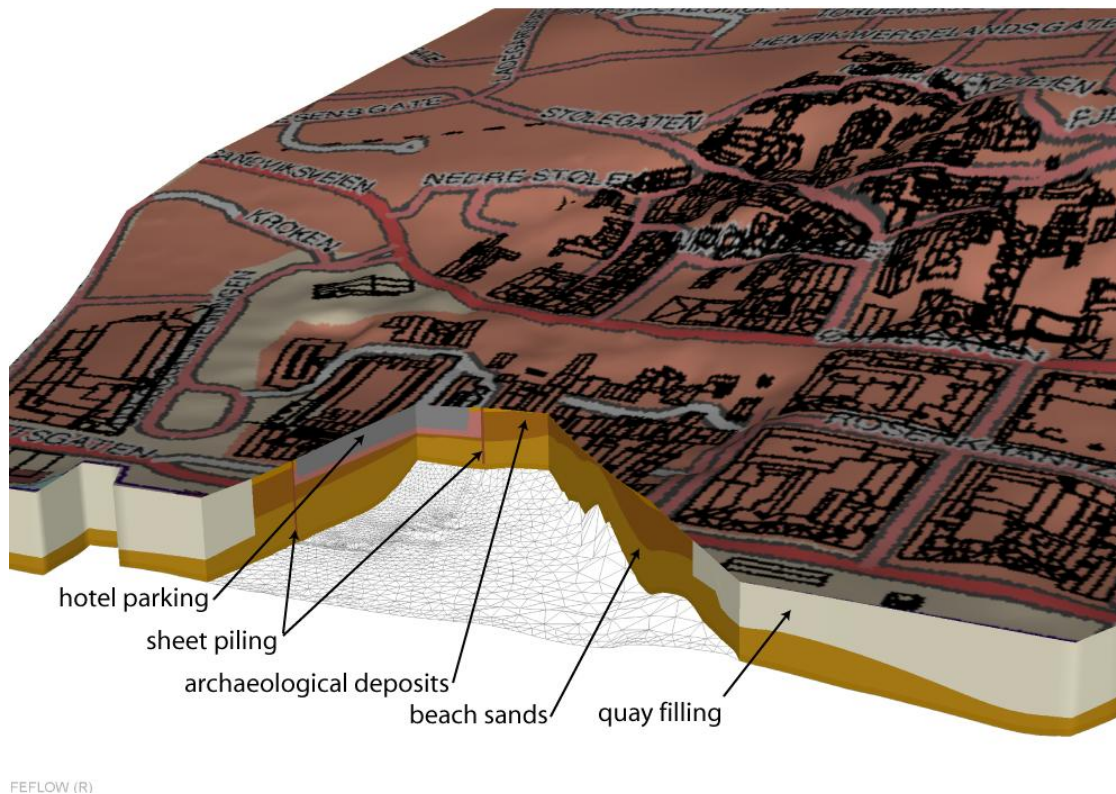


Figure 25: Model results for the spatial groundwater variation. The black arrows indicate the different layers in the sub surface that is included in the 3D model (De Beer and Matthiesen, 2008).

