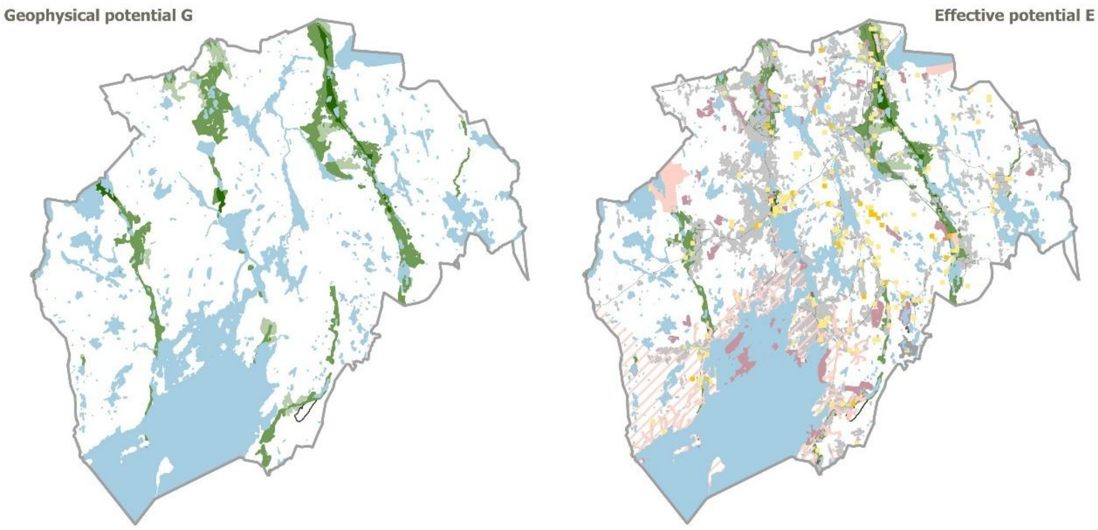
CHALMERS
UNIVERSITY OF TECHNOLOGY



Mapping of Geosystem Services for Comprehensive Planning

A Case Study of Askersund Municipality

Master’s Thesis in Infrastructure and Environmental Engineering

ANJA GUSTAFSSON

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
www.chalmers.se

MASTER’S THESIS 2026

Mapping of Geosystem Services for Comprehensive Planning

A Case Study of Askersund Municipality

ANJA GUSTAFSSON

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Architecture and Civil Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026

Mapping of Geosystem Services for Comprehensive Planning- A Case Study of Askersund Municipality
ANJA GUSTAFSSON

Supervisor: Fredrik Mossmark, Sveriges Geologiska Undersökning
Supervisor: Emrik Lundin-Frisk, Chalmers University of Technology
Examiner & main supervisor: Jenny Norrman, Chalmers University of Technology

Master's Thesis 2026
Department of Architecture and Civil Engineering
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Gothenburg, Sweden 2026

ABSTRACT

The subsurface under our feet holds many 'invisible' qualities that are valuable to society, from geomaterials to flood mitigation and storage space. In Sweden, however, subsurface planning is rarely designed to account for these functions and instead often suffers from a “first come, first served” principle, which can hinder sustainable planning and lead to unnecessary costs and loss of value. The concept of Geosystem Services (GS), inspired by Ecosystem Services, has been developed to make these subsurface benefits more visible and support more informed planning decisions.

Previous work by Lundin-Frisk (2025) has resulted in an indicator-based mapping methodology to visualize GS potential, which has been applied to support resilience planning in Malmö (the M-case). This master’s thesis presents a new case study which is inspired by the M-case but applied under the conditions of Askersund municipality. The aim is to evaluate the general improvement potential of GS maps and assess their suitability for supporting municipal comprehensive planning.

The study's process consisted of four main steps. First, relevant geosystem services were selected, resulting in five prioritized services: ‘infiltration of stormwater’ for natural flood mitigation, ‘provision of groundwater’ for extraction on municipal scale, ‘bearing capacity’ regarding surface construction, ‘resistance to erosion’ regarding construction, and ‘provision of rock aggregates’ for concrete production. Second, indicators and data sources were identified or developed. Third, the services were mapped in QGIS, producing two map types for each service: Geophysical potential (G), representing the inherent capacity of the environment to supply the service, and Effective potential (E), representing the share of this capacity that is available and suitable for use. Finally, the maps were evaluated in a workshop with representatives from Askersund municipality to assess their usability and identify improvement opportunities.

The results showed that the methodology overall was applicable to Askersund, although some adjustments were required. The results of the evaluation were generally positive and indicated that GS potential maps can function as a valuable complement for comprehensive planning, particularly as communicative support material in early planning stages. While the findings were considered representative for comprehensive planning in Askersund and suggests potential for broader application, the limited scale of the study still constrains broader generalisations to other municipalities and planners.

Content

1 INTRODUCTION

'Geosystem Services' (GS) is an emerging concept that can be used to highlight the many and varied benefits human society derives from the subsurface, e.g. drinking water, geomaterials, flooding prevention by stormwater infiltration and ecosystem habitats etc. (Lundin-Frisk et al., 2022). Recognising and integrating these services in urban planning is therefore important for sustainable resource management. In Sweden, municipalities are responsible for planning activities that often involve managing or altering the natural subsurface, ranging from residential area development to water infrastructure and energy or material extraction. To support such processes, municipalities have access to large geodatabases with a wide variety of geologic and geomorphologic information. However, a common challenge is that many municipal planners lack the expertise to navigate and utilise these data resources effectively. As a result, GS are frequently overlooked, leading to large and unnecessary costs and value losses as consequences.

To address this issue, researchers within the UNDER-project (2021–2025) are developing methods to make geological information more accessible and meaningful for municipal planners through exploration of the GS concept (Chalmers University of Technology, 2021). The project is a collaboration between the Geological Survey of Sweden (SGU), the City of Gothenburg, Chalmers University of Technology and several other universities and organisations. Its overall goal is to establish a structured framework for the systematic consideration of GS in Swedish planning practices, thereby supporting sustainable urban and regional development.

One part of this work is carried out in collaboration with the Doctoral thesis project 'Geosystem Services to support Planning and Management of the subsurface', which focuses on developing new and useful thematic information to support sustainable subsurface management in spatial urban planning (Chalmers University of Technology, 2025). The project has gradually advanced the understanding and usefulness of the GS concept. Early work (Lundin-Frisk et al., 2022), mapped and categorised geosystem services and explored how the concept can be applied in planning. Later studies (Lundin-Frisk et al., 2025) investigated how indicators can be used to represent GS potential, presenting a comprehensive list of 75 indicators for 23 GS, of which 21 indicators were adapted as 'national' for Swedish conditions.

The most current work (Lundin-Frisk, 2025) includes a case study in Malmö, where thematic GS maps are produced in QGIS using locally adapted versions of the national indicators. The maps aim to visualise the potential delivery of various GS and support municipal planning by improving consideration of subsurface conditions. This mapping methodology has been applied in collaboration with the Municipality of Malmö (the M-case) to strengthen their climate resilience planning and is summarised in Appendix B.

This master's thesis is part of the same research initiative to continue the development of the mapping methodology for Geosystem Services. The study explores the approach developed by Lundin (Draft) in a different geological and planning context; the more rural Municipality of Askersund (the A-case), in order to examine the mapping's potential to support the municipality's comprehensive plan (CP).

1.1 Aim and Objectives

The study's overall aim is to further explore the applicability of the methodology used in the M-case by developing maps adapted to Askersund's local conditions. Focus is set on choosing relevant GS and associated indicators and creating GS-maps. The purpose of these maps is to evaluate the potential of GS maps in general, and their ability to support the municipal comprehensive planning in Askersund. To meet the aim, the following objectives are formulated:

Objectives

- Choose GS and adjust indicators relevant to the A-case conditions.
- Produce GS potential maps in QGIS.
- Evaluate the developed maps, including end-users' points of view.

