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Mapping subsurface qualities for planning purposes: a pilot study

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Abstract. The subsurface can be used for a variety of purposes in the urban environment and the subsurface should ultimately be seen as a multifunctional resource, offering a multitude of benefits to humans and the society. Underground construction is commonly planned according to the first come, first served principle and later claims on other resources in the subsurface will have to adapt, often at high costs, or are made impossible. This pilot study is a first step in developing a method aiming to investigate a procedure for mapping an area's subsurface resources, having the multifunctionality of the subsurface in mind, and integrating this information into urban planning processes. A mapping of the existing resources (supporting, provisioning, regulating, cultural) used at present and their future potential is presented, and an analysis, using an interaction matrix, of how the different subsurface resources can influence each other (conflicts and synergies) if the use(s) changes. Conclusions are that: 1) the concept of geosystem services can strongly support the communication about the subsurface between civil/geotechnical engineers and planners; 2) there is a need at the municipality or city level for systematised and digital 3D archives for easy access to information in relevant format; 3) planning based on the perspective that the subsurface has multiple resources, makes subsurface planning not only a metropolitan issue but also relevant for smaller municipalities. Further work is suggested to: i) explore the concept of geosystem services in a planning context; ii) suggest at which planning level different geosystem services can be optimally managed; and iii) develop tools to support planners for handling subsurface conflicts and acknowledge synergies.

1. Introduction

1.1. Background

The subsurface can be used for a variety of purposes in the urban environment: extraction of groundwater for e.g. drinking water; production of aggregates, natural stones and minerals; storage of heat, cold and carbon dioxide; foundations and buildings such as underground garages, tunnels, civil defence, security facilities, public facilities, and sport facilities. In addition, the subsurface may contain geological heritage, archaeological remains and contaminated soil or groundwater in need of remediation. It may also provide habitats for ecosystems and support for surface life. When constructing underground facilities, we permanently impinge the subsurface by removing material, changing groundwater flow, the properties of the surrounding materials etc. Such permanent changes influence future possibilities of alternative uses of the subsurface, and sometimes also influence future above-ground use and constructions. Currently, the first come, first served principle applies [1] and later claims on the subsurface will have to adapt, often at high costs, or will not be possible to be met. This is non-optimal, or unsustainable, from both ecological and societal points of view: the subsurface is a valuable multifunctional resource and should be managed accordingly. Therefore, the planning and design of underground constructions or other uses of the subsurface need to be done with great care.

To achieve a careful and strategic planning process of the use of the subsurface, the resources of the subsurface, as well as its limitations, must be made transparent and clearly accounted for. Conceptualisations or descriptions of the subsurface have evolved from focusing mainly on spaces for different underground facilities and mining, to have a broader resource-oriented perspective [1]. In the pilot study we hypothesise that this broader, multi-functionality perspective, should be included in the planning processes to support a sustainable use of the subsurface.

1.2. Aim and scope

The pilot study presented in this paper is a first step of a method development aiming to investigate a procedure for mapping an area's underground resources and integrating this information into planning processes. The overall aim of this pilot study was to investigate the benefits of mapping a specific area's underground resources from broad perspective for the purpose of integrating this information into planning processes.

Specifically, the objectives were to: i) collect and summarise information about the current use and qualities of the subsurface in a pilot study area, using a broader resource perspective of the subsurface; ii) investigate potential synergies and conflicts along with the foreseen changes in the pilot study area; and iii) to deliver the information in a useful format to planners.

2. Method

The method applied consists of four steps: 1) a description of the study area based on current land use and future plans; 2) a description of the study area based on interpretations of geological maps and other information about the site in an engineering perspective; 3) a mapping of the existing resources or subsurface qualities (supporting, provisioning, regulating, cultural) used at present, and the potential of their use in the future; and 4) an analysis, using an interaction matrix, of how the different subsurface resources can influence each other (positively as well as negatively) if the use of the subsurface changes. Finally, the analysis is summarized based on typical planning themes: Water, Energy, Waste, Transport and communication, Buildings, Green infrastructure, Cultural heritage, and Contamination.