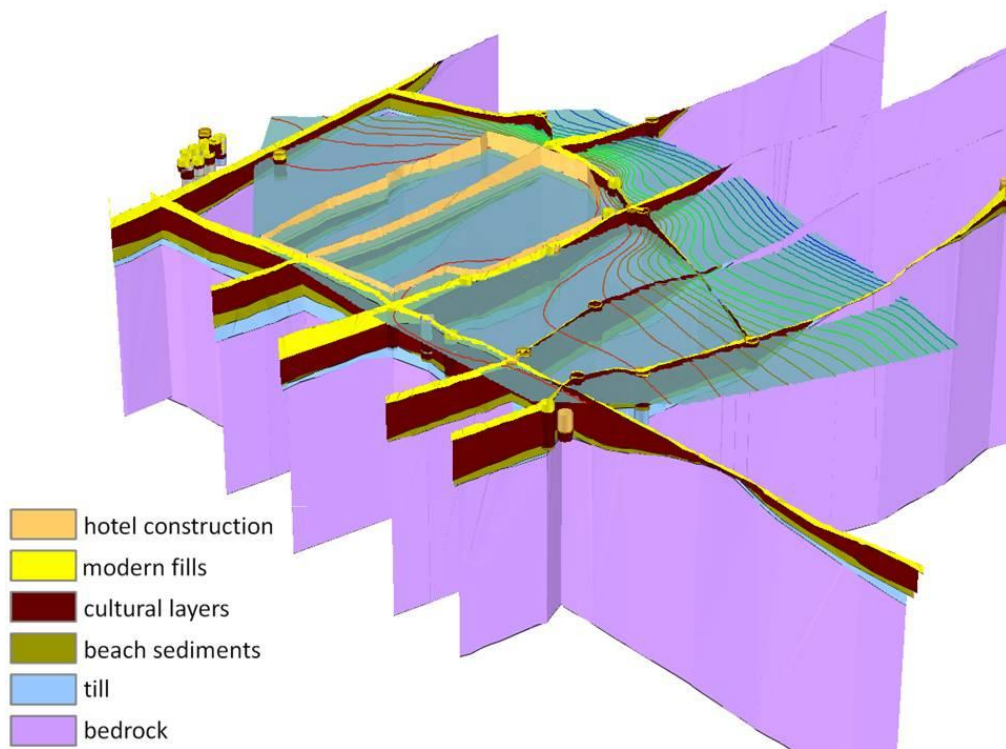


Figure 26: 3D section view with a representative groundwater table of the annual low (de Beer et al. 2012a).

4.2.2 How does the hotel affect Bryggen?

The monitoring data and the respective modelling showed a clear connection between the lowered groundwater table in areas surrounding the hotel and the construction of the underground parking lot of the hotel in the northwest of Bryggen. The hotel was built in 1979 after the archaeological excavations were completed and the area was opened for development. In order to avoid constructional damage of the hotel a drainage system as well as an enclosing wall of sheet piling were constructed in the subsurface. Nevertheless, groundwater levels in the surrounding area, particularly at the rear of Bryggen, were lowered considerably. Due to subsidence in the hotel construction towards the Vågen bay, where the foundation was not properly executed, the original drainage subsided to below sea level. This, as well as the presence of numerous holes in the sheet piling, had a massive effect on the water balance. The area is comparable to a large bathtub that collects and drains water from the area. The groundwater pressure outside that area is high. Hence, groundwater follows the gradient and flows into the “bathtub”, where it is drained quickly (Figure 27). This process continuously withdraws groundwater from the surrounding area. Low phreatic groundwater levels cause increased flux of air in the subsurface, leading to decomposition of organic archaeological deposits by oxygen and subsequent settling of the respective overlying buildings.