1.2 Involvement of Askersund Municipality in this Project

In this project, the Municipality of Askersund serves as the intended user of the resulting maps, and the cooperation was established before the start of this specific study. Municipal employees participate as end-users by providing data, feedback and local insights. Since the project aims to develop maps that support the integration of GS into comprehensive planning, the municipality's involvement is essential to ensure anchoring in practical realities: a tool that does not meet user needs has limited value.

Askersund's new comprehensive plan for 2040 is already well advanced, meaning that the municipality may not have immediate use for the project's final map products. Nevertheless, their recent experience with comprehensive planning makes them a valuable discussion partner. Beyond the maps themselves, this collaboration may still raise awareness of GS within current and future planning processes and also contribute to the development of more useful or improved products over time.

2 THEORETICAL BACKGROUND

The following chapter provides a background of select topics related to this case study. It begins with an overview of essential concepts such as the subsurface, geosystem services and indicators as well as municipal planning practice. Then follows a brief presentation of the subsurface's role in planning procedures in Sweden in general, and in comprehensive planning specifically, but also in other settings around the world. The chapter continues with an orientation of the A-case study site: Askersund's Municipality and ends with a section about data visualisation, including map-construction and geographical information systems: GIS.

2.1 The Subsurface and Geosystems

The 'subsurface' can broadly be defined as the zone below the Earth's surface, including both subterranean and submarine areas (Van Ree & Van Beukering, 2016). This zone consists partly of ecological systems (biological systems near the surface which are dependent on light, water, and oxygen), but also of so called 'geosystems'. These systems are instead abiotic and characterized by geologic structures like rocks, minerals and fossils. These can be shaped by natural geophysical or geochemical processes as well as human activities.

However, geosystems are not isolated from the biotic world: their existence is a necessity for living organisms to thrive. As described by Fox et al. (2020), the variation of geological features in these systems, the 'geodiversity', is closely interlinked with the provision of ecosystem services (benefits humans can derive from ecosystems). The subsurface, or more specifically geosystems, also provides assets for humans, and far more than is immediately visible; from space and material for building, burial or storage, to vital resources such as water, minerals and fuel (Gray et al., 2013). Weathering processes regenerate fertile soil used for food production, and geological structures contribute to numerous cultural and societal values, e.g. sacred mountains or soil layers that can unravel prehistoric history.

Despite its importance, the subsurface is often overlooked in planning and decision-making; 'out-of-sight-is-out-of-mind' as (Lundin-Frisk et al., 2022) formulates it. However, population growth and striving for higher living standards have led to a shortage of developable land areas (Volchko et al., 2020). It has put pressure on natural resources and, assisted by new technology, pushed for underground solutions. This development has led to several challenges. Current planning methods are not designed to systematically consider the subsurface, despite a growing need to do so, but have instead followed the approach of 'first-come, first-served' (Volchko et al., 2020) (Lundin-Frisk et al., 2022). Along with resource scarcity and increasing sustainability demands, there is a clear need for new frameworks and approaches that can integrate subsurface considerations into planning and support long-term, sustainable use.

2.1.1 Geosystem Services (GS) – a Geological Version of Ecosystem Services

Within the field of sustainability of urban planning, the concept Ecosystem Services (ES) is becoming an increasingly integrated framework (Gray et al., 2013), (Lundin-Frisk et al., 2022). It has been used to raise awareness, provide interdisciplinary perspectives and support environmental management (Lundin-Frisk et al., 2022). ES depends on both biotic and abiotic components, but the abiotic ones, consisting of geosystems, tend to become overlooked. For example, groundwater supply clearly contributes to human well-being but is provided by geological features, not ecosystems and is therefore not included in the concept of ES.

There has been a problematic lack of unified terminology to capture these intermediate benefits. Some services, such as mineral or fuel supply, are relatively easy to recognise and appreciate due to their direct market value, while others, like carbon storage potential, stormwater infiltration or the preservation of geological archives, are less tangible and therefore often neglected in decision-making (Lundin-Frisk et al., 2022), (Van Ree & Van Beukering, 2016).

To address this gap of vocabulary, researchers have explored different service definitions. 'Abiotic ecosystem services' (Gray et al., 2013) and ‘Biotic and abiotic services from the subsurface’ (Van Ree et al., 2017) as some prominent examples which have, more recently, led up to the novel concept: 'Geosystem Services' (GS) (Lundin-Frisk et al., 2022). While this term dates back to the 1960s, its meaning has evolved and no full consensus on its use currently exists (Norrman et al., 2020), (Lundin-Frisk et al., 2022). According to Lundin (2022), GS corresponds to the benefits geodiversity provides to humans. They can be described by two complementary interpretations A and B, where this thesis mainly relies on definition B.

> **Definition A:** “All abiotic services associated with geodiversity independent of interactions with biotic nature”. In this view, any service that depends on biological activity falls under ES and is excluded from GS.

> **Definition B:** “The goods and services the contributes to human well-being specifically resulting from the subsurface”. This allows for some overlap with ES in cases where biological processes occur in deeper subsurface environments but is easier to communicate in practice.

Stemming from the same structure as ES, GS holds four different service categories parallel to the ones used in ES-framework: provisioning, regulating, cultural, and supporting services (Lundin-Frisk et al., 2022). Some examples are supply of geomaterials and groundwater (provisioning), regulation of water quantity through infiltration or carbon storage (regulating), cultural values linked to heritage and landscape inspiration (cultural) and processes such as space provision that underpin other services (supporting). A chart over general GS can be seen in Figure 1.

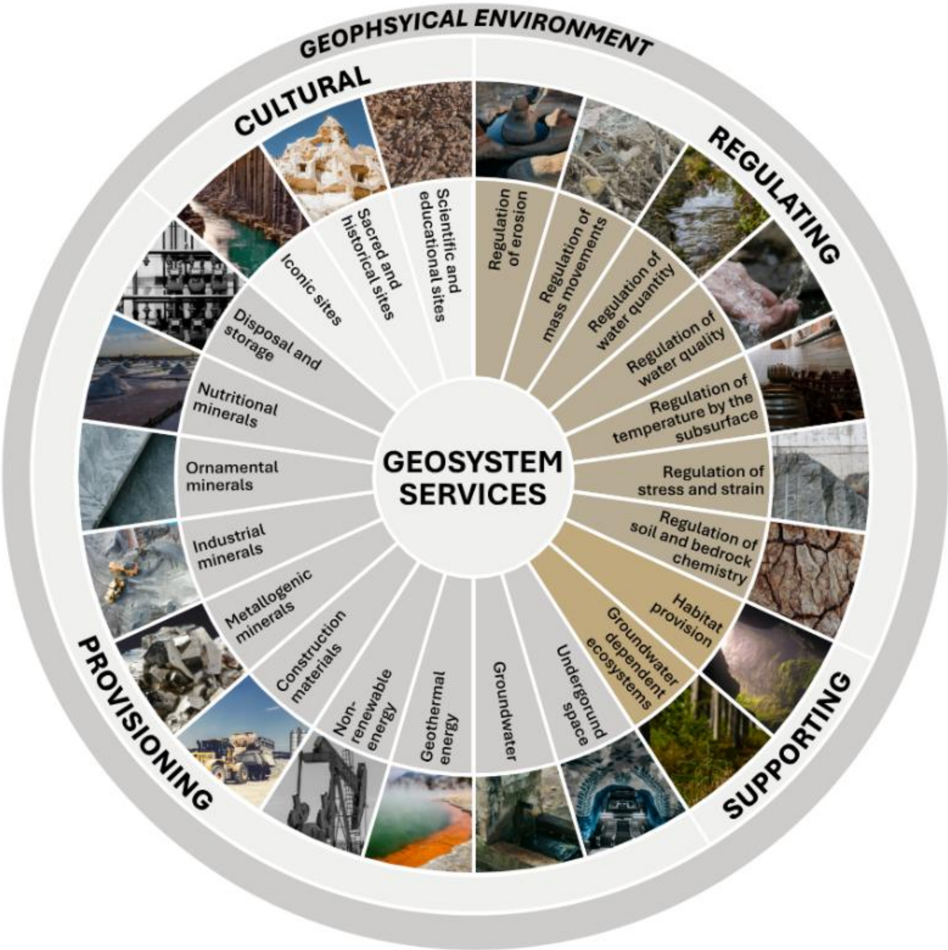


Figure 1: Division of GS into provisioning, cultural, regulating and supporting services. Source: (Lundin-Frisk, 2025).

