NGU REPORT 2016.001

25th Seminar on Hydrogeology and the Environment
February 3-4, 2016
Urban Hydrogeology

GEOLOGY FOR SOCIETY
SINCE 1858

GEOLOGICAL SURVEY OF NORWAY
- NGU -

GEOLOGICAL SURVEY OF NORWAY
NGU

REPORT

Geological Survey of Norway
P.O.Box 6315 Sluppen
NO-7491 TRONDHEIM
Tel.: 47 73 90 40 00

Rapport nr.: 2016.001	**ISSN: 0800-3416 (print)** **ISSN: 2387-3515 (online)**	**Grading:** Open

Title:
25th Seminar on Hydrogeology and the Environment, February 3-4, 2016
Urban Hydrogeology

Author: Engdal, M., Sæther O. M., Ganerød, G. V.		**Client:** Geological Survey of Norway	
County:		**Commune:**	
Map-sheet name (M=1:250.000)		**Map-sheet no. and -name (M=1:50.000)**	
Deposit name and grid-reference:		**Number of pages:** 56 **Price (NOK): 70** **Map enclosures:**	
Fieldwork carried out:	**Date of report:** 29.01.2016	**Project no.:** 336500	**Person responsible:**

Summary:

This report presents the program, list of participants and abstracts of presentations and posters from the 25th Seminar on Hydrogeology and the Environment: "Urban Hydrogeology", held on February 3-4, 2016 in Trondheim.

Participants from Europe have been invited to Trondheim to share their knowledge and experience within the steadily growing field of urban hydrogeology. Scientists from various earth science disciplines as well as users and urban decision makers present their work and discuss the challenges related to groundwater in the urban environment.

The abstracts and program are organised along the following main themes:
1. Urban Groundwater;
2. City Case Studies;
3. Urban Stormwater - Groundwater Interaction, and
4. The Future of Urban Hydrogeology

The 25th Seminar on Hydrogeology and the Environment is co-organised by and with support from COST Action TU1206 Sub-Urban (www.sub-urban.eu) and EEA Norway Grants.

The organising committee would like to thank the International Association for Hydrogeologists (IAH) for its support and contributions. The support from The Norwegian Hydrological Council to increase student participation is highly appreciated.

73 seminar participants are registered of which 61 are external.

Except for formatting, spell check and minor editorial revisions, the abstracts are published directly from the material delivered by the presenters who are fully responsible for the content.

We wish you all two informative and engaging days!

Guri Ganerød
Marianne Engdal

Keywords: Hydrogeologi	Grunnvann	Seminar
Miljø	Groundwater	Report
Environment	Urban	Fagrapport

CONTENTS

Co-organisers:

COST EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Sub-Urban

ICELAND LIECHTENSTEIN NORWAY eea grants

norway grants

Seminar Wednesday 3rd of February

Changes in program may occur

			Session chair: Johannes de Beer
09:30	Registration		
	URBAN GROUNDWATER		
10:00	Key note: Groundwater in urban areas; the last 30 years	Ken Howard	President IAH, Univ Toronto, CA
10:30	Changing relationships between geoscientists and decision makers. COST Action TU1206 Sub-urban.	Diarmad Campbell	British Geological Survey
10.50	Coffee break		
11.20	3D modelling and management of the subsurface in Bucharest, Romania	Radu Gogu	Groundwater Engineering Research Centre - Technical University of Civil Engineering, Bucharest
11:40	Disaster projects. Can we learn from our mistakes?	Roelof Stuurman	Deltares, NL
12:00	Light refreshment		
	CITY CASE STUDIES		Session chair: Guri V. Ganerød
13:00	Supporting urban infrastructure developments with city scale hydrogeological modeling in Bucharest, Romania	M.A. Boukhemacha	Groundwater Engineering Research Centre - Technical University of Civil Engineering, Bucharest
13:20	Understanding the historic grounds of Trondheim City	Sylvi Gaut	Sweco Norge
13:40	Hydrogeological Data and Visualization Tools for Urban Areas	Dragos Gaitanaru	Groundwater Engineering Research Centre - Technical University of Civil Engineering, Bucharest
14:00	City-Link Stockholm; an integrated hydrogeological and geotechnical risk assessment.	Jonas Sundell	Chalmers/COWI, Göteborg, SE
14:20	*Coffee break*		
	URBAN STORMWATER - GROUNDWATER INTERACTION		Session chair: Achim Alfred Beylich
14:50	1.000 solutions for a single problem? Multiple benefits of SuDS.	Floris Boogaard	University of Applied Sciences (HUAS) Groningen, NL
15:10	Center for Research-based Innovation (SFI) Klima2050	Tone M. Muthanna	Norwegian University of Science and Technology
15:30	Changing relationships: ASK project UK	Helen Bonsor	British Geological Survey
15:50	From Hydro/Geology to the Streetscape: Evaluating Urban Underground Resource Potential	Michael Robert Doyle	Deep City Project at LEURE, Swiss Federal Institute of Technology, Lausanne
16:10	Poster presentations	Multiple presenters	
16:30	Poster session and refreshments		

Seminar Thursday 4th of February

Changes in program may occur

			Session Chair: Atle Dagestad
	THE FUTURE OF URBAN HYDROGEOLOGY		
09:00	Introduction to the project “Future of Hydrogeology”	Pål Gundersen	NGU, Trondheim
09:10	User needs and media	Kevin Tuttle	IAH / Norconsult
09:25	Educating hydrogeologists for the needs of society	Helen French	Norwegian University of Life Sciences
09:40	Research and Innovation; funds, projects and infrastructure	Per Aagaard	Univ. of Oslo, NO
09:55	Information flow and databases	Pål Gundersen	Geological Survey of Norway
10:10	3D information exchange between geoscientists and decision makers (PhD).	Ane Bang-Kittilsen	Geological Survey of Norway / Norwegian University of Science and Technology
10:30	Discussion and concluding remarks	Johannes de Beer	Geological Survey of Norway
11:00	Light refreshment		

Participants - 25th Seminar on Hydrogeology and the Environment February 3-4, 2016 URBAN HYDROGEOLOGY

Family name	First name	Organisation	email
Bang-Kittilsen	Ane	Geological Survey of Norway	ane.bang-kittilsen@ngu.no
Beylich	Achim A.	Geological Survey of Norway	achim.beylich@ngu.no
Bolstad	Hege Christine	Os Municipality, NO	hcbo@os-ho.kommune.no
Bonsor	Helen	British Geological Survey	helnso@bgs.ac.uk
Boogaard	Floris	Univ. Applied Science (HUAS) Groningen, NL	floris.boogaard@tauw.com
Brandvold	Vibeke	Norconsult, NO	vibeke.brandvold@norconsult.com
Braskerud	Bent	Oslo Municipality, NO	bent.braskerud@vav.oslo.kommune.no
Brattli	Bjørge	Norwegian Univ. of Science and Technology	bjorge.brattli@ntnu.no
Brenden	Marius	ITAS - Instrumenttjenesten AS, NO	marius.brenden@it-as.no
Campbell	Diarmad	British Geological Survey	sdgc@bgs.ac.uk
Cramer	Jan	Geological Survey of Norway	jan.cramer@ngu.no
Dagestad	Atle	Geological Survey of Norway	atle.dagestad@ngu.no
Daviknes	Hans Kristian	Bymiljøetaten, Oslo Municipality, NO	hanskristian.daviknes@bym.oslo.kommune.no
de Beer	Johannes	Geological Survey of Norway	hans.debeer@ngu.no
Dick	Gillian	Glasgow City, UK	gillian.dick@glasgow.gov.uk
Doyle	Michael	École polytechnique fédérale de Lausanne (EPFL), CH	michael.doyle@epfl.ch
Eggen	Gro	Norconsult, NO	gro.eggen@norconsult.com
Engdal	Marianne	Geological Survey of Norway	marianne.engdal@ngu.no
Eriksson	Ingelöv	Oslo Municipality, NO	ingelov.eriksson@pbe.oslo.kommune.no
Fergus	Tharan	Oslo Municipality, Water and Sewerage Authority, NO	tharan.fergus@vav.oslo.kommune.no
Fleig	Anne	The Norwegian Water Resources and Energy Directorate (NVE)	afl@nve.no
Flø Gustad	John Anders	Student at Norwegian Univ. of Science and Technology	jagustad@stud.ntnu.no
Forbord	Rolf	Asplan Viak AS, NO	rolfe.forbord@asplanviak.no
Fredriksen	Ivar	Geonor AS, NO	if@geonor.no
French	Helen K	Norwegian Univ. of Life Sciences	helen.french@nmbu.no
Gaitanaru	Dragos	Tech. Univ. Of Civil Eng. Bucharest, RO	dragos.gaitanaru@utcb.ro
Ganerød	Guri	Geological Survey of Norway	guri.ganerod@ngu.no

Family name	First name	Organisation	email
Gaut	Sylvi	SWECO, Trondheim, NO	sylvi.gaut@sweco.no
Gjengedal	Sondre	PhD student at Norwegian Univ. of Science and Technology	sondre.gjengedal@ntnu.no
Gogu	Constantin Radu	Tech. Univ. Of Civil Eng. Bucharest, RO	radu.gogu@utcb.ro
Gundersen	Pål	Geological Survey of Norway	pal.gundersen@ngu.no
Hagen	Unni	Multiconsult ASA, Bergen, NO	unni.hagen@multiconsult.no
Haukedal	Joakim	Student at Norwegian Univ. of Science and Technology	Joakim.haukedal@gmail.com
Helgason	Peder	Multiconsult, NO	peeh@multiconsult.no
Henriksen	Helge	Sogn & Fjordane University College	helge.henriksen@hisf.no
Hilmo	Bernt Olav	Asplan Viak, Trondheim, NO	berntolav.hilmo@asplanviak.no
Howard	Ken	Univ Tronto, CA, IAH president	gwater@utsc.utoronto.ca
Ihler	Harald	SSAB Svensk Stål AS, NO	harald.ihler@ssab.com
Jensen	Jann Atle	Multiconsult ASA, Bergen, NO	jann.atle.jensen@multiconsult.no
Jensen	Niels-Peter	I-GIS A/S, DK	npj@i-gis.dk
Jæger	Øystein	Geological Survey of Norway	oystein.jager@ngu.no
Jørlo Haugerud	Haakon	Student at Norwegian Univ. of Science and Technology	haakjh@stud.ntnu.no
Kvitsand	Hanne	Asplan Viak AS, NO	hanne.kvitsand@asplanviak.no
Lawrence	David	British Geological Survey	djdl@bgs.ac.uk
Linderberg	Johan	VandCenter Syd, DK	jl@vandcenter.dk
Lysen	Svein Ragnar	Multiconsult ASA, NO	svein.ragnar.lysen@multiconsult.no
Mielby	Susie	Geological Survey of Denmark and Greenland	smi@geus.d
Moen	Kjersti	Implenia, NO	kjersti.moen@implenia.com
Muthanna	Tone	Norwegian Univ. of Science and Technology	tone.muthanna@ntnu.no
Nygård	Ingvild Haneset	Student at Norwegian Univ. of Science and Technology	ingvildhnygard@gmail.com
Petersén	Anna	Norwegian Instituet for Cultural Heritage Research	anna.petersen@niku.no
Ramstad	Randi Kalskin	Asplan Viak / Norwegian Univ. of Science and Technology	randi.kalskin.ramstad@asplanviak.no
Riise	Mari Helen	Asplan Viak, Trondheim, NO	marihelen.riise@asplanviak.no
Rosén	Lars	Chalmers Univ. of Technology	lars.rosen@chalmers.se
Sandbakken	Marit Eline	Student at Norwegian Univ. of Science and Technology	marit.sandbakken@gmail.com
Seither	Anna	Geological Survey of Norway	anna.seither@ngu.no