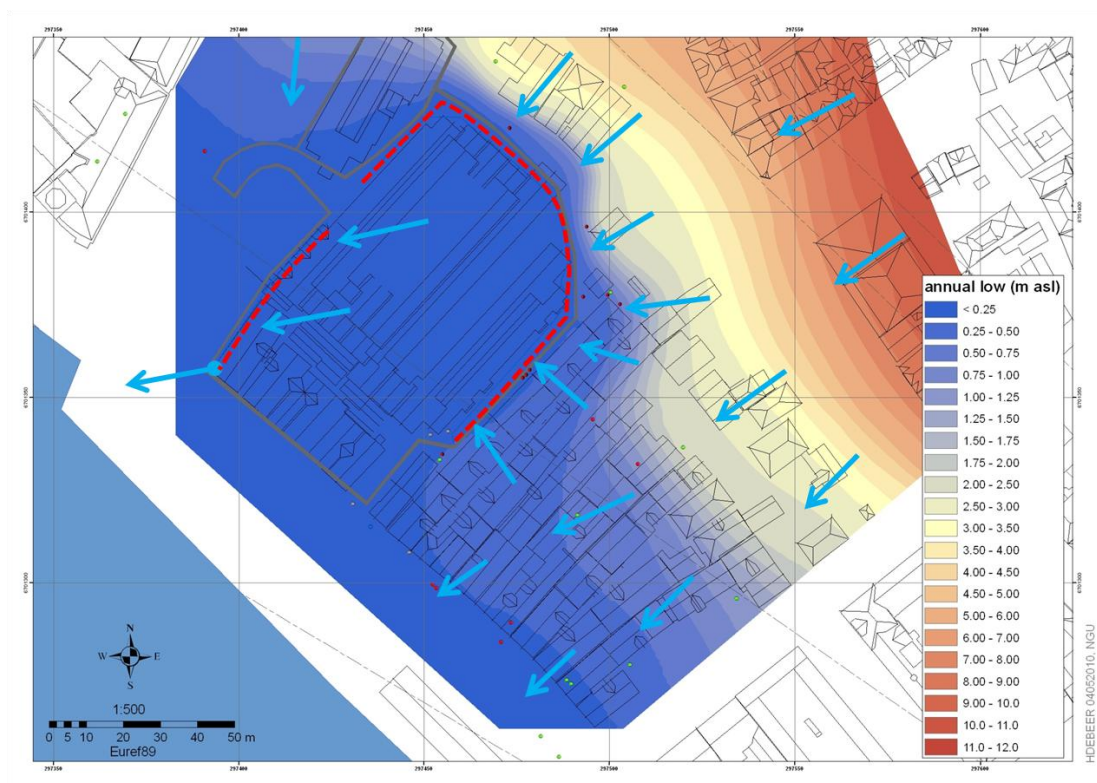


Figure 27: Simulated groundwater level and direction of flow at Bryggen (Christensson et al, 2012).

4.3 Course of action

In the period 2006-2014 several measures have been executed to stop the exposure of the foundation of the historical buildings at Bryggen. The key challenge for the management of the area is related to shortage of groundwater in the organic-rich, archaeological deposits. All measures were thus directed towards elevation of the groundwater level.

One decisive task was to decrease the leakage of groundwater into the hotel area. A first idea was to decrease the gradient of the hydraulic head. This was partly achieved by raising the drainage level under the hotel to firstly 45 cm above sea level with the aim of 1 m above. Unfortunately, an endless number of holes all around the sheet piling (Figure 28) limited the impact of that measure. Massive leakage came through the strut holes in the sheet piling, causing much of the ground water in the area to be drained. These strut holes are now sealed. Nevertheless, the water flow from the surrounding area onto the other side of the sheet piling could not be stopped entirely. Especially the NE part of the sheet piling adjacent to the "Schøtstuene" continues to leak. The problem was approached by continuously pumping intruding water and injecting it into an infiltration well on the outside.



Figure 28: Deteriorated sheet piling (Photo: Hans de Beer).

Simultaneously, infiltration of rain water into the ground and retention of the water in the ground had to be improved. With 2250 mm precipitation per year on average, lack of water in the ground should not be an issue. However, compacted and capped surfaces lead the bulk volume directly into the sewage system.

Several measures (Figure 29 - Figure 31) that focus on infiltration and water retention have been accomplished: Compact cobblestone pavements were exchanged with gravel that is easily infiltrated. Swales were constructed at several locations above Bryggen. Infiltration basins were built, and a large rain garden between Øvregaten (street) and Bryggen is under construction (spring 2014). In addition, a stepwise infiltration ditch/channel with water dams with which the water level can be regulated, was built in the alley between the hotel and the historical buildings.



Figure 29: Rain garden (left) at Bryggen under construction. Swales and modified terrain (right) to enhance infiltration (Photo: Hans de Beer, 12.05.2014).