According to Lundin-Frisk (2025), the GS concept is valuable because it provides a common framework that unifies previously fragmented research and highlights subsurface contributions that often go unnoticed. By distinguishing GS from related concepts like ES, it can facilitate better communication between researchers, planners, and decision-makers and ultimately offers tools for more sustainable planning and management by making subsurface benefits visible and comparable. Although still relatively new, GS has begun to gain traction in academic contexts and has so far been applied in practice in one pilot study on GS-potential mapping.

Despite its potential, GS remains a developing concept. Its frameworks and terminology are not yet consistent, which makes systematic implementation challenging (Lundin-Frisk et al., 2022). Practical difficulties also arise in selecting, measuring, and visualizing services in ways that are meaningful for planning (Lundin-Frisk et al., 2025). Lundin stresses that since planning processes already face complex bureaucracy and involve multiple frameworks, the introduction of GS must demonstrate clear value in order to be effectively integrated. This underlines the need for continued refinement and testing of GS approaches as practical planning tools.

2.1.2 Ways to Measure Services by Using Indicators

Since GS, similarly to ES, can involve complex processes, they can be tricky to measure (Lundin-Frisk et al., 2025) in a straightforward way. This makes them elusive in practical frameworks. Some services, such as the provision of minerals or fuel, are directly linked to market value and can be quantified in e.g. mass or volume per year. Other services, however, such as subsurface contributions to stormwater retention or support for ecological systems, are less tangible and therefore more difficult to measure directly. A way to address this challenge in ES-frameworks is to use indicators with quantifiable data (e.g., tons of carbon stored per hectare, m^3 retained water, number of visitors) as a substitute for the intangible service. By studying indicator data from a specific geographic unit, such as land area, one can estimate the supply of the service the land area provides without measuring it directly. And as soon as numerical values exist, the service can be visualized in map form.

Several frameworks in related fields attempt this so called 'spatial measurement' of services (Lundin-Frisk et al., 2025). ES frameworks such as CICES, MA, and TEEB provide structured approaches which, in some cases, include also abiotic services, see e.g. (Grima et al., 2023). Other approaches use so called 'geodiversity indices' to map abiotic variation (Gray et al., 2013). However, when it comes to capturing the full range of services defined by the GS concept, Lundin et al. (2025) presents the only dedicated method that has been identified. This method builds on the widely used 'Cascade model' from ES research, which illustrates the link between the physical environment (supply) and the human benefits derived from it (demand).

In Lundin et al.'s GS-adaptation of the cascade model, see Figure 2, the supply side is represented by geophysical structures and processes that generate functions that can be utilised as a service. On the demand side, there are human benefits of the service and the economic, social or cultural value that can be derived from it.

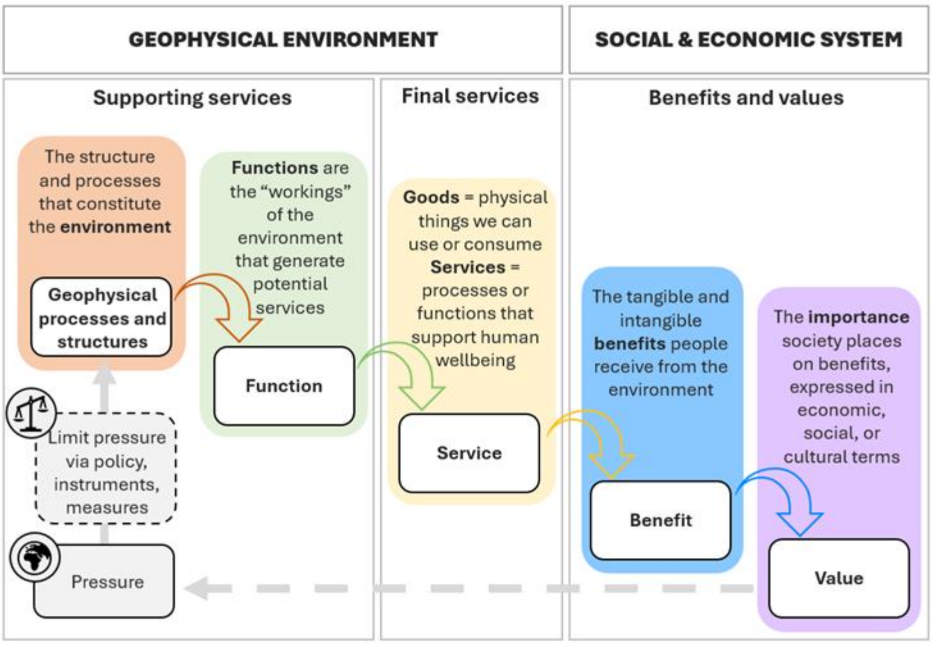


Figure 2: Cascade model adapted to GS. Source: (Lundin-Frisk et al., 2025)

In order to map GS spatially, Lundin et al. (2025) have represented each with *GS-indicators*, i.e. measurable parameters that reflect the subsurface's potential to deliver their specific services. By mapping indicator data to a target area, the approach results in GS-potential maps; visual representations of where and to what extent the subsurface can support different geosystem services. Overviews of GS and their corresponding indicators relevant for Swedish subsurface planning can be found in (Lundin-Frisk et al., 2025) and (Lundin-Frisk, 2025).

GS can be viewed in different levels of detail: general services or specific services with specific use (Lundin-Frisk et al., 2025). For example, the general service 'Regulation of stress and strain' has specific services as 'Suitable construction conditions in the subsurface' for the use of subsurface as a construction medium and 'Suitable construction conditions above the subsurface' for using it as a stable platform or foundation. This type of separation also helps to avoid issues with double counting if a service happens to fit under multiple general definitions at once. One example is Underground space, which can be described as both a provisioning and a supporting service. Which one to use do not necessarily matter, the important thing is that services are not counted twice.

Depending on the specific use case, one or multiple indicator-parameters are needed to represent the service in a useful way, for example 'Terrain classes' for construction above ground but 'Rock type', 'Lineament density' and 'Soft ground thickness' for subsurface construction (Lundin-Frisk et al., 2025). To link indicator-parameters to different levels of GS-potential, the parameters also need to be assigned specific capacity class, which translates parameter values to *Geophysical GS potential*. This is a numeric value on a relative scale from high to low which represents how big potential the geophysical environment can provide in a specific geographical setting. If multiple indicator-parameters are in play for the same service, the one contributing to lowest capacity class is applied for safety reasons.

Finally, the geophysical environment alone is sometimes not enough to determine the service potential in an area. One must then also consider its accessibility and suitability. For instance, inert conditions for 'Provision of gravel as construction material' can show high potential while the area is covered with buildings or contaminated, which limits access and makes the material unsuitable for certain types of usage. To clarify how much the service can be practically utilized the method used by Lundin-Frisk (2025) can be complemented with these factors to estimate an *Effective GS potential* which in practice is the Geophysical map with overlays showing areas with limited accessibility or suitability.

2.2 Municipal Planning Procedure and Comprehensive plans

The Swedish planning system is primarily regulated through the *Planning and Building Act* (Plan- och bygglagen, PBL), which governs the use of land, water, and the built environment (Sveriges riksdag, 2010). According to the Act, planning should be carried out "with regard to the freedom of the individual, to promote societal progress with equal and proper living conditions and a clean and sustainable habitat for people in today's society and for future generations".

Planning responsibility lies with the municipalities, which hold the so-called *planning monopoly*, meaning they alone decide how planning is carried out within their borders, in accordance with national legislation. However, certain issues extend across municipal borders and in such cases, regional collaboration may be established. Since 2014, the municipalities of Örebro County (Örebro Län), including Askersund, have participated in a joint partnership to better utilise regional resources as a way to promote regional growth, development, and quality of life (Municipality of Askersund, 2016).

