

## **COST Short Term Scientific Mission (STSM) TU1206-16598**

**Improving the delivery and impact of groundwater and wider subsurface data**

**STSM Report to COST MC Chair**

**Review of Database Requirements to Support Ground Water and Integrated Modelling**



**STSM Author:**

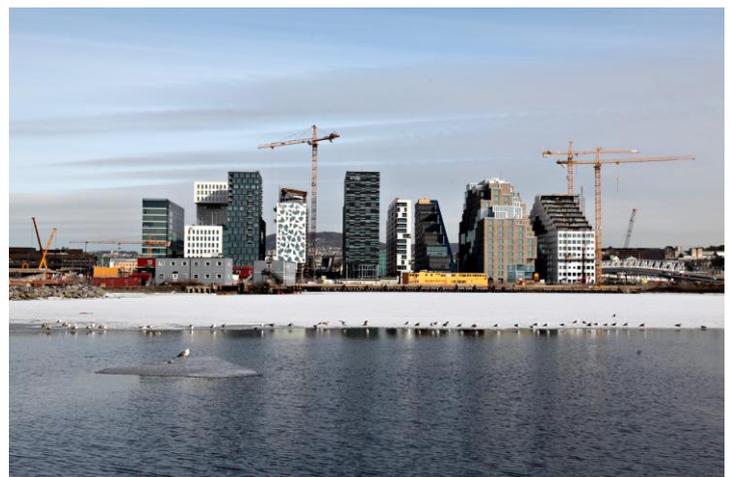
**Andrew Riddick, BGS, Nottingham UK**

**STSM Hosts:**

**Ingelöv Eriksson, City of Oslo, Agency for Planning and Building Services, Oslo, Norway**

**And**

**Johannes de Beer, Geological Survey of Norway, Trondheim, Norway**



\*Cover photographs kindly provided by Oslo Municipality (Rolf Sandnes and André Korsaksel)



**British Geological Survey**  
NATURAL ENVIRONMENT RESEARCH COUNCIL



**NGU**  
Norges geologiske undersøkelse  
Geological Survey of Norway

**STSM report submitted to:**

**COST MC Chair (Dr S. D. Campbell)**

Chief Geologist of Scotland  
British Geological Survey  
West Mains Road,  
Edinburgh, EH9 3LA, U.K.

**STSM reference details:**

COST STSM Reference Number: COST-STSM-TU1206-16598

**STSM Applicant:** Andrew Riddick, British Geological Survey, UK

**STSM Topic:** Improving the delivery and impact of groundwater and wider subsurface data

**Hosts:** Ingelöv Eriksson, City of Oslo, Agency for Planning and Mapping Services, Oslo, Norway

and

Johannes de Beer, Geological Survey of Norway, Trondheim, Norway



**British  
Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



**NGU**  
Norges geologiske undersøkelse  
Geological Survey of Norway

## Acknowledgements

The help and support of Ingelöv Eriksson at the City of Oslo, Agency for Planning and Building Services (Plan og Bygningsetaten) and of Hans de Beer at the Geological Survey of Norway (NGU) in helping to arrange and then hosting this STSM visit is gratefully acknowledged. Other members of the Underground Project in Oslo are also thanked for their valuable assistance during the STSM visit, particularly Bjørg Matre for useful discussions on the underground archive. The use of photographs provided by Oslo Municipality (Rolf Sandnes, and André Korsaksel) in this report is also gratefully acknowledged. A number of other Groundwater and Urban Geology and also Informatics team members at NGU contributed to making this a productive visit. I would particularly like to thank, Anna Seither, Inger-Lise Solberg, and Per Ryghaug at NGU for providing their time for useful and stimulating discussions.



# Contents

<b>Acknowledgements.....</b>	<b>ii</b>
<b>Contents.....</b>	<b>iii</b>
<b>Summary .....</b>	<b>iv</b>
<b>1 STSM Rationale and Purpose .....</b>	<b>5</b>
<b>2 Outline of STSM Activities.....</b>	<b>6</b>
<b>3 Environmental modelling in Oslo – aims and objectives.....</b>	<b>7</b>
3.1 Problems to be addressed .....	8
3.2 Datasets available in oslo .....	10
<b>4 Evaluation of Databases to Support Modelling at NGU.....</b>	<b>13</b>
4.1 National Groundwater Database (GRANADA) .....	13
4.2 National Ground Investigation Database (NADAG).....	13
4.3 Further development of the groundwater database.....	15
<b>5 Data Requirements for Integrated Modelling .....</b>	<b>17</b>
<b>6 Opportunities for on-going and future collaboration .....</b>	<b>20</b>
6.1 Developing the database AND APPLICATION FRAMEWORK to support integrated environmental modelling .....	20
6.2 Further cooperation on integrated environmental modelling .....	21
<b>7 STSM Host institution approval / sign-off .....</b>	<b>22</b>



## Summary

This report describes and documents activities undertaken as part of a Short Term Scientific Mission (STSM) visit to Norway forming part of the EU COST SUB-URBAN project. Visits were made to the City of Oslo department of Planning and Mapping Services, and also the Geological Survey of Norway over the period 24<sup>th</sup>-28<sup>th</sup> February 2014



**British  
Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



**NGU**  
Norges geologiske undersøkelse  
*Geological Survey of Norway*

# 1 STSM Rationale and Purpose

The City of Oslo is developing a project (the underground project) to better understand the interaction of geological environmental processes in the subsurface with man-made infrastructure. Specifically there is an interest in being able to better understand the interaction of groundwater and surface water, particularly since lowering of ground-water levels is having an effect on the foundations of older buildings in a number of areas of the City. Other problems include significant drilling of boreholes for geothermal energy, which occupy space in the subsurface and may therefore hinder the placement of other infrastructure. The City of Oslo Municipal Authority have amassed a significant amount of borehole, geotechnical and groundwater data for the City. Currently much of this data is held in an unstructured form e.g. much of the down-hole borehole data is held in pdf files, and so there is an interest in being able to database this data more effectively. The first part of this STSM visit (2 days in Oslo) therefore was focussed on gaining an understanding of the data issues being experienced by the City of Oslo, and offering experience of the way that BGS has tackled some of these issues.

The City of Oslo is being supported in the Underground Project by the Geological Survey of Norway (NGU) who have expertise in 3D framework and groundwater modelling. NGU have also developed a number of databases to support this work, particularly for groundwater and geotechnical data. The NGU groundwater and urban geology team are now keen to be able to exploit these databases to maximum effect by developing further data retrieval export, and conversion routines to support 3D framework and environmental modelling activities. The two day visit to Oslo was therefore followed directly by a three day visit to NGU in Trondheim during which the focus of discussion was on knowledge exchange around processes for extracting data from the underlying databases. This provided an opportunity to gain a first-hand understanding of the specific modelling requirements of NGU and to demonstrate some BGS tools and workflows which may be able to contribute to these requirements.