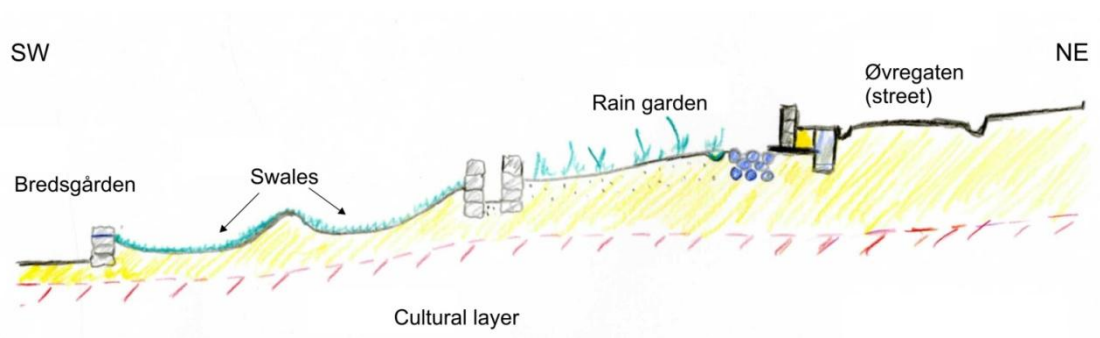


Figure 30: Cross-section from the street Øvregate to Bredsgården, showing the constructed swales and the rain garden (in progress), both of which improve water retention and infiltration (De Beer, 22.08.2012).

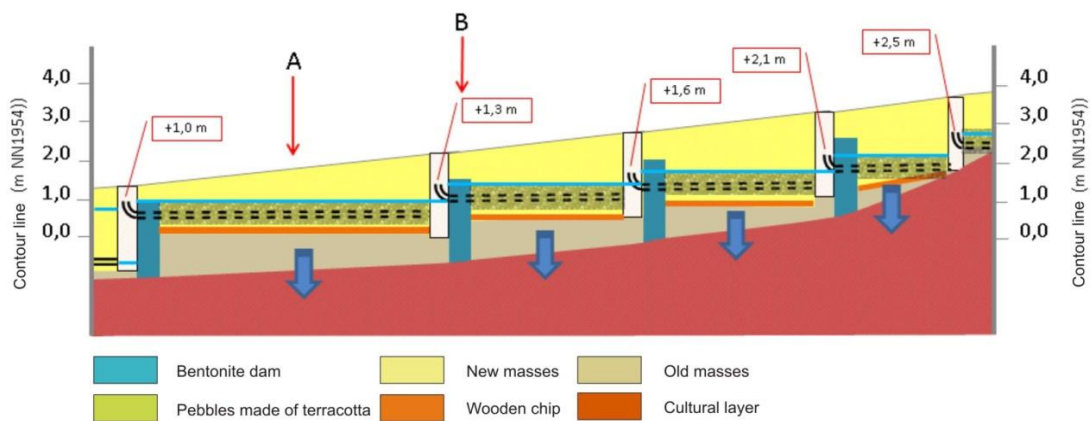


Figure 31: Subsurface staircase in Bugården street for groundwater retention (De Beer and Seither, 2015).

4.4 Preliminary achievements

All the measures described above have contributed to raise the groundwater level in the area. As a result of the stabilised and elevated groundwater level the subsidence has stopped, and the progress is now positive in a (small) upward direction.