As a basis for the mapping of subsurface resources (step 3 above), previous work from [2,3,4] was used, see Figure 1. Here, the qualities of the subsurface are highlighted from a planning perspective, also using the expression of qualities as commonly used in planners' vocabulary. The qualities as outlined in the mentioned works were slightly adapted to be relevant for Swedish conditions.

To investigate potential conflicts and synergies (step 4 above) of changed use in the pilot study area, we used an interaction matrix as a tool for a systematic inventory. All subsurface qualities were listed both on the x-axis and the y-axis, and by going through the matrix cell by cell, all potential interactions were explored. The methodology is schematically shown in Figure 2.

3. Study area – Flatåsmotet

The pilot study area is situated in Göteborg, Sweden, close to an expressway and interchange, where a current industrial area will be redeveloped into a mixed residential and commercial area (Figure 3). The current industrial area is neighbouring a highly attractive nature reserve area situated rather centrally in the City of Göteborg, Änggårdsbergen. The aim is to connect the current housing situated on the western side of the express highway to the future housing areas on the eastern side, and thus improve the connectivity to the green area. There have been discussions about submerging the express highway below ground in its current location (on clay), but high costs and time aspects have so far hindered such plans.

PROVISIONING QUALITIES	REGULATING QUALITIES	CULTURAL QUALITIES	SUPPORTING QUALITIES
Bio-production capacity	Clean soil	Archaeological archives	Bearing capacity – basis for building activities
Drinking and process water production capacity	Living soil (ecological soil function)	Geological heritage	Underground construction
Groundwater resource	Stable soil	Landscape diversity	Sewerage, cables and pipes
Geomaterials, incl. minerals	Water retention capacity	Ecological diversity	Geo-energy: storage of heat and cold
Fossil resources	Water filtering capacity		Space for storage (in natural formations)
Geothermal energy	Carbon sequestration		Large scale pipelines

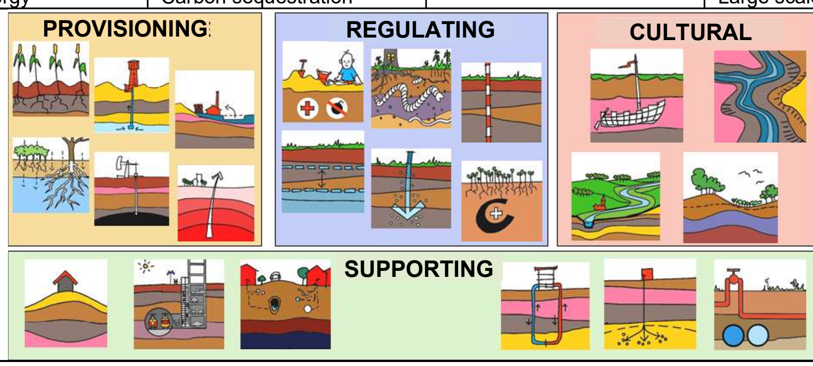

Figure 1. Overview of the subsurface qualities mapped in the pilot study area, including their categorisation. The list is based on Ruimtexmilieu [4], but slightly adapted to Swedish conditions. All icons are from Ruimtexmiliue [4].

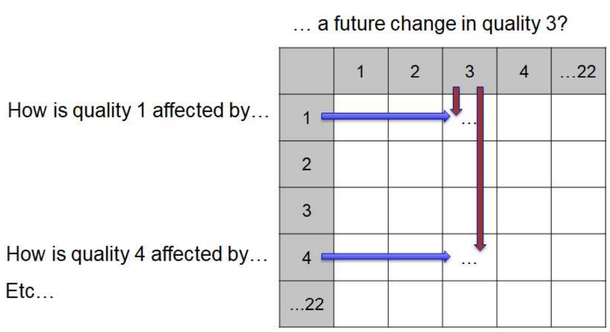

Figure 2. Illustration of the principle of the interaction matrix analysis. The arrows are symbolising that qualities 1 and 4 are affected by changes in quality 3. Each cell thus contains a unique analysis.