Another overarching objective of the STSM was to evaluate the databases available within the City of Oslo Underground Project, and also at NGU to support a future progression to Integrated Environmental Modelling (IEM). IEM involves coupling together different environmental models (often at runtime) in order to better simulate the linkages between real-life environmental systems. A typical example of an integrated environmental modelling scenario would be connecting together a groundwater model to a surface flow model to better understand the potential for infiltration and flooding in the City of Oslo. An important aspect of IEM technologies is that they can provide a predictive functionality by extrapolating current trends into the future. Thus within a wider European city context, there is potential to link for example local groundwater or flooding models to larger scale climate models, and therefore provide an approach to understanding the effects of future climate change on municipal activities. BGS is developing expertise in integrated environmental modelling and thus the STSM also provided an opportunity to explore the potential for collaboration with the City of Oslo and NGU in this area.



## 2 Outline of STSM Activities

The objectives described above in Section 1 were addressed by a two day visit to Oslo to work with the City of Oslo (24<sup>th</sup> -25<sup>th</sup> February 2014), planning and Building services department, followed concurrently by a three day visit to NGU in Trondheim (26<sup>th</sup> -28<sup>th</sup> February 2014).

The Oslo part of the STSM focussed on a number of meetings with members of the Underground project team to understand their requirements in terms of data to support their modelling activities. This included procedures for extracting data from an archive of borehole data (the underground archive), and in integrating together groundwater, pore pressure, and geotechnical data together with information on made-made infrastructure in the subsurface, including water supply pipes, sewerage, electrical cables and gas pipes. There was also an opportunity to present and discuss some aspects of the way in which BGS captures and databases borehole, groundwater and geotechnical data, identifying procedures and data structures that could be used by Oslo City.

The visit to NGU at Trondheim was directed first of all towards gaining an understanding of NGU's existing databases and also discussing workflows and mechanisms to extract data from NGU databases and make this available for integrated environmental modelling. Particular topics covered included:

- An approach to providing a standardised scheme for describing major rock units and lithologies within the unconsolidated Quaternary deposits which form many of the aquifers in Norway. One approach to this might be along the lines of the BGS Lexicon of Named Rock Units created by BGS for the UK.
- Discussion of some database design issues involved in planned extension to NGU's groundwater database
- Mechanisms for extraction of borehole and modelled data in a format that can be used by process modelling tools such as MODFLOW and FEFLOW

These activities are discussed in more detail in Section 3. below.



### 3 Environmental modelling in Oslo – aims and objectives

The Oslo City Municipal Authority have set up the “Underground” project (“Undergrunnsprosjektet”) a major initiative aimed at bringing together all the available sub-surface data for the city, so that this can be linked with infrastructure information and used to solve environmental problems. This project is aimed to address a number of key challenges:-

- The population of Oslo is predicted to increase by 33.2% by the year 2030, leading to increasing conflict of interests over urban planning and use of sub-surface space. There is also a need for more tunnels to be constructed through the sub-surface (several additional tunnels are planned).
- Understanding the impact of an increasing number of geothermal energy boreholes being drilled within the City. Geothermal energy projects provide an environmentally friendly source of heating. However, the drilling of these boreholes does not currently require prior planning approval, and therefore they tend to be drilled in a fairly unregulated way. Geothermal boreholes occupy sub-surface space, and therefore may affect the availability of that space for other infrastructure.
- Lowering of groundwater levels across the City and the impact of this on foundation conditions (discussed further in section 3.1 below). This may be partly related to isostatic uplift, but the primary reasons for changes in groundwater levels are likely to be related to the influence of urbanisation on ground and surface water movement. Therefore there is a need to obtain more detailed information particularly about groundwater movement, in order to better understand these processes.

The Underground Project aims to investigate methods of bringing together all relevant sub-surface information within the Oslo City area, including information required to manage and efficiently utilise the sub-surface, and comply with planning guidelines, as well as meeting security requirements relating to data about essential infrastructure. In order to achieve this with a manageable amount of data, and address some of the key challenges noted above, three test areas have been selected to focus upon, and these are discussed further in section 3.1 of this report. The aim is to develop 3D sub-surface models for the test areas allowing the interaction of man-made infrastructure with geological and other environmental processes to be better understood. Thus the models will incorporate groundwater and other geological data where sufficient data is available. Having developed data capture and modelling methodologies for the three test areas, these methods can then be applied to other areas of the City. The project also seeks to develop methods to manage, plan, utilise and regulate the use of the underground in a more sustainable way.

The Underground Project supports a number of the activities of the Agency for Planning and Building Services, which include implementing Norwegian planning law at a local level (e.g. approval of construction permits) as well as developing an overall city plan, and creating appropriate tools to monitor and regulate use of the sub-surface. A longer term vision of the Underground Project Team is to create a city wide “3D master plan” of the sub surface which can then be evolved as infrastructure develops, to provide a basis for onward planning, and also addressing various often geologically related problems which the city is experiencing. There is thus an aim to bring together the necessary data to undertake various types of environmental and geological modelling.



**British  
Geological Survey**  
NATURAL ENVIRONMENT RESEARCH COUNCIL



### 3.1 PROBLEMS TO BE ADDRESSED

#### 3.1.1 Focus areas for the Underground Project

The rationale within the Underground Project is to focus the collection of data and development of models within three specific areas of the City (shown in Figure 1) which have particular problems. It is hoped that this approach will enable methodologies to be established for addressing similar problems in other areas of the City. The districts of Majorstua, Bryn, and Ekeberg have been selected as focus areas for the project, with an initial emphasis on the Majorstua. These areas have different and contrasting sub-surface issues. The Bjørvika area near to the harbour in Oslo also has some interesting sub-surface issues with the presence of a lot of made ground. However, Bjørvika has a number of complex issues (as described below) and so has not been selected as one of the focus areas. It is anticipated that the methodologies developed for the focus areas can be applied later to Bjørvika.