Municipal planning operates at several levels of detail, where different instruments serve different purposes:

- **Detailed Development Plan (*Detaljplan*)**: A legally binding instrument that specifies how land and water areas may be used and how buildings should be designed (Boverket, 2022). The detailed plan provides precise rules and thereby defines what is permitted or prohibited within a limited area.

- **Area Regulations (*Områdesbestämmelser*)**: A form of regulation positioned between the comprehensive plan and the detailed development plan (Boverket, 2019). These rules are not as detailed as a detailed plan but allow the municipality to prevent developments that conflict with the overarching goals and visions set out in the comprehensive plan.

- **Comprehensive Plan (*Översiktsplan*)**:
  A strategic document covering the entire municipality, setting out long-term strategy for land- and water use as well as developments of the built environment (Boverket, 2024). It is a strategically important guiding instrument which outlines how the municipality intends to manage future development and balance national, regional, and local interests. Although not legally binding, it provides an overarching framework for subsequent planning and decision-making.

The comprehensive plan (CP) is the cornerstone of municipal spatial planning. It sets out the municipality's long-term vision, typically 25–50 years ahead, for how land and water should be used and how the built environment should develop (Boverket, 2024), (Norrman et al., 2020). It is supposed to reflect the political majority's vision for sustainable development and provides the foundation for more detailed planning. Although not legally binding, the CP is crucial as a guiding and communicative instrument (Boverket, 2024). It directs all spatial planning and decision-making within the municipality and clarifies how national interests, regional strategies and environmental objectives are integrated at the local level. As an interdisciplinary instrument, it supports internal coordination between separate sectors such as housing, transport, energy, and environmental protection, as well as major initiatives such as infrastructure projects and development of public services.

CPs also play an important external role (Boverket, 2024). Public authorities use them in their planning and permit processes; for instance, the Swedish Transport Administration refers to them when assessing transport infrastructure, while environmental agencies consult them for impact evaluations. Businesses use them to identify potential development areas, and for citizens, the plans communicate municipal priorities, identify areas for preservation, and outline future growth directions.

Municipalities may also prepare thematic or area-specific CPs focusing on particular settlements or sectors such as renewable energy, coastal zones, or cultural environments (Municipality of Askersund, 2016). These supplement the main plan and allow more detailed guidance where necessary. For the plan to be effective, it must be accessible, well-reasoned and clearly structured (Boverket, 2024). It should clearly distinguish between background material and the plan itself, avoid excessive detail and be presented in a transparent manner that is understandable to both professionals and the public.

2.3 Subsurface Planning

According to the report *New Dimensions in Swedish Planning – An Investigation of Subsurface Planning and Geosystem Services* by Norrman et al. (2020), 'subsurface planning' refers not only to the location and design of structures and facilities below ground, but also to managing trade-offs between competing subsurface resources and ensuring that underground activities are sufficiently integrated with those on the surface. The report identifies several factors that make subsurface planning particularly challenging. First, the subsurface is composed of naturally heterogeneous materials whose properties are difficult to predict and costly to investigate. Although technical tools and modelling methods are continuously improving, a significant degree of uncertainty in geoscientific assessments remains. At the same time, increasing urbanization, densification, technological development, and stricter environmental regulations have made subsurface issues both more complex and more relevant. These conditions underscore the need for greater understanding of subsurface processes, supported by structured data management, monitoring, and long-term planning strategies.

However, subsurface planning is not purely a technical or geological matter. It also involves a wide range of contextual factors that differ between countries and regions, including physical conditions, the economic feasibility of construction and operation, and social, cultural, and legal frameworks (Delmastro et al., 2016). For instance, in Helsinki, ownership of subsurface land is not necessarily limited to a fixed depth, but access rights typically extend only about six meters below the lowest surface point of a property. This contrasts with, for instance, Singapore, where landowners have no such depth restrictions, which results in lots of stakeholders when it comes to large underground constructions e.g. subways. This example illustrates how unclear or restrictive regulations, particularly concerning land ownership and mineral rights, can significantly hinder the development of subsurface projects and the efficient use of underground space.

Despite growing attention, Norrman et. al.'s report stresses that subsurface planning continues to face significant limitations in both global and Swedish contexts. Historically, it has been dominated by engineering concerns related mainly to buildability, and although the perspective has broadened, current planning frameworks remain largely sector-based. This often leads to the addressing of only specific types of subsurface resources, which is insufficient when it comes to managing interactions and trade-offs between competing uses. Furthermore, much of the ongoing research, as noted in the report, still focuses on underground construction while aspects such as environmental protection and geo-/ecosystem services receive only partial consideration.

The report also identifies a few key obstacles for more holistic and efficient planning:

- **Lack of a common language**: terminology is inconsistent, with the same terms used for different phenomena, and different terms applied to the same ones.
- **Fragmented perspectives**: although the subsurface is widely recognized as a multifunctional resource, planning has traditionally concentrated on physical space or extractable assets, such as load-bearing formations, fossil fuels, or groundwater. A more holistic perspective is needed to integrate geosystem services.
- **First-come, first-served practices**: in many countries, including Sweden, subsurface use is effectively regulated by priority of claim, often leading to overuse or suboptimal allocation.
- **Limited accessibility of legal frameworks**: information on laws and policies relevant to subsurface planning is fragmented and insufficient. In practice, systematic approaches for including subsurface issues early in planning processes are largely absent.

2.3.1 Subsurface Planning in Sweden

In Sweden, subsurface use is regulated through a broad planning framework composed of multiple interconnected laws (Norrman et al., 2020). In addition to binding legal provisions, the regulatory framework also includes general guidelines from authorities, technical rules and standardizations issued by national agencies or the EU, as well as sector-specific recommendations. Some advisory material also exists, for instance, in relation to geo-energy or contamination, though generally these are less detailed than those for building regulations. To comply with these frameworks, municipalities and developers commonly conduct geological investigations. Such studies have traditionally been conducted in connection with detailed planning or project design, with the focus on buildability. Their purpose has been to provide technical and economic information on subsurface conditions relevant to construction and infrastructure projects.

Over time, an extensive set of data resources and thematic materials has been developed to support these investigations. The Geological Survey of Sweden (SGU) provides wide-ranging data on soil, bedrock, and groundwater, while municipalities manage information on infrastructure, land use, foundations, utility networks and other underground installations. Much of this data focuses on documenting existing subsurface use or identifying restrictions and vulnerabilities rather than providing proactive planning guidance. Despite several research efforts since the 1970s, systematic and holistic tools for subsurface planning remain rare in practice, particularly in the early stages of municipal planning, such as for the CP.

2.3.2 Subsurface Considerations in Comprehensive Plans

When municipalities develop a CP, they are required to conduct an Environmental Impact Assessment (EIA, or Miljökonsekvensbeskrivning) of the plan's potential impacts (Municipality of Askersund, 2024b). These assessments cover issues such as surface and groundwater, natural environments, cultural heritage and landscape, recreation, and environmental protection as well as risks to health and safety, including noise and pollution. However, subsurface conditions are typically addressed in these assessments only indirectly and from a sectoral perspective rather than holistically. Although GS are not explicitly mentioned, they can be embedded in references to other considerations such as "building where it is suitable" or "protecting groundwater resources." This underlines the sector-based limitations described by (Norrman et al., 2020), where subsurface aspects are considered only in relation to specific activities rather than as part of an integrated resource perspective.

2.3.3 Best Practices and Ongoing Developments

International experiences highlight both shortcomings and promising directions for subsurface planning (Norrman et al., 2020). A review of European planning practices reveals that systematic approaches to incorporating subsurface issues remain rare. In most cases, the subsurface is not fully addressed until the implementation stage, potentially resulting in lost opportunities and functions. Some of the more proactive examples are described below, along with Swedish procedures.