The area represents a rather typical geological situation in Western Sweden with quaternary deposits overlaying old, Precambrian, magmatic rock, granite and granodiorite [5,6]. The different types of quaternary deposits and their locations are related to the last glaciation (till, glacial clay), the deglaciation and associated land rise (postglacial clay, sand and gravel, gyttja and peat). The area was free of ice but below sea level (except at the highest elevations) between about 10 – 14 thousand years ago. At present, the land rise in the region is about 1 mm/year. The area is situated in a valley with rock outcrops on each side (west and east), the valley being filled with clay deposits on top of glacial till. The depth of the clay is up to 50 m, largest depth is in the southern parts. Along the hillsides, there are some

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areas with sand, washed-out from the till and sorted as a result of the land rise, i.e. a marine regression. The till areas are typically important for groundwater recharge into the deeper layers and maintaining pore pressures in clay. The rock outcrops are either bare or covered with thin layers of till. A schematic cross section of this type of geology is shown in Figure 4.

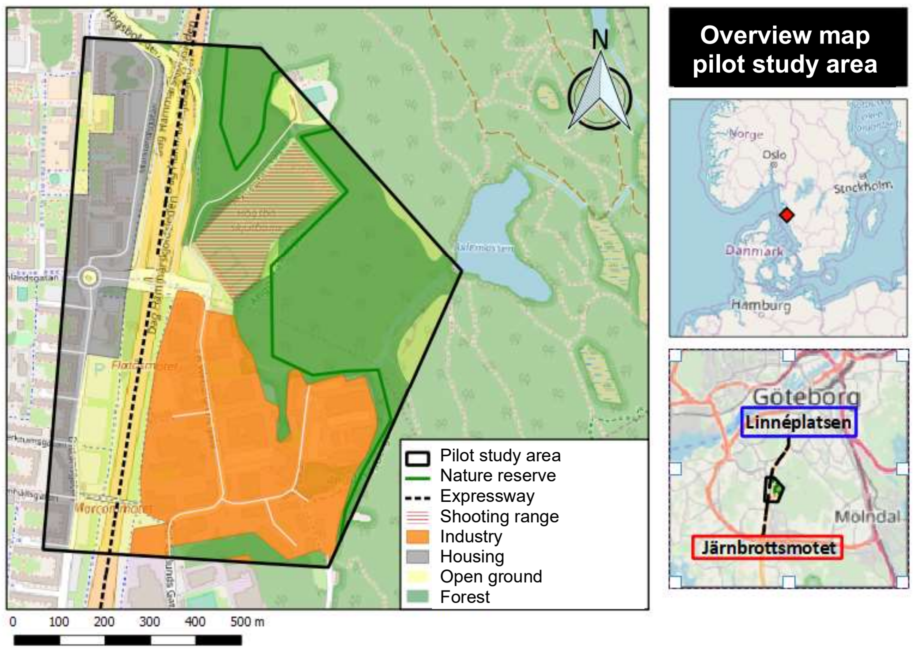

Figure 3. Overview over the pilot study area. Maps adapted from Lantmäteriet [7].

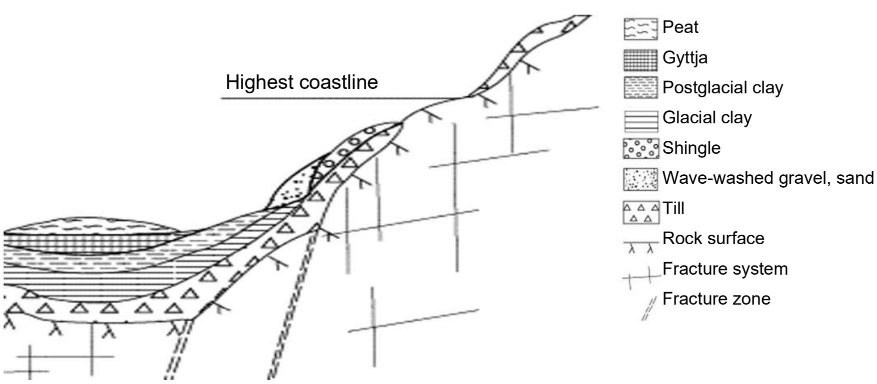

Figure 4. Schematic geological cross section for the Flatås area.