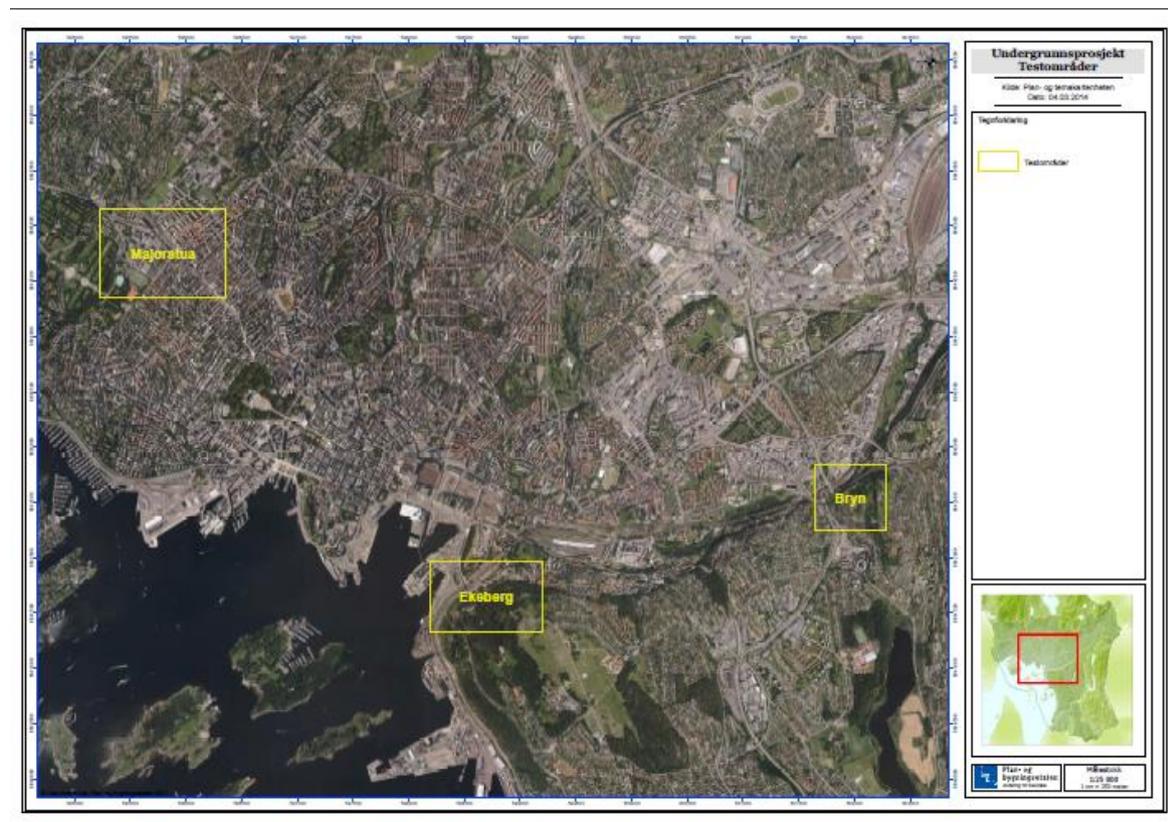


Figure 1. Map of Oslo showing locations of focus areas for the Underground Project

- **Majorstua:** It was common practice during the construction of older brick buildings for the foundations to be built upon wooden “rafts” placed on top of clay deposits. Historically this worked fairly well where the ground water levels were above the wooden rafts . However recent lowering of groundwater in a number of areas of the city has meant that the wooden rafts are now often no longer within the saturated zone, and are thus beginning to degrade. Groundwater levels are lowering in general. The reasons for this are complex and related to a number of factors including less infiltration of precipitation in certain areas due to the increasing paving over of the ground surface with impermeable paving materials, and also the effect of tunnels on

the groundwater system. Isostatic uplift (currently 2-3mm per year in Oslo) may also have some impact on lowering groundwater levels, but is likely to be a secondary cause. In turn the foundation degradation has caused stability problems with cracks developing in walls and the roofline often being affected. The Majorstua area contains a lot of these older brick built buildings and so provides good examples of this problem. There was also a tunnel constructed through Majorstua in the 1980's as part of further development of the Oslo underground system, and there is interest using this to examine the interaction of the tunnel infrastructure with the groundwater regime. There are also two disused metro stations forming voids in the subsurface, which may affect groundwater locally.

- **Bryn:** This is an area of older buildings located towards the eastern side of the city. The stability and settlement problems associated with building on clay substrates are also present here, and there is also presence of tunnels running through the area.

- **Ekeberg:** Located in the south east this area is traversed by several tunnels including a major waste water tunnel, a tunnel providing a culvert for a minor river, and a rail tunnel is planned. The area also contains geothermal boreholes. Good data on sub-surface infrastructure is available from a number of major infrastructure providers, including the companies involved in tunnelling projects, and utility companies maintaining water and sewerage pipes. There is less data available here on environmental and geological processes (few groundwater measurements for example). However the good quality infrastructure information available provides an opportunity to model the integration of different types of infrastructure data.

### 3.1.2 Other issues affecting management and use of the sub-surface in Oslo:

The Bjørvika area adjacent to the harbour in Oslo has experienced significant new building development over recent years. Much of this building has taken place on unconsolidated deposits. These include deposits from rivers flowing out to the harbour which in the past carried with them large volumes of saw dust and man-made wood debris from sawmills up-stream, resulting in often several metres of wood debris within the unconsolidated deposits.

The subsurface in the Bjørvika area contains a significant amount of medieval, mostly organic, deposits. These deposits are automatically protected by law, and are due to the high organic content extremely vulnerable for changes in groundwater level and construction weights.

The combination of made ground and various other unconsolidated deposits tends to result in a lot of settling, the area around Oslo Central Station is a particular example where several millimetres of settlement has taken place over the last few years resulting in damage to the train tracks. Settling rates in the Oslo harbour and station area can reach 3-4 mm per year.

There are a number of underground metro, train and road tunnels which go through the sub-surface in this area, with excess water accumulating in the tunnels sometimes needing to be pumped out to prevent on-going flooding. There is a need to understand the interaction of groundwater and surface water processes in more detail, to be able to address such flooding problems in the long term.

Other more general problems affecting the city include the very frequent presence of geothermal boreholes. Whilst water is generally not abstracted from these boreholes, they do take up sub-surface space, and may restrict the potential to develop other sub-surface infrastructure in these areas. There is no system of regulation or approval for geothermal borehole drilling. There are now approximately 40,000 registered geo-thermal boreholes in Norway.



**British  
Geological Survey**  
NATURAL ENVIRONMENT RESEARCH COUNCIL



Other unconsolidated deposits encountered within the city include various types of clay, including “quick clays” (i.e. clays of marine origin from which the original salt content has been leached or washed away) and which can behave in a very unstable way when a load (e.g. foundations) is placed on them, and therefore these deposits present an important problem in city planning.

There are a number of factors affecting groundwater levels in the city including seepage into the sewerage system, and into various tunnels. Reduced infiltration of precipitation due to increased use of impermeable concrete and asphalt for man-made surfaces is thought to be one such factor. Other activities related to urbanisation such as pumping water from cellars, and the effect of tunnels, as well as water and sewage pipes on groundwater flow are also likely to have an impact. The interaction between these processes, and also between these processes and longer term changes in climate for example may be better understood through the application of integrated environmental modelling techniques.

Oslo has experienced flash floods on several occasions over the last few years, and the Municipal Authority has therefore undertaken detailed elevation modelling of the city in order to construct a surface drainage model. This drainage model is based on a detailed surface elevation model with a resolution of 0.5m. Many of the drainage lines follow old stream courses and sometimes current streams. The surface drainage model also provides a means to predict where infiltration will occur during times of flooding, as well as where discharge and surface water accumulation is likely occur. There is therefore interest in integrating surface water modelling with more detailed groundwater flow models, for example for the Majorstua area.