2.3.3.1 Consolidated Regulations and Design Tools - Netherlands

The Netherlands can be highlighted as a frontrunner in integrating subsurface considerations into spatial planning (Norrman et al., 2020). Efforts to formalize subsurface management date back several decades (Lamé & Maring, 2014). In 2008, the *Soil Quality Decree* aimed to balance environmental protection with the economic and social use of soil. Subsequent reforms sought to simplify the regulatory landscape by combining environmental, planning, and construction legislation under a single framework, the *Environment and Planning Act.* It was originally scheduled for 2018 but was postponed to 2024. This reform process strengthened the role of the subsurface in planning and decentralized responsibilities to municipalities, while maintaining a national strategy for overarching issues. Recent policy developments have continued in similar directions. In 2022, the Netherlands introduced a new guiding principle, *Water and Soil Leading*, to emphasize the importance of subsurface conditions in spatial planning (Tarozzo Kawasaki et al., 2025). This has paved the way for initiatives such as *Vision on the Subsurface 2040*, an inventory and visualization project commissioned by the Municipality of Utrecht.

However, challenges regarding the integration of subsurface data into spatial and climate adaptation planning remain limited, mainly due to issues of data accessibility and standardization. One project addressing these challenges is presented by (Tarozzo Kawasaki et al., 2025), who propose a combined use of an online digital design portal and a unified framework for standardized land administration. The online tool, *CLIMACAT* (Climate Catalogue), consolidates climate adaptation and subsurface information into one single platform. The catalogue features 25 climate adaptation interventions, each linked to relevant subsurface and climate data. It is created to improve access to information during early design phases and strengthen the connection between climate adaptation strategies and subsurface resources. Early evaluations of the tool have been positive, particularly regarding its checklist-based design that supports, rather than constrains, users' creativity. Suggestions for further development include improving usability and user guidance, enhancing data traceability, and ensuring adaptability for other national contexts where different data and subsurface models are available.

Overall, the Dutch experience illustrates how a combination of clear legislation, decentralized responsibility, and accessible data infrastructure can strengthen the role of the subsurface in sustainable spatial planning.

2.3.3.2 Underground Masterplans – Finland and Singapore

Across the world, several countries, including China, Turkey, Canada, and the Netherlands, have developed sectoral underground plans which primarily focus on construction and engineering aspects (Delmastro et al., 2016). However, a few cities have taken a more holistic approach by developing 'Underground Master Plans'. These function as strategic spatial frameworks similar to CPs for land-use but are instead dedicated to the subsurface.

According to Delmastro et al. (2016), these master plans typically include:

- Existing and future underground facilities and tunnels
- Space reservations for potential development
- Access and maintenance networks
- Identification of suitable new locations for various underground functions
- Technical requirements and planning guidelines

One of the most advanced and fully implemented examples is found in Helsinki, Finland (Norrman et al., 2020). Initiated in the 1980s, the city's 'Underground Master Plan' has evolved into a planning framework that manages both public and private underground spaces (Vähäaho, 2016). It defines policies for construction, establishes coordination mechanisms, and evaluates rock resources for potential future use. The overall goal of the plan is to enhance the management and coordination of subsurface space to provide efficient and sustainable long-term use of underground resources. It also promotes cross-sectoral data sharing and cooperation among planners, engineers, and policymakers. One notable multifunctional project developed under this framework includes an underground wastewater treatment facility. This has replaced several surface plants, which has freed land for other uses and improved urban aesthetics. Another project is an underground swimming pool in Itäkeskus that can be rapidly converted into an emergency shelter for 3,800 people. Inspired by Helsinki's success, other Finnish cities such as Tampere have since begun to develop their own underground plans (Delmastro, 2016).

According to Vähäaho (2016), the plan's success can partly be explained by favourable geology, Helsinki's moderate size and available underground space, but also other factors. Highlighted examples are *Longterm stakeholder commitment* that ensures continuity in planning efforts, *Development of a suitable legal framework* that clarifies responsibilities and ownership, as well as *Systematic management of geotechnical and infrastructure data*, which can provide a strong knowledge foundation.

Another prominent example of proactive subsurface planning is Singapore, where rapid urbanization and land scarcity have spurred strong interest in subsurface development (Zhou & Zhao, 2016). In 2007, the government established a national task force to explore the potential for an Underground Master Plan. By 2010, underground space development was incorporated into the country's long-term economic strategy, resulting in several practical initiatives, including targeted policy reforms, increased investment in research and the systematic mapping of underground resources.

2.3.3.3 Developing Practices in Sweden

In Sweden, several recent projects have sought to advance subsurface planning (Norrman et al., 2020). The HUMP-project 'Storstadsutveckling – behov av undermarksplanering', is a feasibility study commissioned by SGU, the Swedish Transport Administration (Trafikverket), and the National Board of Housing, Building and Planning (Boverket) and was tasked with identifying current challenges and proposing solutions (Nordström, 2017). The study concluded that there is no shared understanding of what sustainable subsurface planning entails, that the first-come-first-served principle still dominates, and that while the existing legal framework is clear for individual actors, new instruments are needed to strengthen coordination in the early stages of planning. Another initiative, the *Eko-Geokalkyl*, has developed a GIS-based tool for preliminary cost assessments of different land functions in the early planning phase (Carlsson et al., 2020).

Norrman et al. (2020) have also proposed a new tool called the SUB-matrix; an advanced checklist designed to integrate subsurface considerations into municipal planning from a holistic perspective. Grounded in the concept of geosystem services, the SUB-matrix aims to support cross-sector communication and ensure that important subsurface aspects are not overlooked. Complementing this, ongoing research within the UNDER-group on geosystem services continues to expand the knowledge base and provide valuable input for future planning practices (Lundin-Frisk, 2025).

2.4 Data Visualization, Maps and GIS

Most forms of data visualization aim to present a simplified picture of a more complex reality. In spatial planning, which combines many interconnected fields, this is essential for enabling well-founded and transparent decisions (Sourd & Ricker, 2025). Among all visualization tools, maps have been a central instrument since early civilizations and remain as one of the most important tools in geospatial planning (Jochen, 2025). Maps function as practical interfaces between data, space, and people, making large-scale information, such as geological conditions, infrastructure networks, or land-use patterns, accessible in a way that neither text nor numbers can achieve. Their flexibility allows for tailored representations at different scales and for different users and purposes, ranging from technical analyses to participatory planning.

Despite their usefulness though, maps are never neutral. By definition, they simplify and generalize reality, meaning that some information is emphasized while other aspects are downplayed. The design and production of meaningful maps therefore require thoughtful decisions about purpose, audience, and technique. Two cartographers at one of the world's leading GIS-companies, Esri, have presented a 10-

step checklist of how to make a map meaningful (Buckley & Field, 2011). The content basically involves answering the question “How to say what to whom and is the result effective?”. This entails considering:

- Purpose and target audience (Whom)
- Type and nature of the data being represented (What)
- Methods and conventions applied to create the map, such as visual variables, appropriate scale, generalization level and standard map elements such as titles, legends, etc. (How)
- Evaluation of how clearly and accurately users can interpret the message (Effective)

Since the usage of maps is widespread, different fields face different specific challenges. In geospatial planning, this can, for example, include visualizing uncertainties or overlapping data (e.g., soil depth or lithological layering) without cluttering the map or displaying contradictory datasets (e.g. areas where buildability is good due to one factor but bad due to another). According to Buckley and Field (2011) design choices, including colour schemes and contrast, scale, and projection, also strongly affect interpretation. As a result, effective mapmaking requires a careful balance of scientific accuracy, technical precision, and visual design to achieve both clarity and credibility.

Geographic Information Systems (GIS) are digital technologies used to manage, analyse, and visualize spatial data (Esri). Common examples are ArcGIS, QGIS, Google Earth Pro and Mapbox. All of them integrate location information (where things are) with descriptive attributes (what/how things are) to support pattern recognition, scenario testing and spatial decision-making. By allowing users to manage, share, and interpret large datasets, GIS can facilitate a deeper understanding and more efficient management of spatial information. This project uses the software QGIS (Quantum Geographic Information System), which is a flexible open-source GIS platform widely used in research and spatial planning (Palino & Sparks, 2024).