4. Result

Figure 5 summarises the mapping of the subsurface qualities in the area, their current use and their future potential, analysed for soil and rock separately as their respective qualities differ substantially. The magmatic rock in the area is of good quality for construction, whereas the clay typically requires piling foundations. Although difficult to access, there is information about current types of foundations, but no available information about other types of underground facilities. There are pipes for water, sewage, central heating and gas, and cables for electricity and telecommunication, and about 150 energy-wells as part of a large Borehole Thermal Energy Storage system (BTES) in the eastern part of the area, drilled to depths of 200 – 300 m. There is no deep geothermal energy production in the area, but with new technologies, this cannot be ruled out in the future.

A few known archaeological remains are mapped in the area, but there can also be unknown remains. The typical West Sweden landscape is partly intact, but the ecological diversity is in general low in the exploited areas, but high or medium in the nature reserve – the same is valid for the ecological soil functions, the carbon sequestration capacity and the bio-production capacity. There is an old abandoned pegmatite mine offering a hidden but dramatic feature in the area. Some locations have suspected contamination problem, e.g. an old shooting range, former and present gas stations and a dry laundry and the magmatic rocks has high natural levels of uranium. Both the clay and rock slopes are subject to stability issues, cohesive slides or rock falls, respectively. The natural water retention and filtration capacity of the dominating clay as well as the rock is in general low and large parts of the area are covered with impermeable surfaces. Although there is no groundwater resource for water production purposes, groundwater levels for maintaining pore pressure in the clay and providing water for vegetation is still important. The area has no fossil resources, but underground constructions in the rock can provide high quality rock material for aggregates.