### 3.2 DATASETS AVAILABLE IN OSLO

- **Borehole data:** The borehole data currently resides in the underground archive located at the City of Oslo Agency for Water and Sewerage Works (Vann- og Avløpsetaten). The archive contains data for approximately 198,000 boreholes in the Oslo area. Much of this data is in pdf format, and key information such as detailed positional information and the depth to bed-rock is gradually being transcribed into an ESRI geodatabase. Typically the boreholes penetrate to variable depth, many just into unconsolidated deposits and some into bedrock. Most having been drilled for site investigation purposes as part of various construction projects.

The data currently being recorded from the pdf files includes data on whether the borehole was drilled down to bed-rock. The presence of sampling points (for example for geotechnical properties) is also recorded. The boreholes themselves are given an identification number based on an internal grid based system for map sheets within the city. The database fields for whether the borehole penetrates bedrock and also for data quality are codified fields making it fairly straightforward to easily identify boreholes with good quality data that penetrate down to bedrock.

Many of the available boreholes contain some information about the lithologies encountered, and sometimes provide some geotechnical or other (e.g. resistivity measurements) data. Typically for the focus project areas described above, the depth to bedrock, and also the depth to ground water (where the latter is available) will have been recorded, and so provides an initial database to support ground water modelling.



So far, staff and time resources have prevented the capture of large amounts of down hole data on thicknesses of lithologies and the more detailed geotechnical and sometimes geophysical data from being extracted for the three initial study areas. However, potentially useful data on which to base for example geological framework models, and supporting data on current ground water levels does exist within the .pdf borehole records.

A test data set of the borehole data from the Majorstua area of Oslo in particular has been used in trial population of the NADAG borehole and geotechnical database being developed by the Geological Survey of Norway (NGU). It is also likely that a proportion of the key data such as depth to bedrock and groundwater levels recorded in boreholes will already be present within the databases maintained by NGU.

- **Pore pressure database:** This database contains approximately 79,000 pore pressure measurements taken between 1954 and 2013, from 1290 locations, including data for the Majorstua area taken during repairs to a broken sewer pipe. This data is currently being integrated with the borehole and geotechnical data for Majorstua via an MSc project.
- **Detailed Digital Elevation Model:** A detailed (0.5m grid) digital elevation model has been constructed for the City of Oslo from laser scan data. This was utilised in the surface water flooding modelling described in Section 3.1 above. This was constructed in 18 sections for different parts of the city to assist processing of large amounts of data and then the sections were joined together to create the complete model.
- **Information about man made sub-surface infrastructure:** Information on the positions of infrastructure such as water and gas pipes, electrical cables and ducts, as well as sewer pipes is maintained and collated on behalf of the City of Oslo (and other users of this data such as utility companies etc) by a commercial company (“Geomatikk”) using a custom designed system called K-Grav. This is a 2D web based GIS system which displays the relative positions of different types of infrastructure down to a depth of c.3m. Organisations wishing to undertake maintenance on any of the gas, electric or sewer networks would make an application to undertake excavations, via this system. The request is routed to the various key organisations involved, so that they have an option to make a comment or to withhold approval for the work. In terms of making data available the infrastructure is available in a 2D GIS format. The K-Grav system does not record the depth from surface to the infrastructure, nor the depth separation between different pipes in the same x,y position. This level of detail is not recorded because often it is not provided by contractors. Where the data is provided there are sometimes questions about how accurate the data is. However the normal practice is to bury infrastructure to a depth of at least 1.8m for protection against frost, and therefore for the purposes of modelling a minimum depth of 1.8 m for pipework, sewers etc. can be assumed.
- **Other potential data which is not currently within the scope of the Underground Project:**
  - Data on radioactivity from black shales is available in the Oslo area. However, currently in the interest of limiting the volumes of data in the pilot areas, and because these levels of radioactivity are under control, this is not being included in the project.
  - There is data available on contaminated ground including levels of contamination of groundwater. This may be used to aid modelling at a later date, but it is considered that this would make the modelling over-complex if introduced at the start of the project.

- There is work on-going on the effects of closing a re-opening older surface water courses and the knock-on effects of groundwater and surface water systems. This is being undertaken within a separate project on surface water, outside the Underground Project.

Whilst this data is not currently within the scope of the Underground project largely due to resources issues. However, the data is available if required at a later date.



**British  
Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



**NGU**  
Norges geologiske undersøkelse  
*Geological Survey of Norway*

## 4 Evaluation of Databases to Support Modelling at NGU

NGU maintains a number of databases which are relevant to geological framework and integrated environmental modelling, and these are briefly described below:-

### 4.1 NATIONAL GROUNDWATER DATABASE (GRANADA)

The database includes the following data pertinent to environmental modelling:

- water levels recorded
- the total depth of the borehole
- depth to bedrock
- x, y coordinates
- purpose of the borehole
- name of the contractor who undertook the drilling
- sub surface geology (mostly for unconsolidated deposits)

### 4.2 NATIONAL GROUND INVESTIGATION DATABASE (NADAG)

The NADAG database has been designed and is maintained by NGU, with some of the associated software development of the interfaces etc. being undertaken by an external company. The database is designed to be a national ground investigation database for Norway as a whole. It will form a central repository for ground investigation data from NGU and other national organisations such as the Roads and Rail Authorities of Norway. The intention is to firstly store geotechnical data in the first release of the system, but then to go on to store other information such as geophysical data for example.

The data model for the geotechnical data is based on the SOSI (Systematic Organisation of Spatial Information) Standard. This means that the data model can be implemented on different platforms including ArcGIS and as in the case of the NGU implementation within an Oracle geodatabase. The methodology is to utilise objects within the SOSI Standard as implemented within Enterprise Architect, and then create the database objects based directly on the UML representations within Enterprise Architect.

The main components of the SOSI data model for geotechnical data are shown in Figure 2. This considers a geotechnical investigation entity which represents the area of study. This may have one or many boreholes, and each borehole may have multiple investigations (for example for different types of analysis) performed upon it.

Current thinking is that to extend the database to hold geophysical and other types of ground investigation data would involve either adjusting that database structure to accommodate these additional data types, or possibly holding geophysical data in a file structure alongside the