Family name	First name	Organisation	email
Serbulea	Manole Stelian	Tech. Univ. of Civil Eng. Bucharest, RO	
Skei	Silje Øren	Student at Norwegian Univ. of Science and Technology	siljeosk@stud.ntnu.no
Skoglund	Rannveig Øvrevik	Dep. Geography, Univ. of Bergen, NO	rannveig.skoglund@uib.no
Sognnæs	Guri	Student at Univ. of Bergen, NO	guri.sognnaes@gmail.com
Staubo Munthe-Kaas	Nille Ragnhild	Implenia, NO	nille.munthe.kaas@implenia.com
Storbekkrønning	Gunnhild Solli	PhD student at Faculty of Law, Univ. of Oslo	g.s.solli@jus.uio.no
Stormoen	Martin Austin	Norwegian government's agency for railway services (JBV)	maraust@gmail.com
Storrø	Gaute	Geological Survey of Norway	gaute.storro@ngu.no
Stuurman	Roelof	Deltares, NL	roelof.stuurman@deltares.nl
Sundell	Jonas	Chalmers Univ. of Technology / COWI AB, SE	jonas.sundell@chalmers.se
Sæther	Ola M	Geological Survey of Norway	ola.sather@ngu.no
Sørlie	Jan Erik	Hydro Geo Service AS, NO	jesorlie@hydrogeo.no
Tuttle	Kevin J.	Norconsult, NO	kevin.john.tuttle@norconsult.com
van Campenhout	Ignace	Rotterdam City, NL	ipam.vancampenhout@rotterdam.nl
Vorenhout	Michel	MVH Consult, NO	m.vorenhout@mvhconsult.nl
Wakker	Joyce	Norconsult, Bergen, NO	Joyce.Wakker@norconsult.com
Aagaard	Per	Univ. of Oslo, NO	per.aagaard@geo.uio.no

PRESENTATIONS
February 3rd

Groundwater in urban areas; the last 30 years

Ken W.F. Howard, *University of Toronto Scarborough*

Scientific interest in the relationship between urban development and the behaviour of streams and rivers can be traced back to the 1950's when reconstruction of cities damaged during the 2nd World War first drew close attention to the strong link between the creation of impervious land cover and the frequency and intensity of urban flooding events. Interest in urban groundwater took much longer to emerge, presumably due to the relatively slow movement of water in the subsurface and the extended time required for changes in groundwater quality and quantity that result from urbanisation to be observed and documented. It was probably not until the 1980s that serious awareness grew for the complexity of the relationship between urbanisation and groundwater, and this likely explains the very serious lack of proactive groundwater management in many of the world's rapidly developing cities.

Thirty years ago, urban aquifers were considered little more than regular aquifers that had been capped by an extensive cover of concrete and asphalt, thus reducing their ability to receive replenishment via direct recharge. Since those times, the science of urban groundwater has advanced considerably and a wealth of knowledge has been gained. Much of this work has related to quantity (the urban water balance and sources of recharge), and water quality (pollution sources and a wide range of contaminating chemicals). However, it has also involved the nature of the aquifer and a realisation that urbanisation can cause fundamental changes to the nature and character of the subsurface flow system, such that the natural hydrogeological behaviour of the aquifer can be radically altered. Key scientific advances in recent decades include:

- The role of "urban fill". Materials used to level the land surface in urban areas prior to the construction of buildings and roads can be far more important than the local geology in terms of defining the presence of shallow aquifers, their recharge behaviour and the nature of shallow groundwater flow.
- Urban "karst". There is now recognition that fine cracks in the impermeable pavement, and permeable zones associated with underground pipe networks also have a strong influence on urban recharge and shallow urban groundwater flow, and can seriously affect contaminant migration and the quality and quantity of water entering urban streams as base flow.
- Aquifer recharge. Studies in cities throughout the world demonstrate that the loss of natural, direct aquifer recharge in urban areas due to the extensive impermeable cover is often more than compensated by sources of aquifer recharge that are entirely new to the region e.g. leaking sewer pipes, leaking water mains, septic tank discharge, excessive irrigation of parks and gardens, and infiltration of storm water run-off (both deliberate and unintentional).
- Water "production". Because urbanisation causes a significant reduction in evapotranspiration, it "creates" additional water which, if harvested and managed effectively, can produce significant net benefits.
- Pollutant source characterization. Considerable progress has been made in the use of major and minor ions, environmental isotopes, trace elements and trace organics to fingerprint and isolate sources of urban groundwater contamination (e.g. the use of

xenobiotics and artificial sweeteners to identify and track the subsurface movement of sewer leakage).

- Contaminant migration. Considerable progress has been made in the understanding of contaminant plume behaviour, including processes such as advection, directional dispersivity, volatilisation, degradation and chemical retardation.

A natural consequence of the improved scientific understanding of the inter-relationship between urbanisation and urban aquifer systems has been the development of various techniques for monitoring and managing urban groundwater (e.g. resource enhancement through recharge management, aquifer vulnerability mapping, well head protection methodologies and specialized processing and disposal techniques for all types of domestic and industrial waste). Moreover, powerful aquifer modeling and evaluation tools have been developed that have the potential to greatly facilitate urban water management decision-making.

The most sophisticated of these modeling tools is "AISUWRS" (Assessing and Improving Sustainability of Urban Water Resources Systems) published in 2006 as part of an "Urban Water Resources Toolbox" following a three-year international multidisciplinary research project involving research teams in Europe and Australia. The AISUWRS modeling tool links an Urban Volume and Quality (UVQ), developed through Australia's CSIRO urban water programme (UWP) with a groundwater flow model (FEFLOW®) via a series of (ARCINFO®) GIS layers and various modules designed to simulate unsaturated flow and pipe network exfiltration/infiltration. UGROW, an urban groundwater modeling tool published in 2011 is less versatile than AISUWRS but retains many of its key features and includes a fully integrated modeling package.

To date, neither of these urban water management tools has been widely used. This probably reflects an approach to groundwater management in urban areas that, in most cases, focus considerably more on problem resolution (water supply, spills, contaminant plumes, rapidly rising/falling water tables) i.e. urgently "putting out fires", than on the painstaking development of long-term strategies for the protection and sustainable management of urban groundwater resources: It is not so that the appropriate methods of resource management and protection are not available, – on the contrary! Both the science and the technology are sound and well developed. What seems to be lacking in many of the world's cities is the structured framework of good governance that can fully exploit the scientific and technical advances of the past thirty years. This is the remaining challenge. Sustainable management of urban groundwater will never be achieved without the establishment of reliable and effective systems of urban groundwater governance.

Changing relationships between geoscientists and decision-makers - COST Action (TU1206) SUB-URBAN

Diarmad Campbell [1], Johannes de Beer [2], Helen Bonsor[1], Ignace van Campenhout[3], Susie Mielby[4], Ingelov Eriksson[5], Gillian Dick[6], Michiel van der Meulen[7], Jeroen Schokker[7], David Lawrence[1], Guri Venvik Ganerod[2], Rob van der Krogt[7], Alex Donald[8], Mario Bacic[9], Grzegorz Ryzinski[10] & Renate Taugs[11]

[1] British Geological Survey, United Kingdom, [2]Norwegian Geological Survey (NGU), Norway, [3]City of Rotterdam, Netherlands, [4]Geological Survey of Greenland and Denmark (GEUS), Denmark, [5] City of Oslo, Norway, [6]Glasgow City Council, United Kingdom, [7]Geological Survey of the Netherlands (TNO), Netherlands, [8] Geological Survey of Northern Ireland, United Kingdom, [9] University of Zagreb, Croatia, [10]Polish Geological Institute, [11]State Geological Survey of Hamburg (Germany)

Cities worldwide are vital engines for economic growth. Europe's population is already substantially urbanised, and UN-HABITAT (2012) estimates that by 2050 two-thirds of the world's population will be city dwellers. Sustainable urban development is under pressure, but despite this, there is a widespread lack of appreciation of the importance of the urban subsurface amongst those who plan, develop and manage cities. This is manifested in: a lack of integrated policy for the urban subsurface, inefficient and unsustainable use of areas beneath cities, inadequate safeguarding of urban subsurface ecosystem services, and conflicting use of the urban subsurface.

SUB-URBAN, a European Cooperation in Science and Technology (COST) Action (http://www.cost.eu/COST_Actions/tud/TU1206) scheduled from 2013-17, is a network to improve understanding and use of the ground beneath our cities. SUB-URBAN aims to transform relationships between: experts who develop urban subsurface geoscience knowledge - principally national Geological Survey Organizations (GSOs), but also university researchers and others; and those who can benefit the most from it - urban decision makers, planners, practitioners (private consultants and contractors), developers, and the wider research community. Now under the EU's Horizon2020 Framework Programme, and operating under a Memorandum of Understanding, SUB-URBAN has established a network of GSOs and other researchers in 30 European countries, to draw together and evaluate collective urban geoscience research in 3D/4D characterization, prediction and visualization.

The underground is a spatial asset which needs to be more clearly understood by urban decision-makers if it is to achieve its full potential in helping cities adapt to the many challenges they will face in coming decades. There will also be a need to plan and manage uses of the subsurface (as with any other asset), to protect subsurface ecosystem services on which cities depend, and to recognise and address conflicting uses of the subsurface. These have been pioneered spatially in Helsinki's Underground Space Allocation Plan (since 1984) and in Master Plans for Montreal and St Petersburg, where subsurface urban development has been integrated into the land-use planning system.

To achieve maximum effectiveness, however, planning for urban areas must advance beyond the spatial (2D) arrangement of surface facilities and consider full 3D (volumetric), and 4D (temporal) interactions between the built environment above and below ground, its supporting infrastructure and subsurface space. Depth zonation enabling coexistence of multiple uses of the subsurface should also be considered, and implemented where possible.