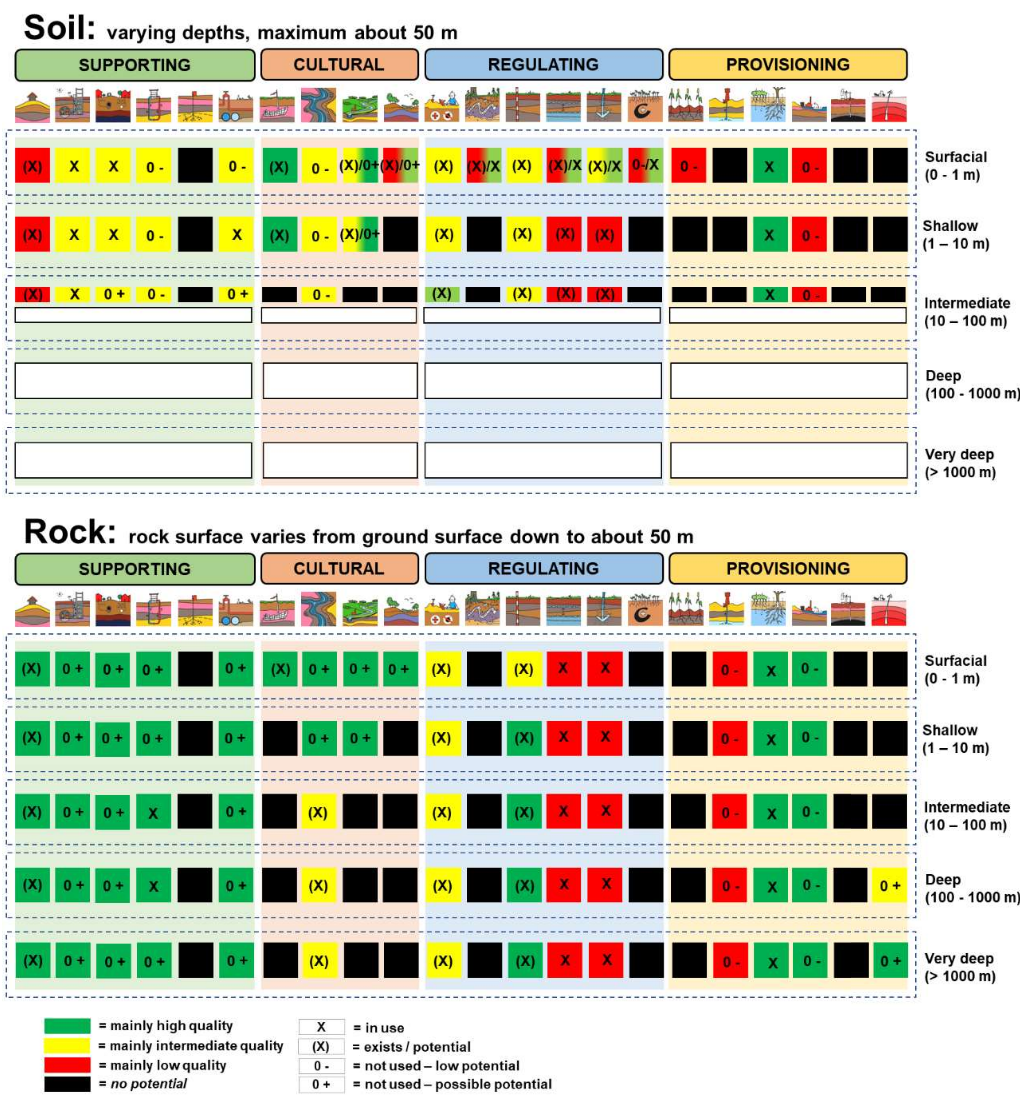

Figure 5. Summary of the mapping of the subsurface in the Flatås area for soil (top) and rock (bottom). All icons are from Ruimtexmiliue [4].

The interaction matrix allowed an analysis of possible conflicts and synergies with a change in use of the different subsurface resources. Figure 6 presents and an overview of the resulting matrix, where each cell is colour coded. The details of each cell are presented (in Swedish) as a digital appendix in the Swedish report of the pilot study [8]. Many cells are coloured light yellow (striped), indicating that the interaction may be positive or negative, dependent on how plans are designed and implemented. This indicates that with good planning, potential conflicts can be avoided or at least minimised.