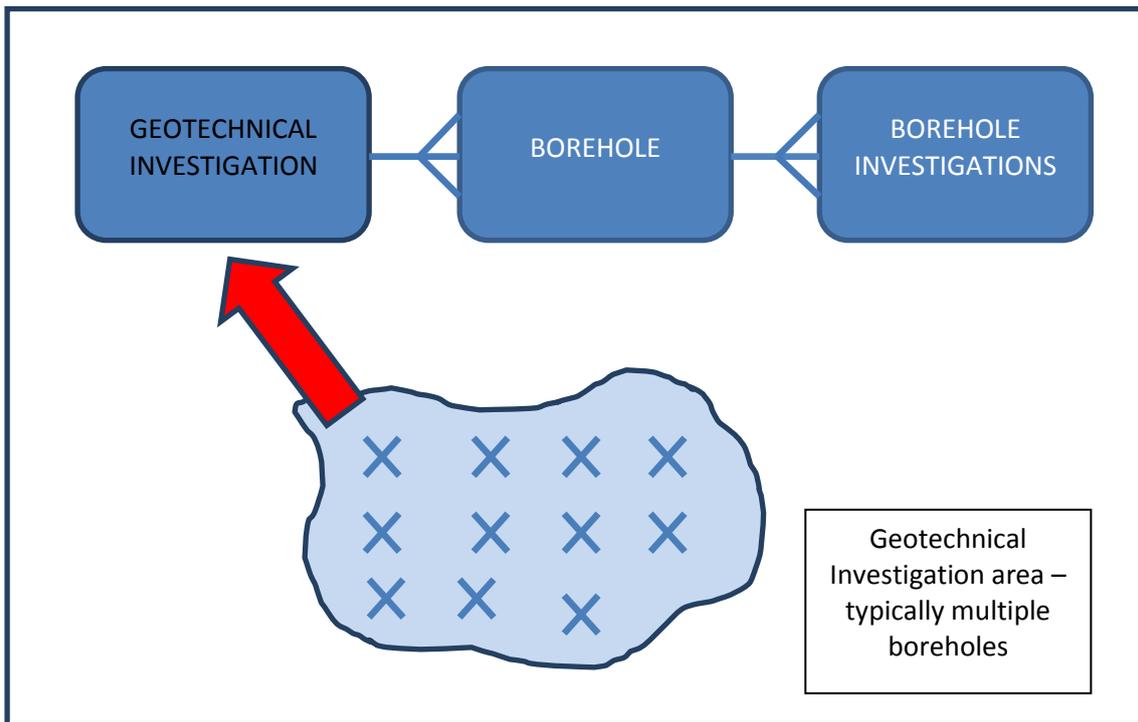


Figure 2. Main components of the NADAG Ground Investigation Database

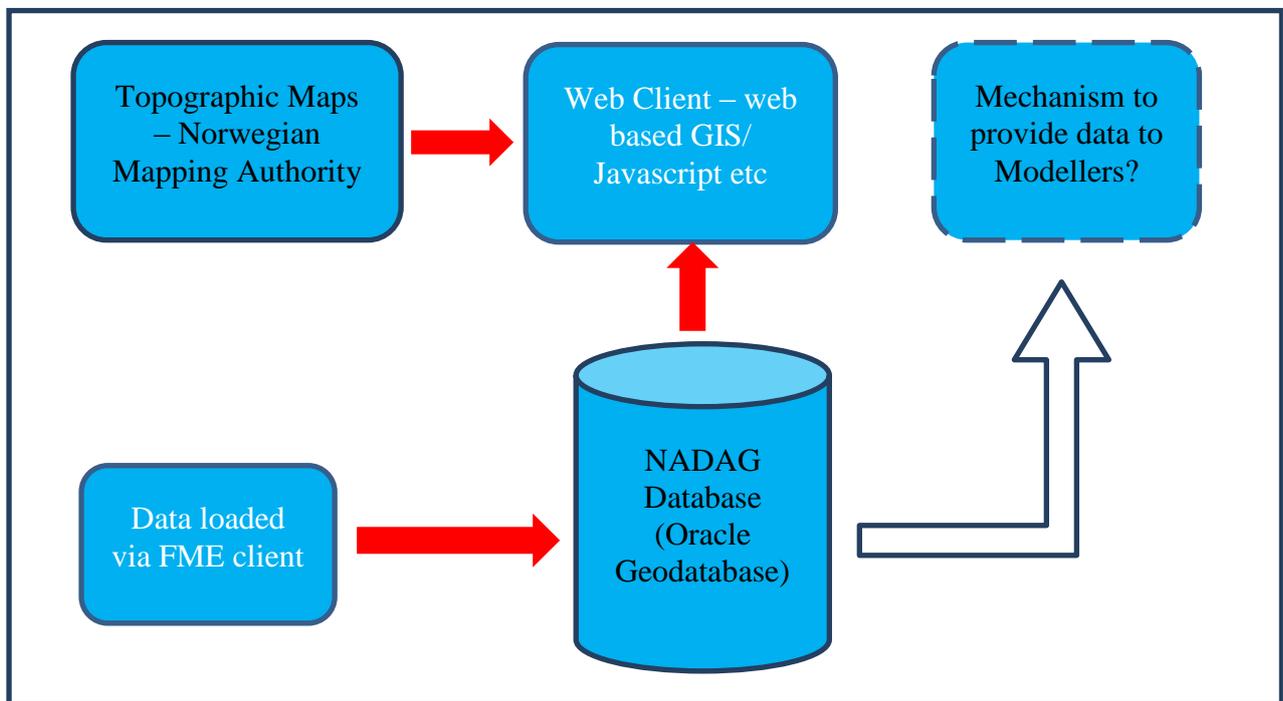


Figure 3. Outline System Architecture for NADAG version 1.0

database. However, based on our experience at BGS, holding some data outside the relational database structure may make it more difficult later to query the NADAG database across different types of data.

The down-hole data available to populate the database is often restricted to data for superficial deposits. The current implementation of the NADAG database is at version 1.0, and the outline system architecture is shown in Figure 3.

Development of NADAG v2.0 is now in progress, and will include additional facilities to allow some smaller companies to upload their data, for example by using spreadsheet templates. The system provides various levels of access:

- Metadata only, essentially borehole position information and who has provided the data.
- Properties of clays and depth to bedrock
- Metadata plus access to the raw data.

The NADAG database is also being tested by the Oslo City Department of Planning and Building Services.

## **4.3 FURTHER DEVELOPMENT OF THE GROUNDWATER DATABASE**

### **4.3.1 Work on extending the database design at NGU**

There is a requirement to extend the groundwater database functionality available in the GRANADA system have an improved groundwater database which could integrate with the NADAG database. There are elements of the SOSI standard which are relevant to groundwater, but an explicit set of UML entities does not exist for groundwater in the same way that it is present for geotechnical data for example.

This is currently being designed, but there is a proposal to have the same sort of hierarchy as for the geotechnical database. That is considering the concept of a “groundwater investigation” by analogy with that of a “geotechnical investigation”. Like the geotechnical data model a groundwater investigation would have one or many boreholes associated with it, and each borehole would have multiple borehole investigations. This approach follows the SOSI standard and is therefore also in line with INSPIRE.

One of the issues in dealing with boreholes in Norway is that borehole density tends to be low, and therefore there is a requirement to extract and store the maximum available information from each borehole.

### **4.3.2 Outline of the main features of the BGS “WELLMASTER” groundwater database**

The key structure of database entities within the BGS WELLMASTER groundwater database is illustrated in Figure 4. In this diagram the main entities within the data model (which approximate to physical Oracle tables in the database implementation) are shown in blue.. The green boxes alongside the entities indicate some of the key database fields which are populated within these entities.

The WELL entity contains what we term index level information about the borehole, its location, the drilling method used etc. This has a “one to many” relationship with the HYDRO\_INDEX



entity which contains information about a group of wells, for example several wells may occur on one map sheet. This part of the structure is then fairly similar to the concept of a groundwater investigation having several boreholes belonging to it in the SOSI scheme.