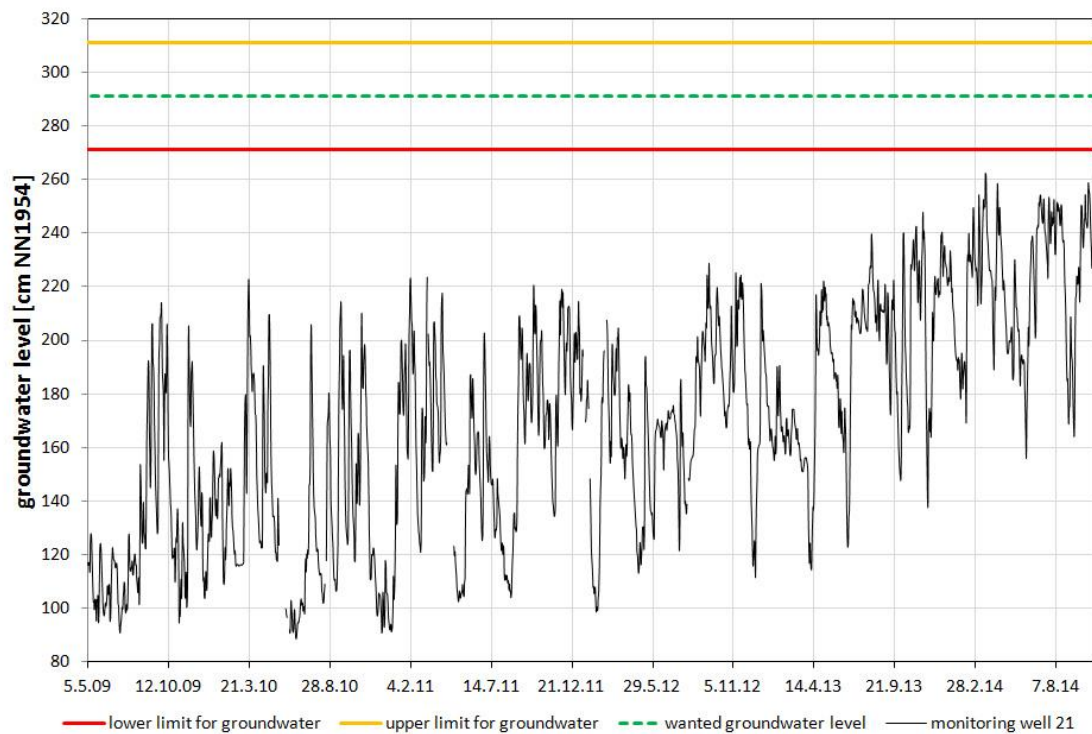


Figure 32. Groundwater level from 2009 to 2014 at Bryggen (De Beer and Seither, 2015).