A key barrier to progress has been the way subsurface knowledge has been previously made available to urban decision makers – as specialised data and maps needing geoscience expertise for interpretation. Recent advances in technology and software have revolutionised the ways subsurface can be interpreted, visualised, analysed, and delivered, with a move from 2D, to 3D and 4D. These advances have been adopted, and often initiated, by GSOs and other researchers in Europe. However, research has been proceeding independently, with duplication of effort and dissipation of impact, especially in relation to policy.

SUB-URBAN's network is therefore: assessing current state of knowledge and practice in relation to the urban subsurface, including monitoring and modelling across Europe, and further afield; promoting improved subsurface data accessibility; integrating and accelerating subsurface modeling; and developing a Toolbox of good practice guidance, with related training, to enable subsurface knowledge to be widely disseminated, and used more effectively. A key strength of the Action is direct participation of partners representing cities across Europe (Oslo, Rotterdam, Odense, Warsaw, Ljubljana, Glasgow, Cardiff, Hamburg etc.). Their expertise in planning and policy, management and delivery of city infrastructure, and approval of licenses and plans submitted by developers, is vital in guiding the Action, and its priorities at all stages. They will also be national pioneers of the use of the Action's outputs, influencing others to follow in their footsteps.

Existing city-scale 3D/4D model exemplars are being improved, and bespoke variants developed by SUB-URBAN'S partners in for example Glasgow, Hamburg and Vienna. These draw on extensive ground investigation (10s-100s of thousands of boreholes), monitoring, and other data. Model linkage enables predictive modelling of groundwater behaviour (e.g. in Hamburg, Basel, Rotterdam and Bucharest), heat (e.g. in Basel and Barcelona), SuDS, and engineering properties. Combined subsurface and above-ground (CityGML, BIMs) models are also in preparation. These will provide valuable tools for more holistic urban planning; identifying subsurface opportunities and saving costs by reducing uncertainty in ground conditions. Knowledge exchange between city-partners and researchers has facilitated new city-scale subsurface projects. Oslo (Norway) and Odense (Denmark) have been leading with ambitious and comprehensive multi-disciplinary teams engaged in data management and modeling of the shallow subsurface*, including its buried infrastructure, and development of comprehensive new subsurface planning and management systems.* Rotterdam (Netherlands) is pioneering innovative knowledge transfer between its geoscience specialists and planners, including the use of the 'Serious Game'. With training, other cities will follow. At policy level, the Netherlands is pioneering legislation for mandatory consultation of, and contribution of data to, BRO, its subsurface key-register. Alternatively, in the UK, free-flow of subsurface data is being encouraged through the ASK (Accessing Subsurface Knowledge) network, and use of an agreed digital data transfer template (GSPEC) in framework contracts of national stakeholders – an approach successfully championed by the City of Glasgow, and increasingly looked to by other local and national authorities. Both approaches work in practice, and support improved decision-making. SUB_URBAN is also promoting: economic assessments of improved subsurface data and knowledge delivery; conurbation scale geochemical surveys and interpretation of near-surface contamination; protection of buried archaeological and heritage assets from threats from variations in groundwater level and quality. Crucially SUB-URBAN is supporting the development of integrated volumetric sub-surface planning (in Glasgow, Rotterdam, Oslo and elsewhere) supported by dedicated geoscience expertise, which will serve as a model for the future.

3D modelling and management of the subsurface in Bucharest, Romania

Constantin Radu Gogu, Mohamed Amine Boukhemacha, Dragos Gaitanaru & Irina Serpescu

Groundwater Engineering Research Center, Technical University of Civil Engineering of Bucharest, Romania

Nowadays, the importance of the ground beneath cities is overlooked or not even recognized. Management of the urban underground includes groundwater and infrastructure elements. This requires the understanding of both hydrogeological science and infrastructure development. Hydrogeological resource management in urban areas can be performed only by applying groundwater modeling. The models can provide truthful results if they are based on accurate data and they may properly reproduce the hydrogeological processes and the interaction between groundwater and the infrastructure.

Bucharest, a city of about 1.9 million inhabitants and covering a surface area of about 228 km^2, faces two main hydrogeological problems. Both are produced by the interaction between the aquifer system and the underground infrastructure. The first problem consists in the barrier effect produced by the extensively channelized Dambovita River that cuts through Bucharest and divides the city in two parts, from NW to SE, and consequently increasing the groundwater hydraulic heads in the surrounding areas. The second problem is actually of twofold concern and it is due to the strong hydraulic interaction between the sewer system and the groundwater. As a consequence, seepage into the sewer network increases the used water flow and volumes that need to be treated. Restoration of the conduits in the city´s sewage system consequently triggers an increase in the hydraulic heads in several residential areas.

An interdisciplinary research project started in 2010 with the purpose of setting up the concept and carrying ou the first steps in establishing a hydrogeological model of the Bucharest city (CCIAS, 2013). Several institutions, companies, and experts contributed with data and knowledge to perform this work. After compiling about 1800 boreholes, an accurate 3D geological model has been developed by stratigraphical litho-correlation using in-house research software (Gogu et al., 2011). It focuses on the Quaternary sedimentary deposits of the first 50 m below ground level and it was used to identify, delineate, and describe the existing hydrogeological units composing the shallow aquifer system. Pumping tests and grain size distribution analysis has been performed to hydraulically characterize these units. By intersecting the model with the existing urban infrastructure elements it has been possible to provide the geometrical parameters needed to quantify the groundwater flow barrier effect (Boukhemacha et al. 2015), induced by the presence of the underground engineering works (e. g. subway infrastructure, underground parking lots), as well as to identify the position of the sewer conduits and their potential hydraulic connection with the aquifer strata.

Finally the hydrogeological model has been developed by incorporating the following datasets: hydraulic head data, surface water, groundwater recharge coming from precipitation as well as from the water supply system distributed losses, drainage systems and subway tunnels seepage information. On this basis, the estimated hydrological water balance identified that about 0.92 m^3/s is wastewater surplus distributed on the entire network, and is identified as groundwater seepage into the sewer network. It also has been determined that about 16.9 km (3.5 %) of the sewer network is completely immersed into the groundwater and about 79.8 km (16.5 %) is partially immersed. The possible wastewater conduits susceptible to groundwater seepage as well as those predisposed to leak into the aquifer have been outlined.

The described model framework is currently used to carry out distinct hydrogeological studies related to rehabilitation of the city sewer system, future underground infrastructure developments, groundwater protection and environmental impact assessment.

The rehabilitation of the sewer system network represents many very challenging steps due to the complexity of the hydrogeological collateral issues. This work will be tied up to the implementation of a new drainage system. The hydrogeological modelling simulation of the two operations outlines the efficiency and the extent of impact of both. Results put into evidence the value of using accurate geological and hydrogeological urban modelling.

Local studies that are developed to solve different hydrogeological problems use the already existing city scale model, and by doing so, will increase feed-back related to its content and accuracy. Distinct examples regroup design procedures of groundwater monitoring systems, the barrier effect of deep foundations, and scenarios which simulate disturbance of the urban city lake (Gogu et al., 2015).

References

Boukhemacha MA, Gogu RC, Serpescu I, Gaitanaru D, Bica I. (2015). *A hydrogeological conceptual approach to study urban groundwater flow in Bucharest city, Romania*.Hydrogeology Journal, Springer-Verlag Berlin Heidelberg 2015;

CCIAS (2013). Hydrogeological flow model for the Moesic aquifer system (Bucharest Area). Research project: Sedimentary Media Modelling Platform For Groundwater Management In Urban Areas (SIMPA). – Scientific Report, No 10 [in Romanian], Bucharest, Technical University of Civil Engineering Bucharest.

Gogu RC, Velasco V., Vazquez-Sune E., Gaitanaru D., Chitu Z., Bica I. (2011) *Sedimentary media analysis platform for groundwater modeling in urban areas*. Environmental Earth Sciences, Vol 2, pp 489-496, Berlin.

Gogu C R, Serpescu I, Perju S, Gaitanaru D, Bica I. (2015), *Urban groundwater modeling scenarios to simulate Bucharest city lake disturbance* , 15th International Multidisciplinary Scientific GeoConference SGEM 2015, Conference Proceedings, June 18-24, 2015, Book1 Vol. 2, 834-840 pp, ISBN 978-619-7105-32-2 / ISSN 1314-2704

Disaster projects. Can we learn from our mistakes?

Roelof Stuurman, *Deltares, The Netherlands*

In order to achieve our ambitions on climate, energy and a comfortable living environment the subsurface will be used more intensively in the future. Rapid innovations and economic circumstances lead to several opportunities for increasing our use of the subsurface. This increase in multiple uses create a pressure on the subsurface which needs to be managed. Unforeseen events occur in every-day projects and can have negative social, cost or environmental impacts and limit other uses of the subsurface. This was the reason for a preliminary Dutch study and recent publication „Unexpected events in the subsurface" (TCB, Witteveen & Bos and Deltares).

This study implies a broad analysis of causes and consequences combined with lessons learned from illustrated cases. It resulted in insights with respect to the negative impact of unforeseen events and the factors that play an important role in occurrence and prevention. Traditional tendering (knowledge sharing, risk evaluation and liability) and highly reliable - organizations helps us to find possible solutions to manage unforeseen events. The preliminary study has shown that knowledge availability and sharing, risk sharing during tendering, transparency and attitude toward unforeseen events and good governance play an important role in enhancing our grip on unforeseen events.
During the presentation several examples will be presented and directions towards improvement will be proposed.

Rapport Onverwachte gebeurtenissen in de bodem - Gevolgen van ons handelen in beeld - TCBodem
(http://www.tcbodem.nl/nieuws/archief/121-rapport-onverwachte-gebeurtenissen-in-de-bodem-de-gevolgen-van-ons-handelen-in-beeld)

Supporting urban infrastructure developments with city scale hydrogeological modeling in Bucharest, Romania

Mohamed Amine Boukhemacha, Constantin Radu Gogu, Irina Serpescu & Dragos Gaitanaru

Groundwater Engineering Research Center, Technical University of Civil Engineering of Bucharest, ROMANIA

Managing aging infrastructure elements and developing new ones represent important challenges that modern cities must face. The complexity of these issues can be increased significantly by the presence of direct or indirect interaction with groundwater systems. It is now recognized that major infrastructure elements can affect the regime and water quality of urban aquifer systems in many ways; by introducing new recharge sources (e.g. leaky water supply networks and sewer systems) or new discharge sinks (e.g. defective subway infrastructure and sewer system, dewatering and groundwater abstraction systems), by reducing groundwater flow cross section, by degrading groundwater quality (e.g. leaky sewerage, sea water intrusion, etc.) and others. More information on the subject can be found in reviews on urban hydrogeology (Attard et al., 2015; Boukhemacha et al., 2015a; Schirmer et al., 2013; Vazquez-Suné et al., 2005).