The GEOLOGY entity contains information such as the details of the geologist making the interpretation together with key units identified, this would also contain an indication of any known aquifer units which have been penetrated. The GEOLOGY then links to the BGS Lexicon of Named Rock Units, in that recognised standard codes for main aquifers and other geological units are recorded. The database is configured so that only valid codes in our Lexicon system can be entered to the ground water database.

Other important concepts are depths to important datums recorded in the borehole, such as water strike and rest water level. Other tables hold data on with recovery of water at points within the borehole, and yield from the borehole on pumping. There is a separate set of tables which record water chemistry data from recovered water samples

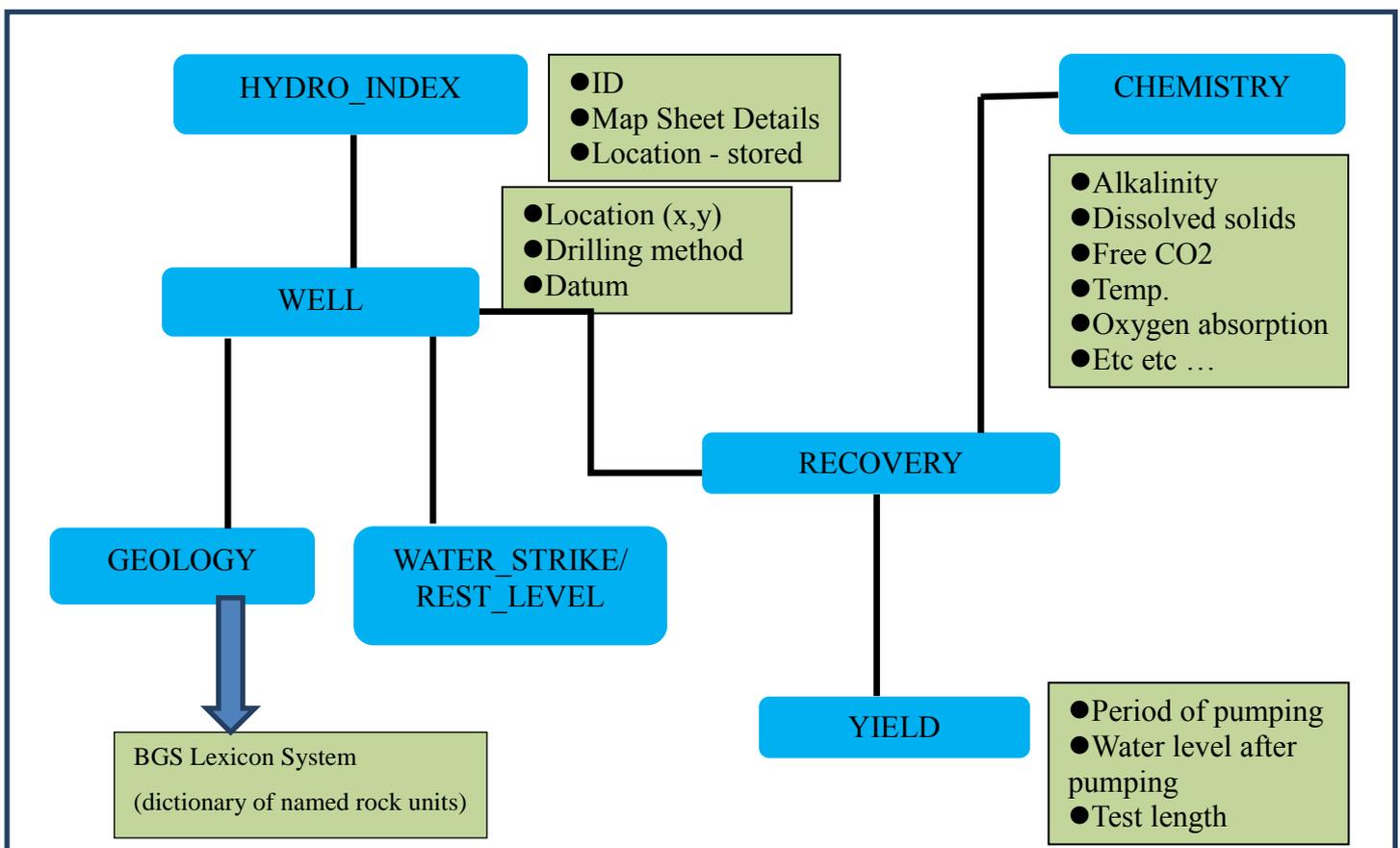


Figure 4. Key features of the BGS Wellmaster (groundwater) database design

## 5 Data Requirements for Integrated Modelling

Currently there are 1296 ground water bodies defined in Norway under the terms of the European Groundwater framework directive. In fact each of these groundwater bodies often contains more than one aquifer. Many of these aquifers are small in geographic area and volume (Norway depends for only c.10% of its water supply on groundwater) but a number may have more significant local importance. Currently NGU are able to roughly define the extent of these aquifers in 2D by using the data from geological mapping, and the GRANADA and NADAG databases, but to provide better estimates of groundwater supply and quality there is a need to be able to make better estimates of aquifer volume. Where for example there are only two or three boreholes through an aquifer this becomes difficult to do accurately and there is therefore an increasing need to be able to model aquifers in 3D.

Previously there was a focus on non-urban areas of Norway for water supply, but there is less knowledge generally on aquifers in urban areas, and this needs to be addressed. In order to meet the requirements of the Water Framework Directive there is a need to include information on aquifers in urban areas, including aquifer volume, quantity and quality of the water supply, and information on risks to the security of the aquifer.

The usual modelling process adopted by NGU involves firstly defining the area to be modelling in ArcGIS then creating the geological map from available data, and then building a geological framework model, usually in GSI3D. To create the framework model borehole data from the GRANADA database is utilised.

The GRANADA database contains approximately 80,000 boreholes. Approximately 4,500 of these penetrate only superficial deposits, whilst the remaining c.75,000 penetrate bedrock. For the wells which penetrate the superficial deposits only there is often a fairly detailed coarse breakdown of the lithologies encountered. There is also often a lack of porosity and permeability data requiring the modeller to make estimates, though pumping test data may be available in some boreholes.

A typical small aquifer scenario involves an aquifer formed from fluvial sediments being flushed with fresh water from snow and ice melting in the spring, and then flushed again in the autumn due to higher rainfall. It is important to be able to understand for example how complete this flushing process is, since complete flushing would tend to ensure recharge by high quality water potentially suitable for human consumption.

Current mapping of unconsolidated deposits in Norway is based on process descriptions, for example of glacial processes. From the perspective of groundwater modelling a particular glacial deposit such as a Till may be quite heterogeneous and therefore there may be a range of hydraulic conductivities. Both fluvial and glaciofluvial deposits are likely to have high infiltration, but two fluvial deposits may have different hydraulic properties. This means that this process based description of unconsolidated deposits is hindering accurate sub-division on the basis of hydraulic properties and so effectively limiting groundwater and integrated modelling.