3 CASE STUDY AREA - ASKERSUND

Askersund is a medium sized Swedish municipality located in Örebro County (Örebro Län) (Municipality of Askersund, 2024a). It is positioned 58°53′00″N 14°54′00″E, mainly within the province (landskap) of Närke but partly in Östergötland as well. The central locality is Askersund town, a city with emphasised small town-character and surrounded by several smaller service- and residential communities such as Åsbro, Åmmeberg, Zinkgruvan, and Olshammar. The municipality covers about 1,020 km² and borders to the municipalities of Hallsberg, Laxå, Karlsborg, and Motala. Population numbers have shifted from decline towards slow growth, from 11,156 inhabitants in 2015 to 11,477 in 2024 where about 4,700 live in Askersund town, 4,000 in other towns or villages and 2,500 in rural areas. Demographically there is an ongoing change towards an increasing share of elderly citizens relative to the working-age population.

3.1 Geography and Climate

Geographically, Askersund is situated at the northern tip of the lake Vättern. The area is predominantly rural with 74% forest cover, including the Tiveden and Tylöskogen forests, intermixed with cultivated lowlands (Ekholm & Hallin, 1980). Characteristic natural areas include the northern inland archipelago of Vättern and Tiveden. Apart from forests, water is a defining feature of the municipality. Lake Vättern, Sweden's second largest lake, dominates the hydrology and serves as a central drainage point. Numerous smaller lakes and watercourses are situated within fracture valleys and upper soil layers.

The county can generally be said to have inland climate but is locally influenced by the proximity to Vättern which heats during winters and cools during summertime(Ekholm & Hallin, 1980). Average temperatures for the province Närke range between –2 to –3 °C in January and 16–17 °C in July, with annual precipitation of 550–650 mm(SMHI). Highest monthly precipitation has been measured to 240,8 mm in august 2023.

3.2 Geology

The geological setting is dominated by Precambrian bedrock, mainly gneiss, with younger bedrock types such as sandstone and limestone occurring mainly around Vättern (Ekholm & Hallin, 1980). Tylöskog has a long history of quarrying and zinc ore continues to be mined in Zinkgruvan. The Quaternary deposits are mainly moraine, but the area is also notable for its relatively large proportion of glaciofluid deposits. The landscape has been strongly shaped by fault lines and fracture zones in the bedrock. These zones were later accentuated by external pressure and glacial processes, creating marked valleys and ridges (Ekholm & Hallin, 1980). One example is the rift valley that became Vättern.

3.3 Social and Economic Situation

Askersund's economy is shaped by its rural and forest-based surroundings with traditional industries such as agriculture, forestry, fishing and mining production (Municipality of Askersund, 2024a). Public services account for the largest share of employment, while the business landscape combines a few larger actors with many smaller, geographically spread enterprises (Municipality of Askersund, 2024a).

In 2023 the municipality showed an employment rate of 84% where Zinkgruvan Mining AB is the largest private employer with about 525 employees in 2024 (Ekonomifakta). Though the local labour market is strong, the municipality also utilize regional collaborations (Municipality of Askersund, 2024a).

3.4 Askersund's Comprehensive plan

Askersund's currently active CP covers the period 2015–2025 (Municipality of Askersund, 2016). In 2021, the municipal executive committee decided to prepare a new plan with a timespan extending to 2040 (Municipality of Askersund, 2024a). The process began in 2022, was reorganized in 2023 and a first draft, including both digital and analogue versions, was presented for public consultation in 2024. Revisions are planned for autumn 2025, with final adoption expected during the first half of 2026. Following sections gives a brief overview of the plan's content.

3.4.1 The Identity of Askersund

The 2024 draft highlights the municipality's main qualities and development potential. Askersund's proximity to Lake Vättern, its scenic surroundings and varied housing environments are seen as key strengths, complemented by access to regional labour markets. Together, these factors support an attractive living environment valued by residents who prioritize quality of life and access to nature over workplace proximity. The plan seeks to build on this image by strengthening Askersund's rural identity while encouraging sustainable business growth, particularly along major transport corridors such as Highway 50.

3.4.2 Targets and Plan Objectives

Unlike many municipalities, Askersund's comprehensive plan does not define a population target for 2040. Instead, its overarching aim is to secure a high quality of life and a long-term supply of competence through a balance between development and preservation. Land and water are set to allow for future growth without compromising valuable landscapes, farmland, or cultural environments. To achieve this, the municipality is divided into seven subareas, each reflecting local conditions and development priorities. The strategy focuses on reinforcing existing settlement and business corridors to concentrate resources, strengthen local services, and attract employment.

In the plan, farmland protection remains a guiding principle: small-scale development at the edges of agricultural land may be acceptable, but large industrial projects on productive farmland are discouraged. Instead, new business areas are prioritized on forest land or in locations with good access to energy, transport, and workforce resources, balancing economic development with the preservation of natural and agricultural values. Business growth is primarily directed to areas along Highways 50 and 49, especially between Åsbro and Askersund, where existing industrial activity and suitable land create favourable conditions for expansion. Nature and recreation are also prioritized factors. In towns like Askersund town, greenery and park areas integrated into future planning to ensure access for all residents and new housing developments are guided to retain a rural character in line with Askersund's identity and settlement traditions.

3.4.3 Specific Areas of Development

Apart from the general corridors of business growth, the plan identifies several transformation areas which are likely to undergo major land changes in the coming years. These include northern areas around Åsbro, where the railway will be relocated and a former wood impregnation site remediated. Another one is southern Askersund, where part of the nationally important Highway 50 will be shifted eastward leaving the old section as a local road.

Southern expansion zones are examples of areas which aims to combine new development with protection of landscape and environmental values. One example is development along the western coast of Lake Vättern. The plan for this area is to keep it available for public while still allowing limited new development on small scale. The strategy is meant to utilise the attractiveness of the water while still protecting the unique environment from overexploitation.

3.4.4 Mining areas

Historically, Askersund has been shaped by mineral extraction and material processing, leaving both environmental and cultural traces. The plan includes maps of historic and ongoing mining areas, particularly around Zinkgruvan, where zinc, lead, and copper concentrates are extracted. While no explicit municipal stance on future land use is defined, these areas are highlighted to emphasize the need for continued dialogue and coordination when conditions change.

3.4.5 Infrastructure projects

Infrastructure development is also a central part of the transformations. There is an ongoing double-track expansion of the Hallsberg–Mjölby railway which passes through the municipality. This is a part of the Scandinavian–Mediterranean link in the Trans-European Transport Network (TEN-T) which is expected to increase capacity and prevent operational disturbances, while providing more sustainable transports through Sweden and down to Europe.

3.4.6 Climate adaption

Climate adaption is another issue which the plan considers in different ways. Erosion and landslides, as well as flooding risks effects on national food production, are issues that are taken into special regard. To mitigate these and similar climate induced problems the CP in general stresses the importance to plan and build carefully and as far as possible in locations where nature and ecosystem services are not negatively affected. Drinking water issues are also mentioned in the plan, but since Askersund, compared to many other places areas, has good access to both Vättern and groundwater aquifers that is not considered as a pressing issue.

3.5 Askersund's EIA

Following sections summarise the EIA of Askersund, with particular focus on parts that can relate to various GS. The document identifies major challenges concerning climate impact connected to municipality's rural structure. Long travel distances, car dependency, and low population density make densification within main settlements essential to reduce emissions and improve resource efficiency. Several conflicts of interest are also recognized:

- Preserving traditional small-scale settlement patterns versus concentrating resources through densification.
- LIS-areas (Landsbygdsutveckling I strandnära lägen) versus maintaining public access to recreational areas.
- Using agricultural land for housing versus preserving farmland as a resource.

Climate changes also call for measures regarding stormwater management. Risks of flooding and increased erosion highlight the importance of early integrated sustainable stormwater management, including contamination treatment of runoff from roads and industrial areas.

Other types of water protection are also of central concern. Lake Vättern and the municipality's many smaller lakes and streams contribute to recreation and biodiversity as well as being sources for drinking water. According to classifications by the Swedish Agency for Marine and Water Management, all groundwater bodies in Askersund currently maintain "good" chemical status, whereas most surface waters do not reach that goal, primarily due to elevated levels of mercury and PBDEs. The EIA stresses that no measures may compromise environmental quality norms and that, since several planned expansion areas overlap with groundwater zones, additional protection measures will be required in later planning stages.