Bucharest, as a city that is developing fast , has its fair share of issues related to the interaction between groundwater and urban infrastructure, particularly related to the sewer system. The latter has been found to drain important groundwater flow rates. This is based on estimates made by the city water operator and hydrogeological studies (CCIAS, 2013). Having direct negative consequences on the city's waste water treatment plant (i. e. increased treatment costs and reduced efficiency), this issue created necessity need to modernize this aging infrastructure element. Planned actions consist of rehabilitating defected sewer conduits, constructing a new groundwater drainage system and rehabilitating the Dambovita River lining and attached hydraulic works. However, considering the existing interactions between these elements and the aquifer system, implementing these modernizing works could lead to significant perturbations in the hydrogeological system which can further propagate to other interacting elements (subway infrastructure, surface water bodies, building, etc.).

Within this framework, a series of hydrogeological studies were conducted with the purpose of assessing potential quantitative impacts on the urban groundwater system of Bucharest related to the planned sewer system modernizing works. The studies relied on 3D steady-state numerical simulations of groundwater flow run on models built at various spatial resolutions; a city scale low spatial resolution and local scale high spatial resolution models. These models were based on the conceptual approach proposed by Boukhemacha et al. (2015b). Using several scenarios (related to the amount of the rehabilitation works and drainage system operating target), it was possible to estimate the spatial extent and the magnitude of the impact of these planned works on groundwater dynamics (level and flow direction) as well as the associated changes in the urban hydrogeological budget for each of the considered urban infrastructure development scenario. The analysis provided insights on how to achieve an integrated management of the aquifer system (i. e. urban development with reduced impact on groundwater) and a sustainable development of the city infrastructure.

References

Attard, G., Winiarski, T., Rossier, Y., Eisenlohr, L. (2015) Review: Impact of underground structures on the flow of urban groundwater. Hydrogeology Journal, first online. doi: 10.1007/s10040-015-1317-3.

Boukhemacha, M. A., Gogu, C. R., Serpescu, I., Gaitanaru, D., Bica, I. (2015a) General aspects on urban hydrogeology and highlights from Bucharest (Romania). Environmental Engineering and Management Journal, 14(6), pp.1279-85.

Boukhemacha, M. A., Gogu, C. R., Serpescu, I., Gaitanaru, D., Bica, I. (2015b) A hydrogeological conceptual approach to study urban groundwater flow in Bucharest city, Romania. Hydrogeology Journal, 23(3), pp.437-50. DOI 10.1007/s10040-014-1220-3.

CCIAS (2013). Hydrogeological flow model for the Moesic aquifer system (Bucharest Area). Research project: Sedimentary Media Modelling Platform For Groundwater Management In Urban Areas (SIMPA). – Scientific Report, No 10 [in Romanian], Bucharest, Technical University of Civil Engineering Bucharest.

Schirmer, M., Leschik, S., Musolff, A. (2013). Current research in urban hydrogeology: a review. Advances in Water Resources, 51, pp.280-91. doi:10.1016/j.advwatres.2012.06.015.

Vazquez-Suné, E., Sanchez-Vila, X., Carrera, J. (2005) Introductory review of specific factors influencing urban groundwater, an emerging branch of hydrogeology, with reference to Barcelona, Spain. Hydrogeology Journal, 13(3), pp.522-33. doi: 10.1007/s10040-004-0360-2.

Understanding the historic grounds of Trondheim City

Sylvi Gaut[1] & Anna Petersén[2]

[1]Sweco Norge AS, [2]NIKU

Background

On behalf of the Directorate for Cultural Heritage (Riksantikvaren), the Norwegian Institute for Cultural Heritage Research (NIKU) prepared in 2013 a report containing a plan for long-term management and surveillance of archaeological sites and areas in Trondheim (NIKU 2013).

One of the locations recommended for surveillance is the area north of Trondheim Public Library, i. e. Petter Egges plass, Søndre gate 7-11 and Krambugate 2-4. In June 2015, three observation wells were placed in the area to measure fluctuations in the groundwater level, and to compare the groundwater data with the conditions of the anthropogenic sediments.

Anthropogenic sediments in Trondheim

The medieval city of Trondheim is located on the eastern parts of the point-bar Nidarneset, by the mouth of the river Nid, where it enters the Trondheimsfjord. The river plain area consists mainly of fluvial deposits, partly covered by clay from landslides on the opposite bank to the south. The naturally delimited zone, which corresponds with the historic parts of Trondheim and consequently is automatically regulated by law with emphasis on building preservation, covers approximately 560 ha. Trondheim is the northernmost of the Norwegian cities defined as "medieval towns". Unlike the other cities (for instence Bergen and Oslo), the anthropogenic sediments are located in the unsaturated zone above groundwater level.

The anthropogenic sediments are not homogeneous, but varies in thickness, type and composition. Thickness and amount of organic material reflect the activities in the different parts of the medieval city through time. Areas with dense population and long term building activities generates the highest amount of organic material.

In the area north of Trondheim Public Library, the anthropogenic sediments are 2-4.5 m thick. The organic content is high and the sediments represent mainly activities connected to residential areas which have been habitated continuously from early medieval time. There are also several churches and graveyard within the area. Thus, the archaeological materials contain multiple types of materials with different conditions for preservation and decomposition.

Observation wells and measurements of groundwater level

There are few places in Trondheim, where groundwater influences the anthropogenic sediments. However, in the area north of Trondheim Public Library earlier investigations indicates that the lower parts of the archaeological material may be susceptible to changes in the groundwater level, as a result of the high water content observed in the soil. In June 2015, three observation wells (OB1-OB3) were placed in the area to measure fluctuations in the groundwater level (Figure 1). The drilling results showed anthropogenic sediments down to 4 m depth in the boreholes OB1 and OB2, but none in OB3. Most of the anthropogenic sediments had high organic content and preservation increased downwards. According to NIKU (2009), the different layers between 2-4 m depth had condition A3 (medium) or better.

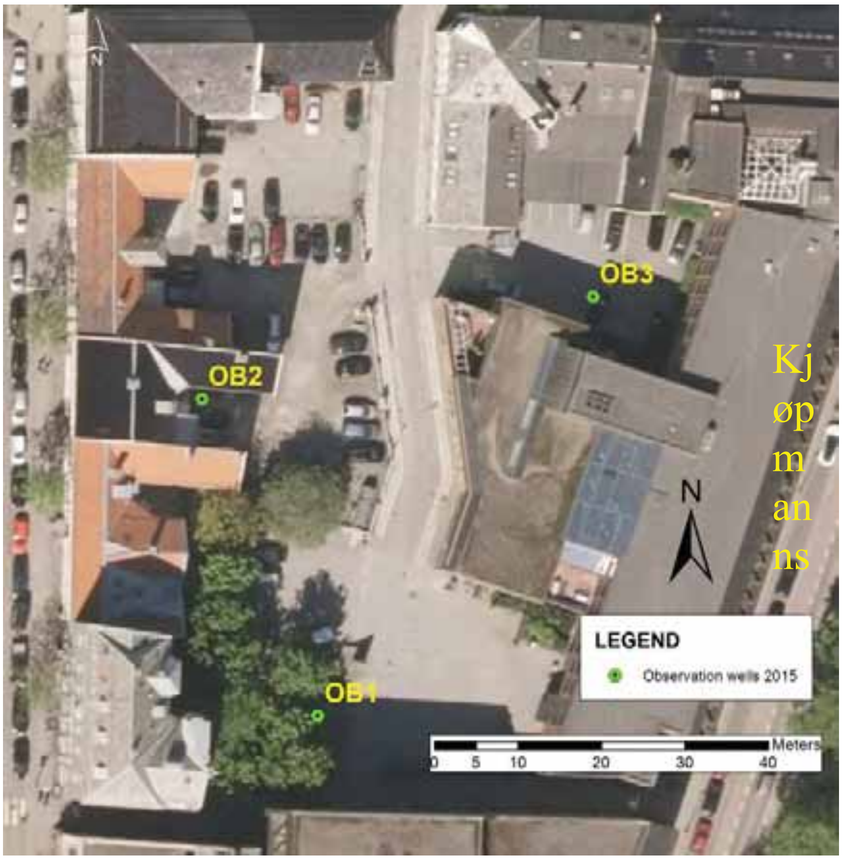


Figure 1 Observation wells located in the area Petter Egges plass, Søndre gate 7-11 and Krambugata 2-4. The groundwater flows towards the east.

Excavation close to OB2 (Søndre gate 9), in September 2015 showed that an early medieval church and churchyard is located on the property. The anthropogenic sediments related to the churchyard has a high sand and gravel content, probably natural sediments from the burial. The sediments were moist, and a hypothesis is that fluctuations in the groundwater level influence the lowermost layers.

The groundwater levels in the area fluctuated very little from June to October 2015. The groundwater level is lowest in OB3 (about 6.8 m below ground) and highest in OB2 (about 6.5 m below ground), and the groundwater flows eastwards toward Kjøpmannsgata. The wells are all 9 m long, with filters 5-8 m below ground.

Groundwater samples from the wells taken in October, shows differences between the wells. The water is analysed on parameters recommended in NS 9451:2009. Observation well OB3 (no anthropogenic sediments) has the highest nitrate and chloride content and are lowest in total organic carbon (TOC) in addition to acid neutralizing capacity (ANC). Highest TOC is measured in OB2, together with manganese, iron and phosphate. Whereas the groundwater in OB1 has the highest alkalinity, ammonium and ANC.

References

NIKU 2013: Plan for miljøovervåking av kulturlag I Trondheim for perioden 2013-2023. NIKU oppdragsrapport 53/2013, 18 s.

NIKU 2009. Kulturminner. Krav til miljøovervåking og –undersøkelse av kulturlag. (Cultural property. Requirements on environmental monitoring and investigation of cultural depositis). ICS 13.020.99, 91.010.99 Språk: Norsk/Norwegian.

Hydrogeological data and visualization tools for urban areas

Dragos Gaitanaru, Constantin Radu Gogu, Leonard Anghel, Mohamed Amine Boukhemacha & Irina Serpescu

Groundwater Engineering Research Center, Technical University of Civil Engineering of Bucharest, ROMANIA

Bucharest City covers an area of around 240 km^2 (area of six districts), and trough the city flows two important rivers which are intensely modified by man. The northern river (Colentina) is landscaped in a series of pervious lakes which communicates directly with the shallow aquifer. The southern river (Dambovita - that flows through the center of the city) is channeled and the communication with the aquifer is interrupted. Also an important artificial lake (Lacul Morii) in the western part of the city was constructed in the 1970´s for flood management and also urban landscape improvement. Another important hydrological feature is the presence of a significant number of artificial and natural lakes. The entire water surface in the city is around 11 km^2.

Underneath the city, the geological setting is dominated by Quaternary sediments) of fluvial, lacustrine or eolian origin. This implies clay, loam, marl, loess, sands and gravel. From the Lower Pleistocene (200 000 -150 000 yrs BP) to the latest Holocene deposits, three important aquifer formations exist in the Bucharest area:

(1) Deeper aquifer, - used for water supply, the (2) Medium aquifer, - used also for water supply in some cases and in a direct hydraulic connection, both naturally and anthropogenically, with the (3) Shallow aquifer, which is in direct connection with the sub-urban infrastructure.