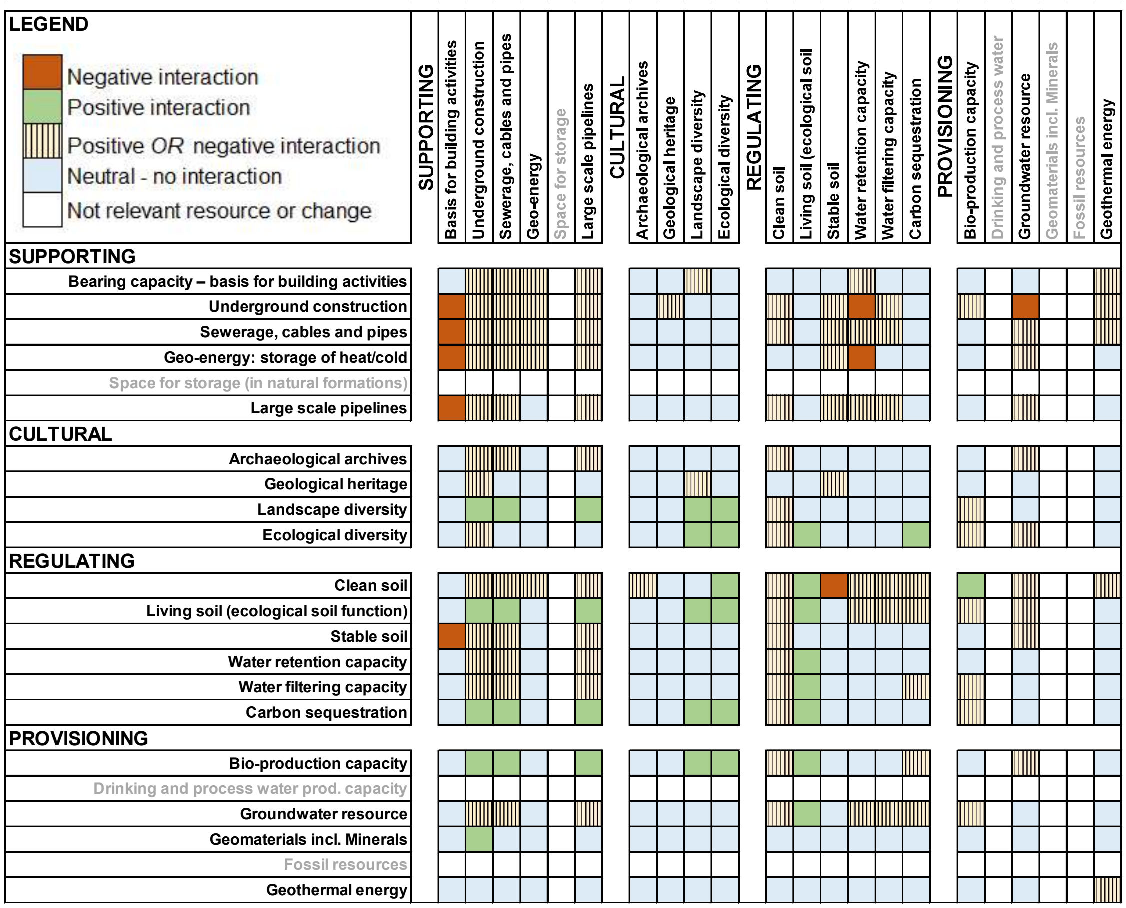

Figure 6. The resulting interaction matrix in an overview format, summarising the expected effects changes in one subsurface resource will have on other subsurface resources. The details of each cell can be found in the digital appendix to the Swedish report [8].

To deliver the information mapped and analysed for the area in a format that could be useful for urban planners, the results of the mapping of subsurface qualities and the interaction matrix were summarised according to common planning themes, see Table 1. For each theme, the needs, possibilities and risks were outlined.

5. Discussion

A lot of the information was easily available from geological maps, databases and reports from the Geological Survey of Sweden (SGU). However, geological information may require interpretation by experts for translating it to a format relevant to planners. Some information was more difficult to access, primarily relating to underground constructions. Cables and pipes are available for limited areas upon request, but all information is without depth data. Building foundations are available upon request from the City of Göteborg, but in pdf format as e.g. piling installation reports that are archived. Finally, the location of other underground constructions in the area is confidential information. For a better understanding of the subsurface, information in 3D is preferred. Although there are several initiatives, national and world-wide, for improved 3D representations of cities above as well as below ground, there is still a substantial amount of work needed to make this standard and applicable.

Table 1. The thematic summary: for each theme, needs, possibilities and risks are outlined to deliver the information retrieved in the analysis in a format useful for urban planners.