Other potential disturbances, such as industrial contaminants, hazardous goods and noise, are also addressed through targeted measures, with the Highway 50 business corridor highlighted as a suitable strategy to concentrate such activities. Overall, the EIA concludes that as long as proposed mitigation measures are implemented, the comprehensive plan can be carried out without significant harm to national interests or violations of environmental quality standards for water.

4 METHOD

This chapter describes how this study was conducted, including methodologies for information search. The practical process can be divided into four main steps. First, relevant geosystem services were selected, resulting in five prioritized services. Second, indicators and data sources were identified or developed to allow mapping of the services. Third, the services were mapped in QGIS with the result of two map types for each service: Geophysical potential (G), representing the inherent capacity of the environment to supply the service, and Effective potential (E), representing the share of this capacity that is available and suitable for use. Finally, the maps were evaluated in a workshop with representatives from Askersund municipality to assess usability and identify improvement opportunities.

4.1 Information Search and Writing

The following chapter describes the methodologies used during the project to find and compile information.

4.1.1 Literature Search

Since this project is a form of product development, the literature study was limited compared to a full literature review. The topic of GS is also fairly novel, which limits the available material. Nine articles and technical reports were initially studied due to their connection to the UNDER-project, and the remaining literature was found by using citation chaining (a.k.a. snowballing) or through independent searches for articles in the database Scopus. Descriptions regarding legal frameworks and municipality data and documents were found through official webpages, for e.g. Boverket and the Askersund Municipality. Information regarding GIS was collected from public material published by Esri.

4.1.2 Previously Collected User Input

To understand the priorities and needs of Askersund's municipality, material from previously collected user input was also studied. There had been an ongoing exchange with the municipality between 2020 and 2023, and the available material mainly consisted of a PowerPoint presentation "Fallstudier om Geosystemtjänster i kommunal planering. Möte med Askersunds kommun", which summarised results from a webinar held during 2020.

4.1.3 AI Tools

During the writing process, the AI-tool ChatGPT was used as a text generator. It was used to produce coherent text drafts from bullet points or to reformulate specific formulations to more concise and appropriate language. When creating full-text drafts, the prompt was provided with logically ordered bullet points with the author's own literature notes, along with an explanation of what the text is meant to convey. The strict purpose was to reformulate given information and avoid any addition of new content or analysis. After the generation, the drafts were refined manually by the author. When working with full texts, the tool was consciously ordered to preserve the author's writing style when possible and small parts of notes were prompted at a time to keep good control of the result.

4.2 Selection of Relevant GS

The first challenge of the project was to identify which GS were most relevant to address. This search and selection process followed a stepwise approach that combined insights from local planning documents, stakeholder perspectives and existing scientific frameworks. The objective was to determine a set of GS which aligned with local challenges, met the municipality's practical demand and was manageable within the scope of the project.

4.2.1 Study of CP, EIA and previous workshop

The process began with a review of Askersund's CP and EIA where key themes and priorities related to the subsurface were identified. In parallel, results from a workshop (W0) previously conducted within the UNDER project was analysed. Together, these sources provided an overview of the issues that local planners had emphasized as well as planned developments and activities that could imply relevance for various GS.

4.2.2 Prioritization of GS

Insights from the CP, EIA, W0 and following discussion resulted in an extensive list of potentially relevant geosystem services (GS). This list was continuously compared against the comprehensive GS exposition presented in (Lundin-Frisk et al., 2022), (Lundin-Frisk et al., 2025), and (Lundin-Frisk, 2025) for anchoring the choices in practical approaches for the upcoming indicator selection. However, due to the wide range of subsurface functions with potential planning relevance, a first prioritization mas made to cut down on material.

The intent was to make the prioritized list short enough to focus participant attention and allow sufficient time for discussion. At the same time, the GS were consciously formulated in relatively general terms to allow wider perspectives at this early stage. More details regarding the webinar are presented in Section 3.2.3.1.

4.2.3 Municipality Meeting 1 – Webinar

The next step was to present the list to end-users at a municipal webinar. The purpose was to gather feedback that could support the final selection of GS and make the choices aligned with practical needs and local planning conditions. A comprehensive planner at the Municipality of Askersund served as the main contact and distributed webinar invitations to other municipal employees with relevant planning roles. In the end three participants with varying background and planning experiences attended.

The meeting was conducted digitally on October 13th, 2025, and lasted approximately 1.5 hours. During the first 35 minutes, the research topic was introduced, followed by an overview of previous exchanges and contacts, as well as brief presentations of both the M-case and the A-case studies. This was followed by a presentation of the prioritised GS list and an outline of the forthcoming discussion, centred around the key question: *Which subsurface information would you prefer to have visualized in the form of* *comprehensive maps?* To provide as good a discussion environment as possible the entire session including question material was conducted in Swedish and has been translated afterwards.

Although all presented GS were considered relevant to some extent, further selection was required due to the project's limited timeframe. The underlying methodological question was therefore: *Which GS should be prioritized within this project?* However, the broader formulation was chosen to encourage participants to think and reason more openly, without being constrained by their level of familiarity with the GS concept. To guide the webinar, three specific discussion questions were formulated and addressed sequentially, with each participant contributing in turn. These were consciously formulated to frame the meeting's main purpose and avoid irrelevant sidetracks.

Webinar discussion questions:

1. *Have we missed any important aspect/subsurface issue?*
2. *Are any of the proposals less relevant (e.g. due to existing user-friendly tools/material?)*
3. *Which three maps would you deem most usable?*

The meeting was recorded and transcribed for documentation. Afterwards, the conclusions were summarized and evaluated, forming the basis for the final selection. An anonymised summary of the results was also sent for approval from the participants after translation to avoid misinterpretations and bias.

4.2.4 Final selection of GS

After consideration of webinar-feedback a list of final GS with assumed practical relevance for Askersund were selected for further development. The choice was guided by four key considerations: municipality opinions, approximated data availability, extended research value and limitation of scope.

4.3 Compilation of indicators and data sources

After the final set of GS had been selected, the next step was to identify appropriate GS-indicators to represent the services' potential. GS-indicators meaning one or multiple data parameters that could link the service's capacity, accessibility and/or suitability to the existing environment. Classification schemes were also required to translate parameter values in various units to GS-potential.

Rather than developing new indicators, the approach intended to adapt those already presented in previous research. In cases where this was not possible due to lack of data, new indicator parameters and classifications were determined. Most indicators were derived directly or took inspiration from the list of National indicators, presented in (Lundin-Frisk et al., 2025), which presents parameters adjusted to reflect general Swedish conditions. This material was further complemented with data from (Lundin-Frisk, 2025) where several national indicators had been refined and described in greater detail to suit the local context of the M-case study.

Parallel with the search for indicators was the search for available data. This was found in the databases for SGU, the Swedish mapping, cadastral and land registration authority (Lantmäteriet), the County Administrative Board (Länsstyrelsen) and the Swedish Environmental Protection Agency (Naturvårdsverket or EPA).

In some cases, the indicators were adjusted to better reflect Askersund's local conditions, for example, by calculating the demanded water volume for the parameter unsaturated zone thickness. Other times, data for established parameters were lacking, which demanded the development of new indicators and classifications.

The process resulted in one list of indicator parameters and data sources corresponding to each selected GS. All lists included at least one parameter for capacity and various numbers of parameters regarding accessibility and suitability.

4.4 Development of maps

For each service, two maps were produced: one showing Geophysical potential (G) and one showing Effective potential (E). The Geophysical potential (G) represents the subsurface's inherent ability to provide a service, while the Effective potential expresses the practical potential that people can actually benefit from, based on local conditions of accessibility and suitability.