The development of an integrated urban groundwater flow model (hydrogeological settings in conjunction with underground urban infrastructure) created the proper framework to solve and simulate different urban groundwater related problems. During the last years the urban development created a direct impact on the groundwater resources at a local scale, but with repercussions upon the entire urban hydrogeological system. A groundwater flow model at the urban scale was used to solve different engineering problems that occurred in Bucharest City by means of downscaling important processes.

The bases of the groundwater flow model are the urban hydrogeological data, and the resolution is given by the amount and the quality of the data. Data acquisition and validation is an elaborated process that relies on external factors (e. g. data availability, time step, continuity) and on the capability to understand and judge the conceptual hydrogeological urban settings.

For Bucharest City it was necessary to acquire a large amount of data in order to have a clear image of the underground settings. Different types of data were collected from public institutions, private companies and professional associations. All the data passed through a validation and filtration process before they were incorporated into the database. Because of the many source domains (i. e. geotechnical, hydrological, geological, civil engineering, etc.) at this stage there is no general recipe and the validation process was performed by means of expert judgment. In parallel with the data collection and validation, new data acquisition was performed. New data acquisition is a continuous process that targets the time dependent hydrogeological information (e. g. water levels, water supply and sewage discharges, precipitation) and it is performed using the Urban Groundwater Monitoring System. At the end of 2014 the urban groundwater monitoring system in Bucharest was composed by a total number of 145 monitoring points/stations.

Another important aspect related to urban hydrogeological information is the management and the visualization of data. For Bucharest City (Romania) an integrated platform for groundwater geospatial data management is available. The software platform architecture is based on three components:

(1) the core of the platform is the hydrogeological geospatial database and the geospatial server application,

(2) the client side, a geoportal application capable to publish hydrogeological data and to make geospatial queries, and

(3) the most developed component is the desktop platform.

City-Link Stockholm; an integrated hydrogeological and geotechnical risk assessment

Jonas Sundell[1,2] & Lars Rosén[1]

[1]Department of Civil and Environmental Engineering, Chalmers University of Technology, Gothenburg, Sweden, [2]COWI AB, Gothenburg, Sweden

City-Link is a planned 14 km long high-voltage tunnel in Stockholm, Sweden. The diameter of the tunnel will be 5 meters and the maximum depth beneath the ground surface is 100 meters. Sub-surface constructions, such as the City-link tunnel, generally involve drainage of groundwater, which can induce land subsidence in compressible soil deposits and cause extensive damage costs in urban areas. In this paper we present an integrated hydrogeological and geotechnical risk assessment for the planned tunnel. The presented work is a collaboration of research at Chalmers University of Technology and consultancy at COWI.

When assessing the risk for land subsidence induced by groundwater drawdown in planned sub-surface projects, the whole damage chain needs to be recognized (Sundell et al., 2015a). This damage chain starts with leakage of groundwater into a sub-surface construction. The leakage causes groundwater drawdown, which reduces pore pressure in compressible deposits and causes subsidence. The damages of the induced subsidence depend on the sensitivity of the constructions founded on the compressible deposits. Subsequently, the consequences depend on the cost associated with the damage. In this damage chain, it is the interaction between geotechnical and hydrogeological conditions and the sensitivity of the constructions at risk that determines the magnitude of the consequences. All parts of this system need certain amount of weakness to cause failure. Several conditions need to be fulfilled simultaneously to cause damage: groundwater drawdown, compressible soils and constructions sensitive for subsidence.

In order to reduce the risk for damages, preventive measures need to be implemented. The damage chain is a complex system of which it is impossible to achieve a complete understanding before preventive measures need to be decided upon. A wrong understanding of the risk for damage will lead to two major project risks: (1) neglecting to take action when there is a risk of harmful groundwater drawdown and subsidence, and, (2) taking action when there is no risk of harmful groundwater drawdown and subsidence. In an economic context, the first risk is associated with costs due to damage, and the second with costs for unnecessary mitigation measures.

The damage chain at the study site for the case study of City-Link is conceptualized in terms of soil stratification, hydrogeology and geotechnics. For the soil stratification, the following distinct layers can be identified: postglacial sand, filling material or organic deposits; glacial and postglacial clay; coarse grained glacial material (glaciofluvial sand, glacial till); rock surface. The leakage to the planned tunnel will occur through fractures in the bedrock. This leakage causes a pressure head reduction in the confined aquifer in the coarse grained material. The pressure head reduction gives a pore pressure reduction in the clay layer and causes subsidence.

As a support for making decisions regarding preventive measures and as a basis for communication of risk, we have developed a probabilistic soil-stratification and subsidence model. The area modelled covers about 1 km distance on each side of the City-Link tunnel. The soil-stratification model is based on more than 20,000 borehole logs collected from various geotechnical reports. After a first check and correction, a MS Access database is built to code all the data in a common referential. From the boreholes, a three-dimensional soil stratification model is constructed with a novel method recently presented in Engineering Geology journal (Sundell et al., 2015b). Compared with other methods, our method makes it possible to combine data with different types of information. Moreover, it can efficiently handle large amounts of data, require little manual adjustment, can easily be updated when new information is added and provide uncertainty bounds for the different stratification layers at each location of the modelled area. The probabilistic soil-stratification model is a useful tool to determine the probability for compressible sediments at locations with risk objects (i.e. sensitive constructions).

The soil stratification model, together with information on drainage conditions and existing hydraulic boundaries such as groundwater recharge, forms a conceptualization of the groundwater flow system. With information on hydraulic conductivity from hydrogeological field-tests a conservative impact area for the drawdown in the confined aquifer was estimated. In future research method development is planned for combining the soil stratification and subsidence model with a probabilistic groundwater model.

To estimate the risk for subsidence over the model area, the soil-stratification model is combined with a probabilistic subsidence model (Sundell et al., 2015c). Predictive calculations for subsidence with compression parameters obtained from sampling points are typically assumed to be valid for small areas close to the sampling point itself. Compared with the modelled area, the number of sampling points in the case study is low (CRS evaluated piston samples from 38 locations). As a result of the low sampling density, neither spatial correlations nor correlations to other known factors were found. Due to this, all data is considered to belong to the same population. For the probabilistic model, the data is detrended, transformed to normal distributions and dependencies among the compression parameters are taken account for by a regression analysis.

Groundwater drawdowns of 0.5, 1 and 2 meters are used for describing the additional effect in the soil profile. In each model analysis a soil profile is first simulated at every calculation point (one point every 10 meter), then the compression parameters are simulated and the ground subsidence calculated. This process is repeated for 1000 iterations at about 800,000 calculation points. With the obtained calculation result, a risk map of where a groundwater drawdown could be expected to cause subsidence is created. The risk area is defined as calculation points where the 95th percentile of the simulations shows a land subsidence exceeding two centimetres. In addition to the risk map, constructions with sensitive foundations are added. With this information, the project-owner of the City-Link tunnel is able to: prioritize monitoring of groundwater heads, pore pressure and subsidence; prioritize safety measures such as infiltration; and communicate the risk to authorities and stakeholders.

In addition to the planned establishment of a refined hydrogeological model, we plan to develop the subsidence model to include soil creep. Moreover, a model for estimating the economic consequences and calculating the risk, i.e. the expected cost, of groundwater-induced subsidence, will be developed to improve decision support.

Sundell, J., Rosén, L., Norberg, T., Wladis, D., & Alén, C. (2015a). *A framework for risk assessment of groundwater drawdown induced subsidence*. Paper presented at the International Symposium on Geotechnical Safety and Risk (ISGSR2015), Rotterdam, the Netherlands. http://ebooks.iospress.nl/book/geotechnical-safety-and-risk-v

Sundell, J., Rosén, L., Norberg, T., & Haaf, E. (2015b). A probabilistic approach to soil layer and bedrock-level modelling for risk assessment of groundwater drawdown induced land subsidence. *Engineering Geology*. doi: http://dx.doi.org/10.1016/j.enggeo.2015.11.006

Sundell, J., Rosén, L., Haaf, E., Alén, C., & Karlsson, M. (2015c). *A PROBABILISTIC APPROACH FOR CALCULATION OF LAND SUBSIDENCE ON A MACRO-SCALE*. Paper presented at the International Conference on Creep and Deformation Characteristics in Geomaterials, Gothenburg, Sweden.

1000 solutions for a single problem? Multiple benefits of SuDS

Floris C. Boogaard, *University of Applied Sciences (HUAS) Groningen, NL*

Summary
Urbanisation usually leads to degradation of the urban dense area by e.g. soil sealing, air water and soil pollution with the result that humans are exposed to floodings, contaminants and loss of biodiversity. This occurs not only locally, but also at broader scales through long-range transport of air-born pollutants and contaminants in waterways. These degradations hamper the delivery of ecosystem services such as food and water supply, flood prevention, climate change regulation and recreation. Some of the biggest challenges are to bring down city temperatures, fight water shortages, protect homes and businesses from damage by flooding and increase biodiversity within small budgets and timeframe.

Figure 2 examples of problems in the Urban areas: degradation of waterways, heatstress, drought leading to lower groundwatertable and subsidence with results as damage of buildings

Storm water floodings, drought and degradation of waterquality are important issues for most of the developed area in cities. Due to the climate change, these issues may contribute to serious problems in dense urban areas in the near future. Therefore, these issues are addressed in this presentation
'1.000 solutions for a single problem? Multiple benefits of SUDS'.

Focus on urban climate measures as SUDS
Surface water drainage systems that have been developed in line with the ideals of sustainable development are collectively referred to as Sustainable Drainage Systems (SUDS). The stormwater industry has developed and adopted new terms to describe these new approaches including: best management practices (BMPs); green infrastructure (GI); integrated urban water management (IUWM); low impact development (LID); low impact urban design and development (LIUDD); source control; stormwater control measures (SCMs); water sensitive urban design (WSUD) and sustainable urban drainage systems (SUDS).

Appropriately designed, constructed and maintained SUDS are more sustainable than conventional drainage methods because they can mitigate many of the adverse effects of urban stormwater runoff on the environment]. They can achieve this through:

* reducing runoff rates, and reducing the risk of downstream flooding,

* reducing the additional runoff volumes and runoff frequencies that tend to be increased as a result of urbanisation, and which can exacerbate flood risk and damage receiving water quality,
* encouraging natural groundwater recharge (where appropriate) to minimise the impacts on aquifers and river baseflows in the receiving catchment,
* reducing pollutant concentrations in stormwater, and protecting the quality of the receiving water body,
* acting as a buffer for accidental spills by preventing direct discharge of high concentrations of contaminants to the receiving water body,
* reducing the volume of surface water runoff discharging to combined sewer systems, and reducing discharges of polluted water to watercourses via Combined Sewer Overflow (CSO) spills,
* contributing to the enhanced amenity and aesthetic value of developed areas,
* providing habitats for wildlife in urban areas and opportunities for biodiversity enhancement.