THEME	NEEDS	POSSIBILITIES	RISKS
Water	Pipes for water and wastewater. Drainage and retention of stormwater. Maintaining groundwater levels	MUT*. Stormwater storage underground (under the express highway).	Impermeable surfaces: too many and/or in critical areas – risk for large/uneven settlements in clay. Contamination of water during construction phase.
Energy	Heating, cooling, electricity.	MUT*. Increased use of geo-energy for heating and cooling, GSHP & GSC**	Conflicts about underground space and thermal resource
Waste	Waste handling. Sorting of organic waste.	Underground system for waste collection. Local use of organic waste to improve ecological soil function.	Possible contamination if local use of organic waste. Conflicts about underground space.
Transport & communication	Traffic from central parts to outer areas (express highway). Space for local traffic and parking. Telecommunication cables.	Separation of different types of traffic, some above some below ground. Cut and cover of express highway. Alternative stretch of express highway through rock. MUT*.	Conflicts about underground space. Cut and cover techniques implies potential restrictions on type of transport.
Buildings	Transformation and densification of former industrial area above ground – need for foundations.	Possible use of underground space for cellars and parking.	Large/uneven settlements in clay due to changes in loads. Buildings close to rock slopes are at risk for rock falls. Archaeological findings may delay/stop construction.
Green infrastructure	Green infrastructure and connectivity. Entrances to the nature reserve area.	Use of old shooting range for allotments, potential combination with gentle remediation.	Handling of contamination.
Cultural heritage	Connection to existing heritage.	Potential archaeological remains from the Mesolithic Sandarna culture. The old pegmatite mine as an industrial heritage and geological site.	Security issues at the old mine (rock falls). Conflicts between exploitation and archaeological remains.
Contamination	More sensitive land use requires clean soil and Radon safe constructions.	Consider more sustainable remediation methods to decrease transports.	Construction and drillings may mobilise contaminants. Radiation.

** MUT – multi utility tunnels. ** Ground Source Heat Pump (GSHP) systems for heat extraction and Ground Source Cooling (GSC) systems for extraction of cold*

Taking this broad perspective on the subsurface highlights the different type of benefits (and difficulties) the subsurface offers and has the potential to communicate a systems perspective, where different aspects are interlinked. On the contrary, treating different aspects of the subsurface in different organisations risk a loss of understanding that e.g. the hydrological and mechanical processes in soil and rock are interlinked. The information, however, needs to be presented in a way that is useful for urban planners and it needs to be delivered timely. Different aspects of the subsurface are likely not suitable to be handled all at the same planning level or at the same scale. In this pilot study, all subsurface qualities were handled in the same way, but obviously there are some resources that should be handled on higher, strategic levels (e.g. drinking water resources, type of energy supply, storage of CO_2), whereas some information is of best use further down in the planning hierarchy.

Recently, similar to the well-established concept of ecosystem services which is used to highlight contributions of ecosystems to human well-being [9], the concept of geosystem services was (re-)launched to describe and highlight the multiple benefits humans gain specifically from the subsurface [10,11]. The authors describe the pedosphere as a shared zone between the ecosystem and the geosystem, where ecosystem services highlight the biotic parts of the ecosystems, and geosystem services include both the abiotic and the biotic parts of the subsurface. This conceptualisation of geosystem services by van Ree et al. [10,11] is different from that of Gray et al. and Fox et al. [12,13,14], who instead relate the idea of geosystem services to the services associated with geodiversity and which are independent of interactions with biotic nature. Figure 1 displays the subsurface qualities mapped in this study, and only some of them are commonly referred to as ecosystem services, but many of them can be referred to as geosystem services, independent of which definition is applied.

6. Conclusions and future work

Although the mapping done here is site-specific, some of the results are generic for this type of geological conditions, and could thus be used in other, similar areas. The main methodological experiences are: 1) the concept of geosystem services is a useful complement to the more widely used concept of ecosystem services and has the potential to strongly support the communication about the subsurface between engineers and planners, as well as highlight its value; 2) the mapping of the subsurface qualities requires collecting information from several different databases and interpretation of some of the material, which implies both a need at the municipality or city level for systematised and digital 3D archives for easy access and information in relevant format; 3) planning based on the perspective that the underground has multiple resources, functions and services, makes subsurface planning not only a metropolitan issue but an issue that is also relevant for smaller municipalities where underground construction is limited, but where other subsurface qualities are used.

Further work is suggested based on the current pilot study to: a) further explore the concept of geosystem services and the usefulness of this concept in a planning context; b) suggest at which planning level (national, regional or municipal) different geosystem services can be optimally managed; and c) develop methods and tools to support planners when handling conflicting claims on different uses of the physical space as well as other resources in the subsurface.

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