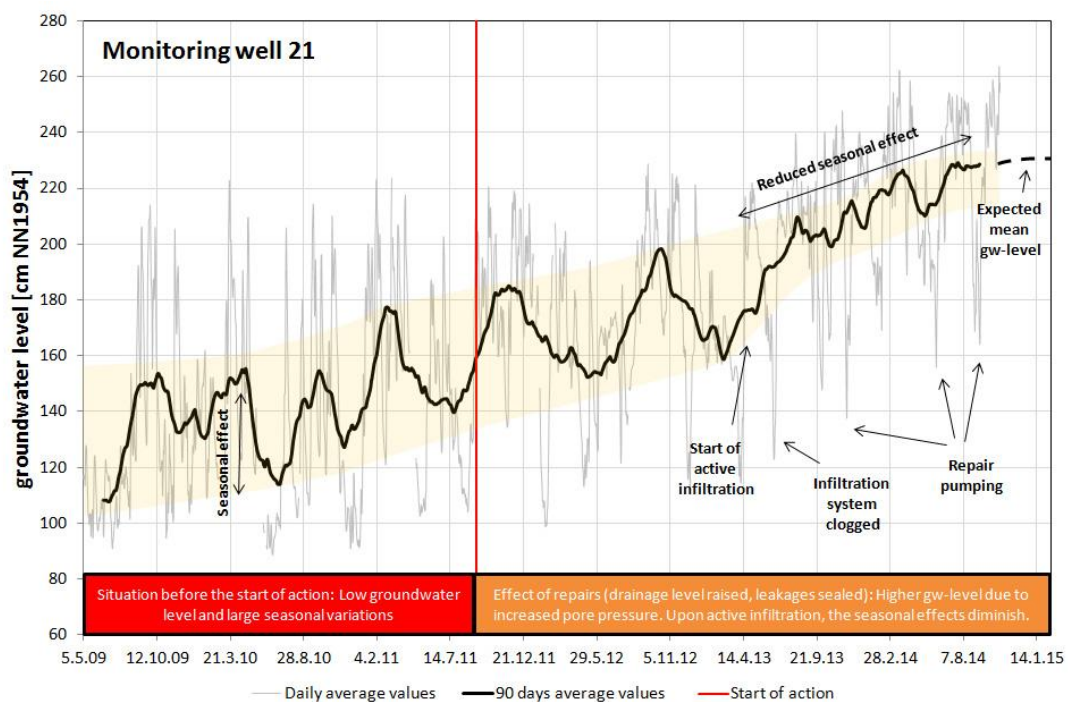


Figure 33: Groundwater level in monitoring well 21 from 2009 to 2014 (de Beer and Seither, 2015).

The groundwater level at Bryggen is rising (Figure 33). The green, dotted line is the required groundwater level to fully protect the historical buildings.

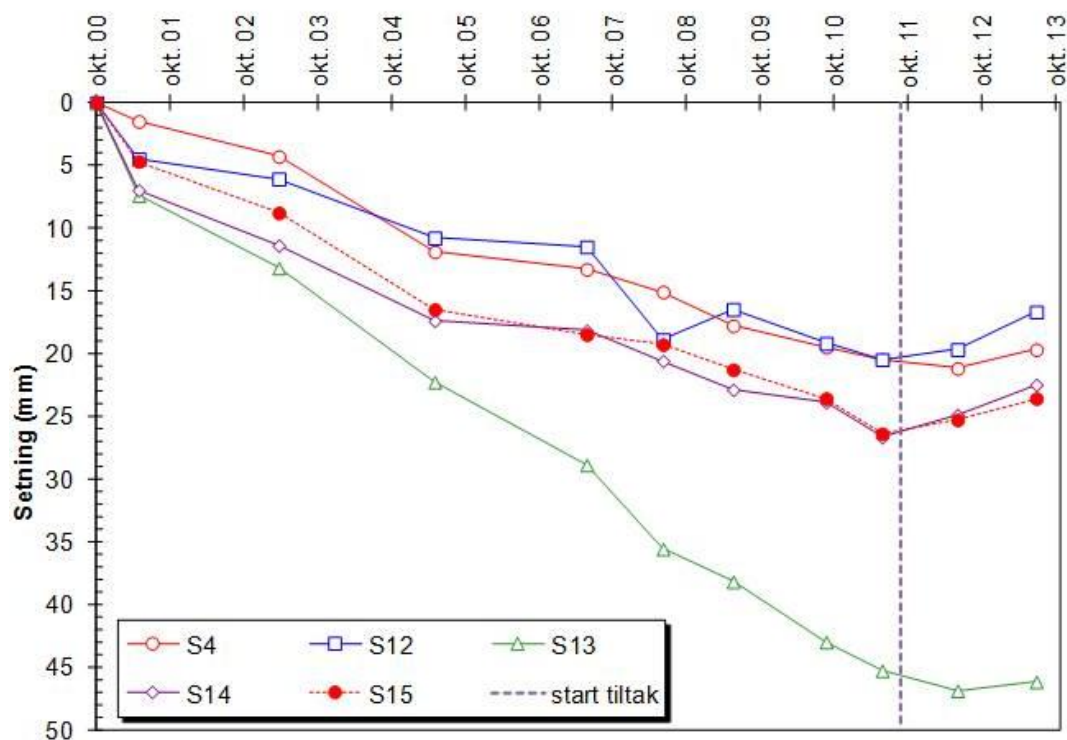


Figure 34: Subsidence measurements at several timber buildings show stagnation and even a moderate uplift (Multiconsult AS).

Subsidence in the Bryggen area (Figure 34) has been negative until approximately 2010-2011 when it came to a standstill. Since 2011 the subsidence has been positive with an upward movement. The active period of *Project Bryggen* finishes this year (2015). All reasonable measures to elevate the groundwater level and to stop subsidence have been conducted. However, the monitoring program will continue for many years hereafter.