Most SUDS use the following techniques for the purposes of sustainable water management: source control, permeable paving such as permeable concrete stormwater detention and infiltration evapo-transpiration (e.g., from a green roof). Some examples of SUDS are:

1. permeable pavements (several types)
2. green roofs
3. bioretention
4. sand and organic filters
5. grassed filter strips
6. grassed swales (dry) and (wet)
7. infiltration trench/soakaway
8. filter drains
9. infiltration basins
10. extended detention pond
11. wet ponds
12. stormwater wetlands
13. sediment trap and oil separator
14. several detailed filtration techniques

Research results quality issues
In order to comply with the Dutch maximum acceptable concentration (MAC) and or WFD standards, SUDS that contain a treatment step with filtration or adsorption can be advised. Two SUDS that are widely implemented in the Netherlands are: permeable pavements and swales. However, the effectiveness of these SUDS is sometimes questioned, especially in the low lying parts of the Netherlands with the soil consisting mainly of clay and peat and its high groundwater tables. Research on the hydraulic performance of these SUDS in the Netherlands is scarce, in particular on their resistance to progressive clogging in the years after implementation.

Research results quantity issues
Research undertaken on (Dutch) SUDS field installations has demonstrated with new, full scale monitoring methods that most of the bioretention swales and permeable pavements tested meet the required hydraulic performance levels even after years in operation and without maintenance (e. g. empty time of swales within 48 hours). The applied methods of

full scale testing of SUDS can easily be applied to observe the hydraulic performance of swales and permeable pavement after years of operation. Innovative monitoring methods and visualization of these experiments using video footage allows real-time observation of the entire infiltration process. Recording these observations in a logbook can provide insight into their demand of maintenance and can also help to improve their design.



Full scale test at swale (left), full scale test at permeable pavement (right), Full scale test at watersquare (right).

CRI Klima 2050 | Risk reduction through climate adaptation of buildings and infrastructure

Tone Muthanna, *Norwegian University of Science and Technology*

Vision

> The Centre for Research-based Innovation (CRI) *Klima 2050* will be associated with excellence within risk reduction through climate adaptation of buildings and infrastructure which are exposed to enhanced precipitation and water flooding. The CRI Klima 2050 will be an effective instrument for the development and implementation of adaptive innovations for the Centre partners and society.

Goals

The CRI *Klima 2050* will reduce the societal risks associated with climate changes and enhanced precipitation and exposure to water flooding within the built environment. Emphasis will be placed on development of moisture-resilient buildings, stormwater management, blue-green solutions, measures for prevention of water-triggered landslides, socio-economic incentives and decision- making processes. Both extreme weather and gradual changes in the climate will be addressed.

The Centre will be recognised for its research training within the field of climate adaptation of the built environment. Through education of graduate students, training of highly qualified research personnel through PhDs and training of professionals in the sector, the Centre will stimulate new solutions and further research and development in the building, construction and transportation (BCT) sector long after the duration of the Centre.

Motivation

The built environment is particularly vulnerable to climate change. If climate adaptation is not addressed now, the predicted effects of climate change will have a profound negative impact on society. The construction industry is a pillar of the Norwegian economy as the second largest mainland sector and by far the most important regional industry. The industry has a gross revenue of more than 200 billion NOK (Goldeng & Bygballe, 2013). The construction sector contributes 15% of the Norwegian onshore economy and will during the next 25 years create values worth 5000 billion NOK, currently equal to the *Norwegian Government Pension Fund Global* (“Oljefondet”).The BCT sector is a service provider for everyday activities, and is as such a key to the quality of life. The BCT sector needs to rethink its needs and practices for profitable investments to adapt to future climate-related challenges.

A multidisciplinary approach

Efficient and sustainable climate adaptation of the built environment will be achieved through close interaction between several different disciplines and stakeholders, represented by the Centre partners. This is a complex and impending scope, and the solutions must by necessity integrate a range of disciplines and skills - from research in meteorology, climate change and natural hazards, through practical innovation and applications in urban architecture and the construction industry, and culminating in adaptation and implementation through societal planning. The consortium partners represent research institutes, public authorities as well as major public and private organisations within the Norwegian BCT sector. Together they have significant and complimentary interdisciplinary expertise providing the technical breadth and depth necessary to achieve the vision. This local expertise will be further strengthened by drawing on collaborative partners from abroad. The research will add value by developing new and innovative solutions and processes, integrating and enhancing the expertise of the partners and stakeholders.

References

Goldeng & Bygballe (2013). *Building, construction and property industry's importance to Norway - update 2013.* Rapport 1/2013, Handelshøyskolen BI, Senter for byggenæringen. In Norwegian.

Changing relationships: Accessing Subsurface Knowledge (ASK) project UK

Helen Bonsor, *H. British Geological Survey, United Kingdom*

The need for cities to make more effective use of the subsurface on which they stand, is increasingly being recognised in the United Kingdom (UK), and further afield, to be essential for future cities to be sustainable and more resilient. However, city planning worldwide remains largely 2D, with very few cities having any substantial subsurface planning, – the cities of Helsinki, Montreal, and Singapore being rare exceptions. The consequences of inadequate consideration and planning of the subsurface, and limited re-use of available data, are much more far-reaching, in economic, environmental and social terms. There are clear spatial correspondences between proximity to vacant and derelict land and areas with the poorest health and greatest deprivation in UK cities. And, poor understanding of ground conditions is widely recognised as the largest single cause of construction project delay and overspenditure across Europe.

Despite the development of 3D subsurface models by geological surveys and within the private sector, there remain fundamental knowledge gaps and disconnections in data usage, which inhibit local authorities, national government, geological surveys and research institutions, to unlock, and de-risk key areas of urban development. Planners are often not aware of the opportunities held by the subsurface for urban development; what data need to be acquired during the planning process to assess these opportunities or how these data should be mapped through the planning process. Equally, there is insufficient awareness and understanding in geological surveys and research organisations, as to what subsurface data is required by city planners, in what formats, and at what stages in the planning processes. The effect of these data and knowledge gaps are exemplified by there being no systematic local or national planning guidance for the subsurface environment in the UK. And critically, there is little re-use of any subsurface environmental data generated within urban areas for development, by either the local authorities, private sector actors, or regulators, or geological surveys.

In the UK, data and knowledge transfer between public and private sector stakeholders is now beginning to change. Glasgow City Council (GCC), – the UKs second largest unified local authority, is the first in the UK to explicitly acknowledge subsurface planning within its City Development Plan (CDP), and the City is working to develop the UK’s first statutory guidance to urban subsurface planning, and a wholly new three-dimensional (3D) planning mechanism. This is underpinned by changes to procurement and ingestion of standardised digital subsurface data from urban redevelopment to national government data centres.

Initially championed by Glasgow, the initiative is now spreading across the UK. National sector stakeholders (public and private) (e.g. Transport Scotland, Scottish Water and major UK consultancies) are strongly engaging with this process, and the Scottish and Welsh Governments are identifying shared opportunities to embed the work into appropriate national policy and procurement requirements, and assist the up-scaling and wider adoption of the knowledge transformation at City-region and national scales.

The work is now being supported by a three-year "Knowledge Exchange Fellowship" from the UK National Environmental Research Council (NERC). This is facilitating the essential co-production of understanding between national research and data centres, with public and private sector data users, for appropriate subsurface data and knowledge to be mapped through urban planning and decision making processes, both at city- and project scales, and to re-use these in the future. In this presentation we will discuss the lessons learnt so far, the changing relationships in the UK, and key challenges.

From Hydro/Geology to the Streetscape: Evaluating Urban Underground Resource Potential

Michael Robert Doyle

PhD candidate in Architecture and the Sciences of the City, Deep City Project, Laboratory for Environmental and Urban Economics (LEURE), Swiss Federal Institute of Technology, Lausanne

Despite a persistent call for a greater recognition of the underground in urban planning practices, cities still tend to address underground resources only when the need arises. Historically, this has proven costly for cities that have neglected the potential synergies and conflicts between, for instance, urban aquifers and underground infrastructure systems or building foundations. For urban planning to remain in a paradigm of needs to resources risks rendering conflicts between urban underground activities irreversible and possible synergies unattainable. Researchers and practitioners from multiple disciplines argue for the many benefits of underground development—alternative renewable energy and drinking water sources, additional urban space and reusable geomaterials. Visualizing underground resource potential in order to make it accessible for a planning team proves particularly challenging. Existing mapping methods tend to focus only on underground space development in contexts where the needs for the underground are already urgent. Furthermore, they do not explicitly engage with the distribution of existing land uses. As an alternative to existing methods, this communication will present a procedure for mapping underground resource potential that incorporates four resources—space, groundwater, geothermal energy and geomaterials—developed by the Deep City project at the Swiss Federal Institute of Technology in Lausanne. Geological data serve as the starting point for the mapping process, which progressively incorporates other spatial information readily available, from the location of aquifers to variations in geothermal conductivity. The author's doctoral work, situated within architecture and urban planning, seeks to advance the method to a regional scale, incorporate a spatial analysis of the surface built environment, improve upon the use of the Analytic Hierarchy Process and Ordered Weighted Averaging for incorporating the knowledge of local experts, and to generate a specific series of maps that allow a planning team to better account for the region's underground resource potential. San Antonio, Texas, a city with a complex relationship to an underground aquifer system but current little need and support for underground space, serves to illustrate the mapping method. Two future surface light rail and bus rapid transit lines, presented in recent planning reports, are examined in light of a latent but as yet untapped multi-resource underground potential.

Advisors:
Aurèle Parriaux, prof. Emeritus of Geology; Philippe Thalmann, Prof. of Economics.

POSTER PRESENTATIONS

Land subsidence monitoring in Rafsanjan plain, southeast Iran from multi-sensor InSAR data

Roghayeh Shamshiri[1], Mahdi Motagh[2], Hossein Nahavandchi[1], Hans-Ulrich Wetzel[2], & Bahman Akbari[3]

[1]*Department of Civil and Transport Engineering, Norwegian University of Science and Technology,* [2]*GFZ German Research Centre for Geosciences, Potsdam, Germany,* [3]*Forest, Range and Watershed (FRW) management organization of Iran*

Overexploitation of groundwater resources leads to reduction of pore pressure and results in consolidation of soil layer and ground surface subsidence. In Rafsanjan plain, southeast Iran, the unrestrained pumping of water from the aquifer for agriculture and industry development has caused a decline of the mean groundwater level by at least 15 m over the past three decades. This work presents the subsidence results of the area due to the depletion of the aquifer obtained by exploring Synthetic Aperture Radar (SAR) data archive of Envisat and ALOS, between March 2004 and November 2010. Twelve Envisat ASAR data in a descending track covering March 2004–June 2006, twenty-three Envisat ASAR data in an ascending track covering June 2004–August 2007, and ten ALOS PALSAR data in an ascending track covering December 2007–November 2010 are used for the small baseline (SBAS) time-series analysis implemented in StaMPS software (http://radar.tudelft.nl/~ahooper/stamps).