A standard means of describing the unconsolidated deposits which is based on the lithologies and stratigraphy is required to address this problem. During the STSM meetings at NGU we discussed the BGS Lexicon of Named Rock Units (<https://www.bgs.ac.uk/lexicon/>) which provides a hierarchical dictionary of the main rock units present on-shore within the UK. The



BGS Rock Classification Scheme (<http://www.bgs.ac.uk/bgsrscs>) can be used alongside the BGS Lexicon to provide standard description of lithologies found within the main rock units described by the Lexicon.

Access to information concerning how BGS has approached mapping unconsolidated deposits would also be very useful to NGU. Some more detailed collaboration on the development of a Lexicon structure for the unconsolidated deposits of Norway was identified as a useful area for collaboration, and is discussed further in Section 6. below. Such a standard scheme would allow a translation to be made between the process based classification and a lithological scheme which allows lithologies to be grouped by hydraulic properties. This translation could be initially applied at the stage of 3D framework modelling, and then be applied to groundwater process modelling.

A key requirement for NGU is to be able to easily obtain stratigraphic and lithological data for modelling with x,y,z coordinates, by for example extracting the data from the GRANADA and NADAG databases. The format required is x,y,z and then a property value, the properties could include lithologies plus other parameters such as permeability. It may also be possible to include analogues for hydraulic properties. For example grain size data may be available for some Quaternary deposits from previous projects, and clearly coarser sediments are likely to have greater infiltration capacity, so it may be possible to infer some hydraulic properties from the grain-size data. The preferred procedure is to add the properties at the framework modelling stage, though they could be added at the process modelling stage. The x,y,z and property data derived from the databases would then be exported to an appropriate tool for modelling (e.g. FEFLOW, MODFLOW or ZOOM etc). It will be particularly important to be able to extract data from the NADAG database in this format, since this will be critical to understanding the properties of aquifers in 3D.

Groundwater and environmental modelling tools such as FEFLOW, MODFLOW and ZOOM frequently configured to take input data in a 3D grid format. One of the software developments BGS has been engaged in recently is to create a software tool which can data from a 3D framework model and convert the input data into a 3D grid with x,y,z points for the nodes of the grid and a property value, this data flow is illustrated in Figure 6. The input to the 3D gridding process is the various surfaces produced by 3D modelling. This software tool is currently called "Platypus", and is written in the Java programming language. As currently implemented in BGS Platypus is integrated with GSI3D, since it processes the surfaces produced in 3D framework modelling to create the grids. However, in principle Platypus could be configured to run outside of the GSI3D environment, so that it could for example work with surfaces created in GOCAD or other modelling tools.

The 3D grid created in a tool such as Platypus also provides a means visualising data in a voxel based format in a visualisation tool such as GeoVisionary, and being able to represent data in this format provides a useful approach to statistical analysis, for example to examine heterogeneities in aquifers.



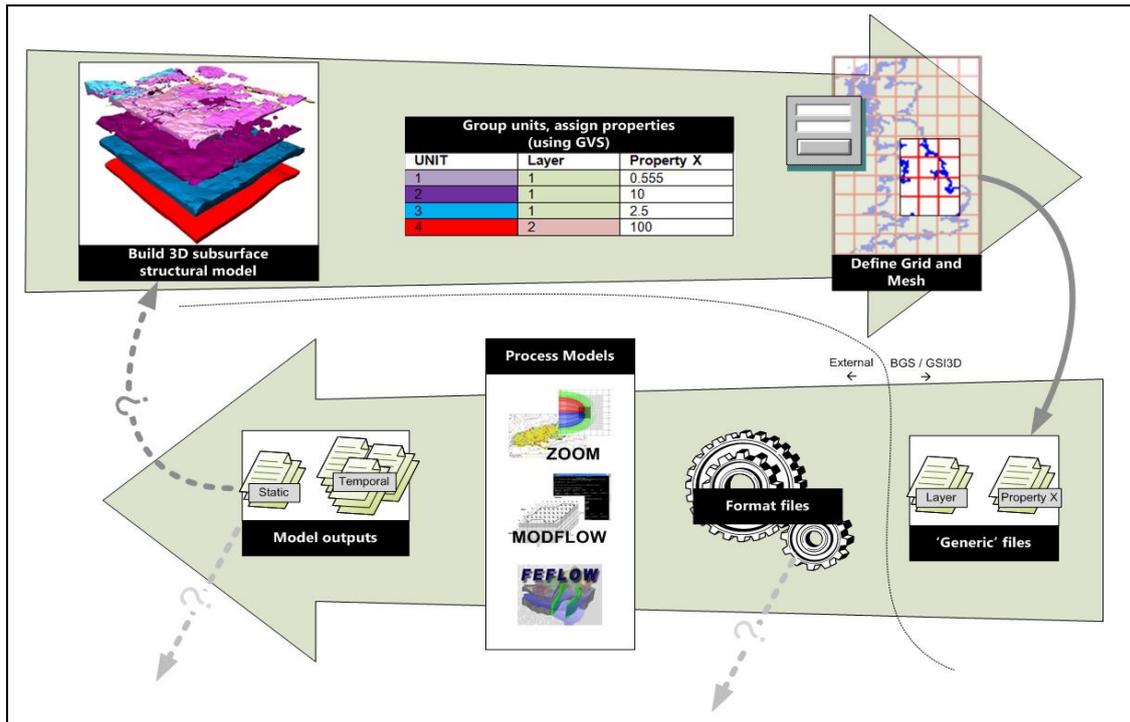


Figure 6. From data to process models – Platypus workflow

## 6 Opportunities for on-going and future collaboration

The STSM provided an opportunity to understand in detail the requirements of the City of Oslo for addressing various sub surface problems concerned with ground water flow and foundation stability. The NGU is aiming to develop modelling methodologies and workflows which can address problems of this kind. Within the STSM visit we focussed on some of the components and building blocks of this workflow, in terms of the underlying databases, and considering some software tools developed by BGS but which could be adapted for use by NGU and the City of Oslo. It is clear that there is much productive and useful work to be done “getting the foundations right” in terms of data, and that BGS can also learn from the application of these techniques in Norway. In particular we identified opportunities to test various BGS software tools (such as Platypus) with data from NGU and the City of Oslo, thus benefiting all three organisations.