5 Project description of Vågsbunnen

During the investigations it became apparent, that not only Bryggen is endangered by decay, but the whole medieval area of the town. A pre-project for the area of Vågsbunnen was conducted and new projects, which consider a large area of the medieval town, are in planning (City Government propositions). The project Vågsbunnen has the aim to build up a comprehensive three-dimensional understanding of the subsurface, and thus to facilitate a more sustainable and cost-effective management of urban space. This approach will help the area management

to benefit more from knowledge and data about the subsurface variability and its physical properties and processes.

The project is limited to the "Medieval City of Bergen", which is subject to regulatory plans (City Government propositions). In the area covered by the plan, groundwater is a very important issue for land management. Groundwater changes may potentially result in both subsidence-damage to, e.g., buildings, equipment, wiring, road surface as well as in loss of automatically protected archaeological sites. After preliminary investigations, the City Government decided to add the proposed new specific regulation for public inspection for the entire planning area, "action resulting in increased risk phrases" why, e.g. intervention on the ground and changes in groundwater level is not permitted within the planning area. Such regulation is unique in Norway, and shows that the Bergen municipality wants a more sustainable urban development of the planning area, which facilitates modern urban development and, at the same time, safeguard the unique cultural values both above and below ground. This requires a more integrated management of the over- and underground than is current practice.

It is proposed that the R & D project is developed and that new mapping, modeling and monitoring techniques are applied to gain a more comprehensive understanding of the subsurface structure and properties, as well as time-dependent processes such as groundwater flow, degradation of cultural deposits and phrases. The methodology developed through the proposed project shall ideally be used for any Norwegian city, regardless of type of challenges and opportunities related to urban development and land management.

We suggest that the project is led by the Geological Survey of Norway (NGU), in cooperation with the City of Bergen, the National Cultural Heritage and the Norwegian Public Roads Administration, of which the latter three have management responsibility for, respectively, public infrastructure and buildings automatically protected cultural deposits and county roads in the plan area. It is proposed to withdraw the project COST Action "Sub-Urban" to ensure access to world-leading knowledge and technology, underground mapping and modeling of cities. The R & D project will also contribute to and benefit from the ongoing development of a national database for site investigations (NADAG), which is a joint operation between NGU, NVE, the Norwegian Public Roads Administration and National Rail.

The following section describes the background for the case of "Medieval City of Bergen" and the main lines of research project and a summary budget proposal.

5.1 Background

The project proposal "Medieval City of Bergen" is based on several meetings on the ground and groundwater conditions in Vågsbunnen and further surroundings, as well as on the following documents:

As described in the above documents, in connection with the upgrading of road and rehabilitation of parts of the district Vågsbunnen some major local subsidence, and in some places lowering of the water level have been uncovered. Within the municipality then has increased awareness of the consequences related to interventions that may alter the groundwater level in Vågsbunnen, especially in terms of damage to cultural heritage in the ground and phrases that can damage buildings, structures, wiring in the subsurface and actions that can damage e.g. buildings, pavements. A municipal pilot project based on these challenges has been initiated. The Pilot project Vågsbunnen has been tasked to look at the situation, to find information, to collect issues and to provide suggestions for further follow-up of these. The pilot project recommended among other things that the existing drainage pumps are mapped, and initiated a monitoring and measurement program for subsidence and altering the groundwater level in Vågsbunnen. In the pilot project report it was recommended that new remediations be studied restricting the right to make interventions that can alter the water table in the subsidence sensitive area (City Government proposition 1470/12). On the basis of these recommendations, the City Council on 8th November 2012 approved the commencement of work aiming to change the plan provisions. In awaiting the results of this work, a temporary ban on measures that could reduce groundwater levels or measures that may impede the planning area has been adopted. The ban also includes measures that do not require official approval if it can lower the groundwater level. On 19th November 2013 the City Council has, at the request of the Directorate of Cultural Heritage, decided to propose an extension of the planning area to include the three development plans (City Government propositions). The planning area is shown in Figure 17.