InSAR survey reveals an area of about 1000 km^2 of the plain showing subsidence of more than 5 cm/year, and locally exceeding 30 cm/yr. The subsidence is limited in its spatial extent to the agricultural land and is bordered by Quaternary faults in the basin. Close to the bounding Quaternary faults, regions with significant differential and horizontal motion (> 20 cm/yr) are found. Field survey in the year 2015 also showed a fracture zone with 200-300 m wide and less than 3-4 m deep tension cracks and gully erosions exists adjacent to the faults.

Groundwater as a resource for heating and cooling purposes

Marit E. Sandbakken

MSc student in Hydrogeology at Norwegian University of Science and Technology

Ground source heating make use of heat stored in the soil, bedrock or groundwater. By using a heat pump, energy stored in the ground is transformed for heating and cooling purposes in buildings.

This study is a part of the project: *Optimal Resource extraction of groundwater for heating and cooling in Melhus and Elverum municipalities (ORMEL)-*. The aim of the project is to provide an improved understanding of the aquifers in Melhus and Elverum and how they interact with the rivers Gaula and Glomma.

The aquifer in Elverum consists of fluvial and glaciofluvial deposits, dominated by sand and gravel. The deposit is thick, - up to 20-30 m in some parts, and has a high porosity and permeability, which results in a high infiltration capacity. There are also alluvial deposits in the area with thicknesses of 10-25 m. The fluctuations in groundwater heads are mainly controlled by the water flow in Glomma, but there are also some unconfined aquifers where the fluctuations are mainly controlled by precipitation.

In Melhus, a gravel deposit with brackish water is used as the groundwater source. A thick marine clay layer covers the gravel deposit. In parts of the valley around the river, fluvial deposits from Gaula, cover the clay layer. The river has evolved in the valley during the isostatic uplift which has taken place over the last ten thousand years. Many avalanches have occurred in the area, which characterizes the distribution of sediments. Parts of a frontal moraine, called Melhusryggen, are located in the centre of Melhus.

How much geothermal energy withdrawn from the aquifer is controlled by two parameters:

1. Groundwater temperature
2. The aquifers thickness and their conductivity

For this project, the latter is the most important factor. A 3D groundwater model for both study areas will be developed by the use of SubsurfaceViewer® and Modflow®. The 3D models gives a better description of the hydrological and sedimentological properties of the groundwater reservoir. An estimate of the size of the groundwater reservoirs and the potential for extraction of groundwater from these, will also be explored.

Data from NGUs map of quaternary deposits, existing wells and various geophysical measurements (GPR, seismic, 2D resistivity, gravimetry) is used to establish the two models. LiDAR data are used to create the digital elevation model.

Bryggen World Heritage Site

Restoring the water balance in order to counteract subsidence and decay

J. DE BEER, A. SEITHER [a], H. MATTHIESEN [b], F.C. BOOGAARD [c], R. DUNLOP [d], J.A. JENSEN [e], M. VORENHOUT [f] and A. CHRISTENSSON† [g]

[a] Geological Survey of Norway
[b] National Museum of Denmark
[c] Technical University Delft, Hanze University of Applied Sciences Groningen and TAUW Consultancy, the Netherlands
[d] Norwegian Institute for Cultural Heritage Research
[e] Multiconsult AS Bergen, Norway
[f] MVH Consult, the Netherlands
[g] Directorate for Cultural Heritage in Norway

Documentation of archaeological deposits and constructions in a section at Bryggen.
Photo: Universitetsmuseet i Bergen, UiB

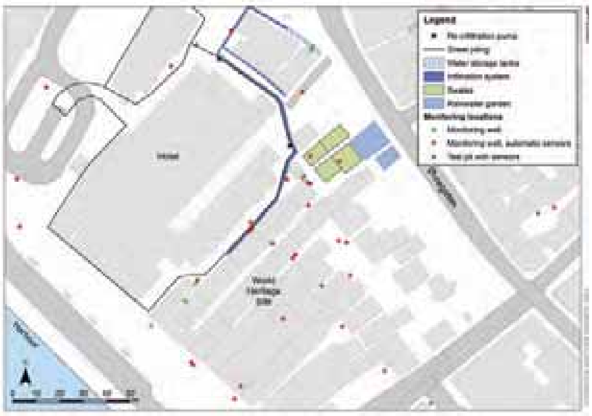
During the last decade, unique multidisciplinary investigations have been carried out to understand and counteract the subsequent deterioration of archaeological deposits and historical buildings at Bryggen in Bergen, Norway.

SUBSIDENCE

Lowered groundwater levels have caused compaction of the ground and decay of archaeological deposits underneath Bryggen. The damage to the World Heritage Site and neighbouring areas is substantial.

MITIGATION

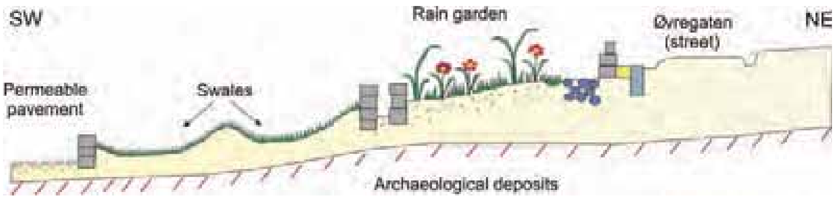
In september 2011, a large-scale mitigation project was started to improve conditions for the preservation of the organic archaeological deposits. The measures are focused on increasing and stabilizing groundwater levels and soil moisture content in affected areas. The main mitigation target is to create a hydrological divide between the area where urban development has disturbed the local water balance and the affected areas at Bryggen that are characterized by poor preservation conditions.



Overview map of mitigation measures carried out by the Groundwater Project, including locations of monitoring wells for measurement of groundwater level, temperature and sampling. Mitigation measures consist of a "treatment train" made up by rainwater gardens, green swales, permeable pavement and a subsurface infiltration/transport system with storage facility and re-infiltration of groundwater.
Map: Anna Seither, Geological Survey of Norway.

Permeable pavement and adjustment of the terrain surface stimulates local infiltration of storm water runoff. On the left hand side, green swales are visible that actively store and infiltrate rainwater.
Photo: Johannes de Beer, Geological Survey of Norway.

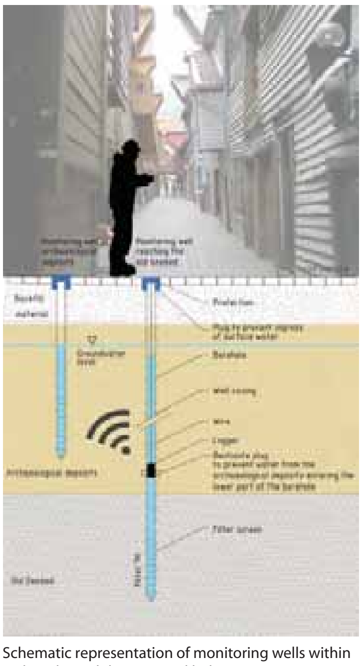
Subsidence in the archaeological deposits underneath Bryggen has caused severe structural damages to the historical wooden buildings.
Photo: Johannes de Beer, Geological Survey of Norway.



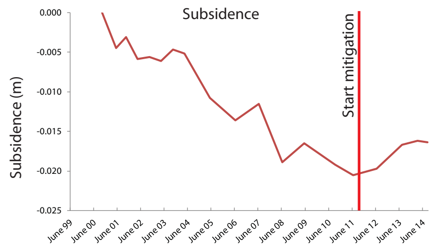
Section of the sustainable water management "treatment train", with rainwater garden, swales and permeable pavement.
Drawing: Johannes de Beer, Geological Survey of Norway.

MONITORING

The initial baseline study at Bryggen included measurements of oxygen, groundwater levels, subsidence rates, soil and groundwater temperatures, redox-potential as well as soil - and stormwater chemistry. After risk assessment and mitigation, a long-term environmental monitoring programme will now document the solutions' performance and their effects on the preservation conditions.



Schematic representation of monitoring wells within archaeological deposits and below.
Drawing: Inger Hageberg, Multiconsult AS

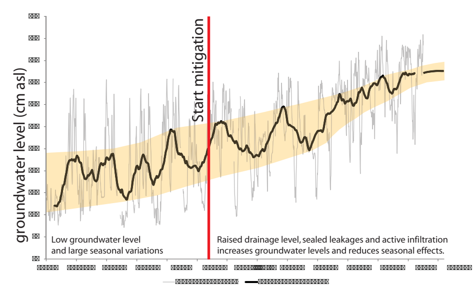


Development of subsidence at point near monitoring well MB21 at the back of Bredsgården/Bugården, downstream of swales.
Graph: Jann Atle Jensen, Multiconsult AS

CONCLUSIONS

The use of sustainable water management solutions specifically targeted on improving in-situ archaeological preservation conditions is an innovative approach with multiple benefits.

The used methods are designed to be resilient in the face of climate change, and can easily be modified for implementation in other Norwegian centres and abroad.



Groundwater level in monitoring well MB21. The grey line shows daily variations of the groundwater level. The black curve gives a simplified impression of the groundwater level, by showing average values over three-month intervals.
Graph: Anna Seither, Geological Survey of Norway

READ THE BOOK

Download the free pdf of the book and read more about the rescue mission: http://brage.bibsys.no/xmlui/handle/11250/300104

Monitoring, Mitigation, Management - The Groundwater Project - Safeguarding the World Heritage Site of Bryggen in Bergen.
Riksantikvaren, 2015. ISBN 978-82-7574-084-5.

PRESENTATIONS
February 4th

Hydrogeological research and education in Norway 2015-2020

Kevin Tuttle[1], Helen French[2], Per Aagaard[3] & Pål Gundersen[4]

[1]IAH Norconsult, [1]Norwegian University of Life Sciences,[2]University of Oslo, , [3]Geological Survey of Norway

Groundwater is a critical resource for municipal water supply as well as agriculture, and one has to expect increased global demand for this resource in the future. Norway is naturally favored with sufficient surface water in most places, but groundwater bodies in Norway generally supply a better and more reliable water quality. Thus, many municipalities use groundwater as the main drinking water supply. Groundwater is also crucial for reliable water supply in many rural areas. From the mid-nineteenth century and up to the turn of the millenium hydrogeologists had a very good reputation for their groundwater knowledge. They facilitated the provision of clean groundwater in sufficient quantities for a large number of waterworks and individual households, particularly farms.