A number of the problems outlined both in Oslo and more generally on Norwegian aquifer modelling would seem appropriate to be investigated by integrated environmental modelling (IEM) a technique which BGS is seeking to develop further by working with partner organisations to develop. Development of such fully integrated models would require more work on the development of databases and software tools to create 3D grids etc (which is discussed below). However, particular examples which could be worked on in future would be the interaction between groundwater flow and surface water in the Oslo City area, and in turn the effect on groundwater levels and foundation conditions. There also appear to be issues associated with localised aquifers which fall under NGU’s remit, for example understanding the interplay between fluvial flow and groundwater, and potentially climate associated with seasonal aquifer re-charge related to spring snow melt which could be better understood through integrated environmental models

The following opportunities for on-going work and further collaboration were identified during the STSM:-

### 6.1 DEVELOPING THE DATABASE AND APPLICATION FRAMEWORK TO SUPPORT INTEGRATED ENVIRONMENTAL MODELLING

- From discussions about the underground archive in Oslo it may be that some of the structures used by BGS to store borehole data may be applicable to extending a digital database particularly for the down-hole data. BGS has developed a website in order to make some of our key data model publically available (including the model for borehole data) and this is available at: [www.earthdatamodels.org](http://www.earthdatamodels.org)
- During the NGU part of the visit we discussed the usefulness of a standard scheme to describe rock units stratigraphically and also in terms of a standard set of lithologies. Much groundwater modelling and other environmental modelling work in Norway involves modelling of unconsolidated deposits often of Quaternary age, and a scheme to describe these deposits would be a very useful goal to work towards. The underlying data model for the BGS Lexicon system will soon be publically available, and so we would be able to make that available to NGU and the City of Oslo in due course. The BGS data model is fairly complex and it may not be necessary to implement the data model in its entirety. We could potentially work towards developing a scheme around NGU, City of Oslo, and BGS experience of quaternary mapping



and modelling. This would also consider wider requirements for modelling of unconsolidated deposits within other cities within the COST project. Some references to Quaternary groundwater modelling work undertaken by BGS are included in the Appendix.

- NGU is in process of extending database facilities to store more information about groundwater. During the STSM we had the opportunity to discuss the design of this part of the database system. The NGU database design will be based on appropriate parts of the SOSI standard. A brief outline of the BGS WELLMASTER groundwater database has been included in this report, including some initial comparisons to the SOSI standard. However there would be potential for BGS NGU and the City of Oslo to cooperate further on this design using the best functionality from the current BGS and NGU systems, and ensuring Norwegian requirements are met.
- We discussed BGS's use of bespoke software tools to assist in the creation of 3D grids for use in environmental process modelling, and also for visualisation of 3D framework models in visualisation tools such as GeoVisionary. As a means of testing the usefulness of this workflow to NGU (and potentially the City of Oslo) NGU would have a potential interest in providing some of their data to BGS so that this could be run through the Platypus workflow by BGS. Typically the input data required by Platypus would be a 3D model (e.g. in GSI3D) which would draw data from the GRANADA groundwater database and NADAG ground investigation database. This could be run through the Platypus workflow by BGS, and the results provided back to NGU for input to their modelling workflows. This type of workflow would clearly have wider application to integrated modelling for other European cities within the COST project.

## **6.2 FURTHER COOPERATION ON INTEGRATED ENVIRONMENTAL MODELLING**

- Prior to arranging the current STSM, we had discussed the possibility of following this up with a further STSM visit – this time hosted by BGS and providing an opportunity for staff from the Underground Project in the City of Oslo and also NGU modellers to visit BGS and work with on some of environmental modelling techniques which BGS are developing, and which would be useful to NGU and the City of Oslo. Such a follow up visit could productively build directly on our discussions concerning tools for extracting data from databases and formatting this data appropriately for modelling.

The activities we discussed involving testing of the BGS Platypus workflow with data from NGU, would usefully be undertaken prior to this visit so that this data would be available to work on at BGS, and this would make maximum use of the available time during a second STSM. The precise areas for a follow up visit require some discussion but it seemed from the requirements of NGU and the City of Oslo that spending some time both with our Geoscience Modelling team, who focus on 3D framework modelling and the attendant data requirements, and also some time working with the BGS groundwater modelling teams to look at their workflows, possibly focusing on work done on the Quaternary in UK.



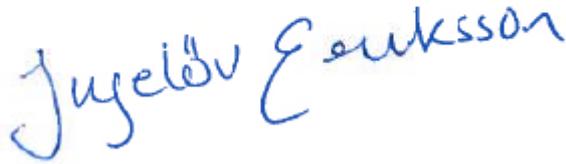
## 7 STSM Host institution approval / sign-off

Report noted with approval.

Oslo, 26<sup>th</sup> March 2014

Ingelöv Eriksson, City of Oslo, Agency for Planning and Building Services, Oslo

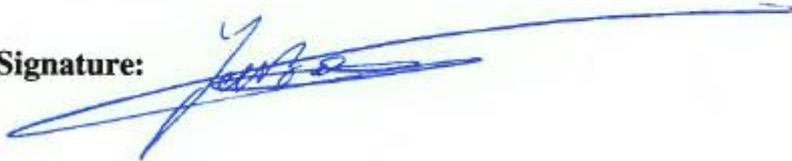
Signature:



Trondheim, 26<sup>th</sup> March 2014

Johannes de Beer, Geological Survey of Norway, Trondheim

Signature:



## APPENDIX

References to work on groundwater modelling of the Quaternary undertaken by BGS:

**Mansour, M.M.; Davies, J.; Hughes, A.G.; Robins, N.S.** 2006 *The Vowchurch gravel aquifer pipeline crossing : hydrogeological evaluation of impact*. British Geological Survey, 44pp. (CR/06/186N) (Unpublished) [<http://nora.nerc.ac.uk/7459/>]

**Macdonald, David;** Hall, Robert; Carden, David; Dixon, Andy; **Cheetham, Michael;** Cornick, Sharon; Clegg, Matt. 2007 Investigating the interdependencies between surface and groundwater in the Oxford area to help predict the timing and location of groundwater flooding and to optimise flood mitigation measures. In: *42nd Defra Flood and Coastal Management Conference, York, UK, 3-5 July 2007*. [<http://nora.nerc.ac.uk/9884/>]

**Wang, Lei; Tye, Andrew; Hughes, Andrew.** 2010 *Riverine floodplain groundwater flow modelling : the case of Shelford (UK)*. Nottingham, UK, British Geological Survey, 28pp. (IR/09/043) (Unpublished) [<http://nora.nerc.ac.uk/9556/>]

**Macdonald, D.;** Dixon, A.; **Newell, A.;** Hallaways, A.. 2012 Groundwater flooding within an urbanised flood plain. *Journal of Flood Risk Management*, 5 (1). 68-80. [10.1111/j.1753-318X.2011.01127.x](https://doi.org/10.1111/j.1753-318X.2011.01127.x) [<http://nora.nerc.ac.uk/17491/>]

**Mansour, M.M.; Hughes, A.G.; Robins, N.S.; Ball, D.;** Okoronkwo, C.. 2012 The role of numerical modelling in understanding groundwater flow in Scottish alluvial aquifers. In: Shepley, M.G., (ed.) *Groundwater resources modelling : a case study from the UK*. London, UK, Geological Society of London, 85-98. (Geological Society Special Publications, 364, 364). [<http://nora.nerc.ac.uk/17850/>]

These papers are available on-line from the NERC Open Research Archive (NORA) using the links provided