There are several challenges that affect the planning process in the area but also for other districts. Planning for Light Rail, with more alternative choice of routes through Vågsbunnen and other vulnerable areas, requires a comprehensive understanding of the subsurface and how interventions affect groundwater level and flow and thus subsidence as a result of either degradation or pore pressure changes. The planned area's location by the harbor provides particularly complex challenges related to the inflow of (fresh) groundwater from land and tides (salt) from the sea. One of these challenges is the former salt treated wood, which upon exposure to fresh water or air are exposed to increased decay.

The underground is a historical heritage of anthropogenic and natural geological processes. It is a complex mix of natural and man-made deposits, formed by geological deposition and erosion processes, as well as historical and contemporary urban development processes such as excavation and backfilling. In order to perform injury risk measures on buildings, infrastructure and cultural heritage and assess the costs of effective solutions for the sustainable development of the planning area, it is necessary to have a comprehensive understanding of the subsurface. The understanding should be based on, inter alia, geological data, terrain heights (geotechnical) drilling, excavation, construction drawings, subsidence, rate, groundwater conditions and an understanding of the processes affecting the basic stability and preservation of the cultural layers.

5.2 The main thrust of the research project and budget

In this research project it is proposed to develop a new methodology to build a comprehensive 3D-model of the subsurface, and thereby facilitate a more sustainable and cost-effective management of urban space. The project proposal includes the development of tools, procedures and working methods which will integrate urban geological knowledge in land management. Method development is illustrated in Figure 2 as a stepwise process where the impact on the planning process increases at each step.

The project proposal is divided into three phases. In Phase 1 it is proposed to develop a three-dimensional basic model for the planning area. Such a model can be produced in several ways, such as object-oriented, based on cross-sections and manual interpretation, or based on a geostatistical approach with grid cells (voxels). There is no "standard" methodology for the development of a model of the subsurface and the choice of method will depend heavily on geological conditions, available data quantity, density and type, and the purpose of soil conditions model. In addition, there is need for the preparation of an urban 3D mapping methodology, and the data collection, systematization and interpretation of existing and new subsurface data are central themes. In the development of NADAG-database the systematization of data from site investigations already begun, and the research project will benefit from this work.

A soil mechanics model forms the basis for the development of spatial and dynamic models to describe and predict the properties of and processes in the subsurface. In Phase 2, it is proposed to develop a model of the groundwater level, capacity and flow in the plan area. In addition, it is proposed to develop a methodology to better identify and anticipate (and degradation) subsidence risks, by integrating information

from groundwater and soil relationship model with regularly updated information about the terrain movements by satellite (InSAR). Such an approach will streamline the engineering work for development projects, and reduce the uncertainty associated with unknown ground conditions. The selected planning area is groundwater, archaeological conservation and geotechnical challenges which are very important issues for management.

The methodology will also permit a better mapping and prediction of aspects which are dependent on urban geological knowledge. Examples of such topics are local storm water disposal, flood management, analysis of the proliferation risk of primary and groundwater contamination, underground engineering and utilization of geothermal energy. Each of these topics will require mapping, systematization and combination of specific subsurface data and properties. It is proposed that the research project takes on the analyses of the possible further method and product development projects related to other urban geological themes.

In Phase 3, it is proposed to test and evaluate the methodology as a basis for selected (or thought) development or refurbishment projects in the planning area. The selection of these projects will be done in collaboration with project partners. It is proposed that, for example, it will be conducted an analysis of the modernization project for Kong Oscars street in Vågsbunnen, which is a pilot project for NPRA related to model-based design. The analysis will illuminate computer technical and professional needs of urban geological data when designing the road. A second project might be an analysis of the consequences of the removal of existing groundwater pumping in the plan area.

It will be a R & D project through all phases of production policies, guidelines and recommendations for the implementation of the methodology in management at local, regional and national levels.

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