Over the last few decades, the development of new groundwater-based waterworks has slowed down. However, society has become more influenced by other aspects related to hydrogeology. One sees that measures like trenching, drainage, various building projects, tunnels and other infrastructure, have influenced or been influenced by groundwater. We now experience the consequences in the form of e.g. landslides, settling injuries and the destruction of archaeologically valuable cultural layers. And the effects may occur at considerable distances and time spans after the measures. Extensive geotechnical investigations are usually performed prior to the projects, but hydrogeological assessments on the effects in the natural or human environment do not get similar attention.

Simultaneously hydrogeological methods and equipment, including mapping services, software and modeling tools, have also undergone a rapid development and represent new opportunities. The increased utilization of geothermal energy also requires increased understanding of groundwater systems in soils and bedrock. Hydrogeology as a discipline is therefore in a situation where education, research activities as well as data collection and data availability does not necessarily respond to society's *current* needs.

The project[*)] we present here aims at assessing an overall status for the Norwegian hydrogeology discipline. We will also present our recommendations on how to develop research, education, data/maps as well as how to get aspects of hydrogeology properly taken into account in society in general. The project is a follow up of the Norwegian Research Council (NFR) initiated geological evaluation project from 2011 and 2014.

The following main topics and proposals are considered most important:

Hydrogeology in the early stages of planning and decision making

The significance of groundwater is not sufficiently understood during the development of urban areas and infrastructure projects in general. Hydrogeological expertise is especially not incorporated sufficiently into the critical early phases of planning and decision making.

Professionals in the field should therefore cooperate to develop better information material and a dissemination strategy. In the future hydrogeological considerations must be emphasized sufficiently and utilized by decision-makers in the appropriate phase of projects.

Priority areas

Three fields of hydrogeology is considered especially important for the Norwegian society: 1) Urban hydrogeology, 2) Building constructions in bedrock and soils, and 3) Natural hazards (landslides and floods). These areas require both understanding of the interaction between groundwater and rock/soils, and how saturated/unsaturated zone affects the stability of slopes/mountainsides. Groundwater in crystalline and metamorphic rocks will be especially emphasized.

Research group

Additional costs may reach tens of millions NOK in projects when potential problems related the groundwater is not considered. The potential benefit to society is therefore significant in terms of developing relevant education and research projects. We propose the establishment of a working group that will work to ensure that future research programs are developed and utilized.

Education

The present hydrogeology education at Norwegian colleges and universities are few and vulnerable and mightbe weakened. This is due to internal competition with other disciplines as well as the fact that many of the most experienced hydrogeologists have recently retired or will reduce their position. Some of these full-time university positions may not be replaced. The education offered at each institution is to a certain extent dictated by the curricula of the associated disciplines. The social benefit of emphasizing the hydrogeology is at the same time probably more significant than ever, but to a greater extent as part of interdisciplinary issues where the hydrogeology currently is not emphasized sufficiently.

As a result the hydrogeology does not have the adequate priority as a separate field within higher education in Norway. It is proposed that a special education committee should be established. This committee should have a regular dialogue and annual meetings to coordinate needs competancy and education. Continuous revision and communication about learning goals and plans should be based on the tasks that graduated hydrogeologists are expected to solve in society. Moreover one must argue for an increased capacity to develop and offer field trips at the national level. Other important tasks will be: a) coordinate educational programs between institutions, b) establish requirements for the title ***Hydrogeologist***, c) further develop and disseminate teaching associated within the *priority fields* (see above) as well as GIS, 3D/4D-modelling and geothermal wells, d) build mutual knowledge about subjects and fields that the students might be able to collaborate with later in their career (e.g. geology engineering, geotechnique, hydrology and limnology).

Data and information

As of today data delivery to the national database for groundwater (GRANADA) is well established and the national database for subsurface surveys (NADAG) is recently constructed and is now being loaded up with old and new data. Quite a lot of information about underground objects and geology is also available through municipal archives. But we are still far from a situation where all relevant data that is generated from, or could be used by, hydrogeologists are recorded, registered, stored, processed and made available in an optimal way. We propose the establishment of a working group that will work with the implementation of conclusions from this project to further coordinate data flow, maps, practices, laws etc.

Website

Even experienced hydrogeologists and users of hydrogeological knowledge does not have the full picture on who possesses special expertise, where equipment might be located and available, which hydrogeological education is offered at the different institutions, and so on. We recommend to enhance cooperation through the establishment and maintenance of a website. This can contain news, articles, IAH-information (revised) groundwater related guides and reports relevant calls for proposals (NFR/ Horizon 2020), list of websites, Norwegian hydrogeologists and their expertise, equipment, etc. We suggest that such a website is created and filled with information from a broad panel of hydrogeologists and institutions.

*) The project consists of seven partners: NMBU, UiO, NTNU, UiB, NGU, NIBIO (formerly Bioforsk) and NVE. IAH has also contributed significantly, espesially to the identification of community needs. The project started in March 2015 and will be reported by the end of February 2016. The preliminary conclusions of the work will be presented and discussed during the 25th Seminar on Hydrogeology and Environment, February 3 to 4, 2016 at NGU. The seminar will thus be the last opportunity for participants to influence and shape the conclusions of the report. We believe the project could create positive effects for the discipline of *Hydrogeology* for many years to come. Input before, during or after the seminar will therefore be very valuable. The project receives financial support from NFR.

Maps as a tool for information exchange between geoscientists and decision makers

Ane Bang-Kittilsen

Geological Survey of Norway Norwegian University of Science and Technical, Trondheim, Ph.D. student

Background

There is a lack of use of hydro geological knowledge in urban management. In Norway, the project at Bryggen in Bergen is a good example where the importance of using this knowledge has been justified (Rytter and Schonhowd, 2015). The geological survey of Norway has over the last decade worked systematically to increase the use of existing geological maps in area planning. Urban geology, where detailed mapping and standardized maps are missing, has been chosen as the focus of this study.

The need for more and better maps and visualizations in order to improve the awareness and communication of geologic information is widely recognized. The aim of this study is to facilitate wider comprehension of the sub-surface urban environment through improving the use of maps.

The goal is to contribute to cartographic theory through methodological recommendations for visualizing sub urban geology effectively through maps.

RQ1: What are the main challenges and possibilities when making sub urban geology maps?

RQ2: What guidelines can be suggested to contribute to better and more effective maps?

The project title of the Ph.D. project is "The use of maps for studying and communicating information about sub urban geology".

Methods and results

To study challenges in production and usability of geologic maps, multiple cases are selected. The first is subsurface geology in the area of Bryggen in Bergen. The cases chosen are ongoing projects at NGU.

Maps will be developed in collaboration with the project members. A usability and qualitative analysis based on interviews, cartographic evaluation, idea sketches and analysis of mental maps will be conducted. Informants will include both project team members and non-expert users. Important technical and resource factors that influence the result and usability will be identified and discussed.

Expected resulting guidelines are development of a series of maps from simple, traffic light maps drawing attention to possible problems that should be addressed, to complex 3D exploratory maps and data showing possible cause and effects. In the one end a design work process should be followed, focusing on communicating simple messages as clear as possible. In the other end the work process should be more exploratory and data-driven. Guidelines on how to pursue graphical excellence and make effective maps will be emphasized, to convey the information in the data best possible, through focus and use of graphic and cartographic theory. The simple maps should be incorporated in decision making work flows, like area development plan and environmental impact assessments with guidelines on how to act upon the information communicated.

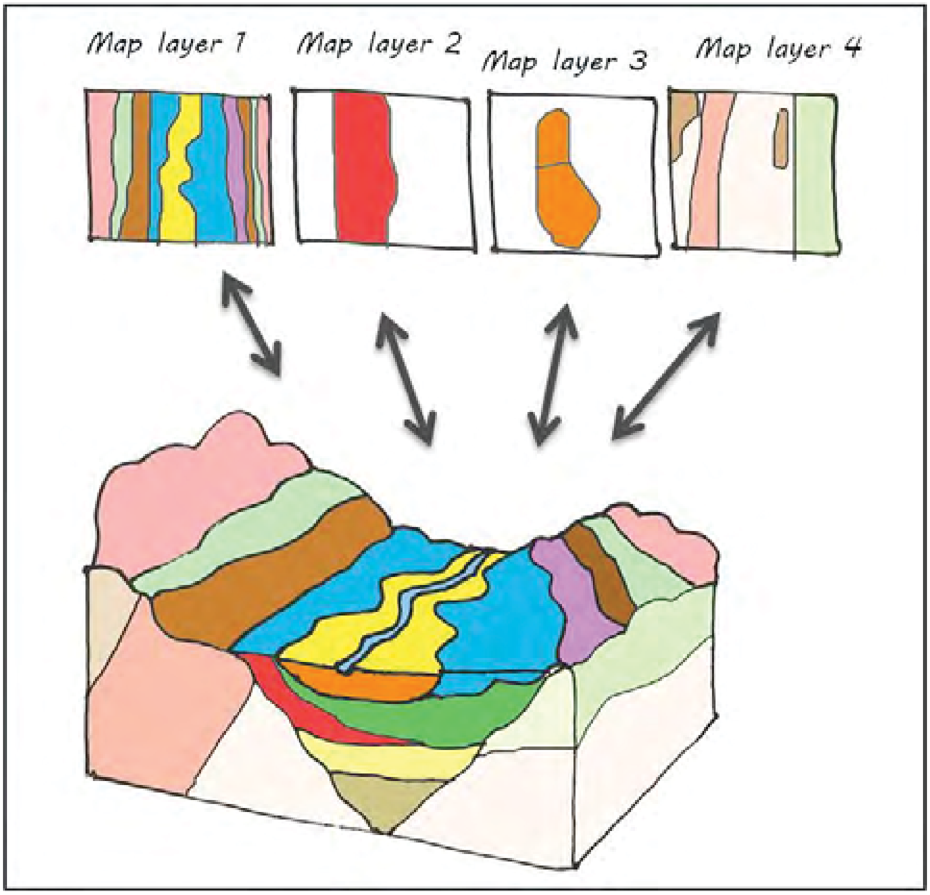


Figure 1: *Joint development of a 3D geological database could be a contribution to a more effective production of tailor made maps.*

References

Rytter, Jens (red.), Schonhowd, Iver (red.) (2015): *Monitoring, Mitigation, Management. The Groundwater Project - Safeguarding the World Heritage Site of Bryggen in Bergen.* Riksantikvaren.

Notes:

Notes:

Notes:

Notes:

Notes:

Notes:

Notes:

Notes:

Notes:

Notes:

GEOLOGICAL
SURVEY OF
NORWAY
- NGU -

Geological Survey of Norway
PO Box 6315, Sluppen
N-7491 Trondheim, Norway

Visitor address
Leiv Eirikssons vei 39
7040 Trondheim

Tel (+ 47) 73 90 40 00
E-mail ngu@ngu.no
Web www.ngu.no/en-gb/