The maps were designed to be interpreted through a set of capacity classes. Each data unit is classified into different categories, divided into spans from high to low and accompanied by an associated numerical value. For Geophysical potential maps, GS-potential is represented by Class A - *High capacity* (value 3), Class B - *Moderate capacity* (value 2), Class C - *Some capacity* (value 1), and Class D - *No capacity* (value 0). The effective potential was classified in a similar way, but since suitability and accessibility are viewed as limitations, these parameters are only classified in either Class C - Limited/Conditional accessibility/suitability (value 1) or Class D -Inaccessible/Unsuitable (value 0). A full overview of the different capacity classes is shown in Table 1.

The mapping approach builds on the methodology presented by Lundin-Frisk (2025), and all spatial processing was conducted in QGIS, version 3.44.2–Solothurn. For all maps, detailed information regarding the application of QGIS tools, the data sources used, the classifications of potential and the specifics of the processing steps is provided in the Appendix.

Table 1: List of capacity-, accessibility- and suitability classes with corresponding GS-potential labelling.

Class	Label	Description
Capacity	A (3) Highest capacity B (2) Moderate capacity C (1) Some capacity D (0) No or limited capacity	High contribution to the supply of the service. Moderate contribution to the supply of the service. Some contribution to the supply of the service. No or Limited contribution to the supply of the service.
Accessibility	N/A C (1) Limited/conditional accessibility D (0) Inaccessible	No restrictions of service in terms of accessibility. Accessibility imposes some limitations to the supply of the service, but not to a prohibited extent. Accessibility imposes significant limitations that preclude the supply of the service.
Suitability	N/A C (1) Limited/conditional suitability D (0) Unsuitable	No restrictions of service in terms of suitability. Suitability imposes some limitations to the supply of the service, but not to a prohibited extent. Suitability imposes significant limitations that preclude the supply of the service.

4.4.1 Data Gathering and Pre-processing

The mapping process began with the collection of raw geospatial data from various national and regional databases. These datasets consisted of polygon, line, or point data, each containing attributes relevant to the indicator parameters. The datasets were imported into QGIS, where they were organised as map layers.

The data was then pre-processed to ensure that only relevant information was included in the maps. This involved filtering, sorting, merging, dissolving, and clipping layers to restrict the spatial extent to the study area and to isolate the specific indicator parameters needed for each service. For example, nationwide groundwater reservoir polygons were reduced to only those intersecting Askersund Municipality and simplified from thousands of features to four polygons, based on documented extraction capacity.

When raw data was available as point measurements (for instance, well-data used to estimate the thickness of the unsaturated zone), the data was first interpolated to a raster surface with a resolution of 100 × 100 meters. This made it possible to process and visualise it as area-based information in the same way as polygon data.

Some accessibility attributes consisted of line data (e.g., roads) and with similar reasoning as for point data, they were surrounded by approximated buffers to create width and area. Many maps also held point data regarding contamination, which was problematic since that visualization do not tell the viewer anything regarding potential spread. To better visualise that, the data was interpolated into a 300x300 m grid. Each grid cell was then classified according to the number and severity of registered contamination points in it. The process is described in more detail in Appendix – A.2.

Since the process came to include multiple data layers and processing steps, each geosystem service was processed in its own QGIS project to maintain clarity and avoid parameter overlap. Once the processing was complete, the final layers were transferred into a shared master project used for producing uniform and consistent map layouts.

4.4.2 Translating Indicator Parameters into Geophysical and Effective GS-potential

For each pre-processed dataset containing indicator parameters, a new attribute, 'capacity class', was added. Each feature in the dataset was then manually assigned a class and GS-potential value according to predefined classification schemes, provided for example in (Lundin-Frisk et al., 2025) and (Lundin-Frisk, 2025). For each GS, these new attribute values were then used as the basis when rendering the Geophysical potential map.

In some cases, the GS-potential depended on multiple capacity-related parameters from different datasets. For those cases, the combined potential was determined through a more extensive processing method. In areas where multiple indicator parameters held different potential classes, the most conservative (i.e., lowest) potential value was selected. For example, in the case of the service 'Infiltration and Retention of Stormwater', the parameter permeability might indicate high potential (A;1), while the thickness of the unsaturated zone indicates moderate potential (B;2) and soil depth provides only some potential (C;1). The final classification for that area would therefore become *Some potential (C;1)*.

The process of mapping the Effective potential was similar to the geophysical one. Just as for that case, parameters representing accessibility and suitability were now assigned new attributes: 'accessibility class' or 'suitability class'. These were assigned effective potential-values using the same logic as for the capacity parameters and used for rendering layers for suitability and accessibility. Finally, these layers were added on top of the Geophysical map as overlays to visually describe the reduction of GS-potential in certain areas. The result was a partly restricted version of the Geophysical potential map: The Effective potential map.

4.5 Evaluation of maps in Municipality meeting 2 - Workshop

To attain an end-user evaluation of the maps, a second meeting in the form of a workshop was held with the Municipality on site in Askersund, December 3rd, 2025. The workshop lasted three hours, including an introduction and the active workshop session. To avoid language barriers, all discussions were held in Swedish, and the workshop material had been translated beforehand.

At the workshop, there were six municipal participants with varying connections to urban planning. Only two of them had taken part in the previous webinar, but the presentation material used there had been included in the invitation to this second meeting to provide newcomers with voluntary preparation material.

To ensure a unified starting point, the workshop began with a short introduction and recap of previous exchange: a presentation of the research group and participants, followed by an overview of the UNDER-group's research project. This was continued by a brief repetition of the geosystem service concept and the indicator method applied in the M-case. After that, a summary of the A-case project was presented, including how the project had progressed since the previous webinar and finally, the five maps were introduced with a short explanation of their purpose and the data behind them.

The participants were then guided through the workshop setup. They were divided into two groups of three people, each joined by two assisting researchers from Chalmers or SGU (thesis author and supervisors). Five stations were prepared, one for each map and the groups were told to spend around 15–20 minutes at each station. To provide a better understanding, all stations were provided with a page of assisting documentation which briefly described the purpose of the GS and the data sources used to create the maps.

The aim of the workshop was to provide answers for the three fundamental questions: *"Are the maps understandable?"*, "*Are the maps useful?"* and *"How can the maps be improved?"* However, since those questions were assessed as too broad and easy to diverge from, four specific questions were provided at every station to guide the discussions. The participants examined the maps and summarized their answers on colour-coded notes corresponding to each question. At the end of the session, each participant was asked for some final remark or reflection. To avoid misinterpretation or bias, the workshop responses were summarized in tables and translated (see Result chapter 4.4) and then sent back to the participants for approval.

Workshop discussion questions at each station:

1. *a) What information can you interpret from the map?*
   b) Does the map provide any new information?
2. *a) How do you think the map could have been used in early planning work?*
   b) Do you think the map is a relevant complement to existing planning material? Why?
3. *Do you have any suggestions for improvement?*
4. *Any other reflections?*

5 RESULTS

This chapter presents the outcomes of the study, starting with findings that guided the selection of GS, followed by descriptions of each service as well as identified indicators and data sources. Then follows a presentation of the produced maps along with a summary of the evaluation responses from the workshop along with an analysing assessment of each of the five maps.

5.1 Results of GS Selection Procedure

This part presents outcomes from the GS-selection process. That includes key themes from Askersund's CP and EI, insights from the initial workshop (W0) and the webinar and in the end a final list of selected services along with a motivation for their relevance to Askersund.

5.1.1 Key Themes from CP and EIA

Neither the Comprehensive Plan (CP) nor the accompanying Environmental Impact Assessment (EIA) explicitly address geosystem services. However, several themes discussed in both documents are closely related to subsurface planning and collectively provide insight into local conditions, priorities, and challenges relevant to geosystem services. Sections below present five identified themes, which are also summarised in Table 2, along with potentially connected GS.

1. **Buildability** emerges as one key theme, shaped by an overarching aim to preserve agricultural land. This policy redirects development toward other, potentially more geotechnically demanding areas. Both documents also describe several planned or ongoing developments, including major infrastructure projects such as railway expansion and the realignment of Highway 50, and the promotion of business development along the transport corridors. In addition, limited development along the scenic western shore of Lake Vättern may also involve increased construction-related challenges.

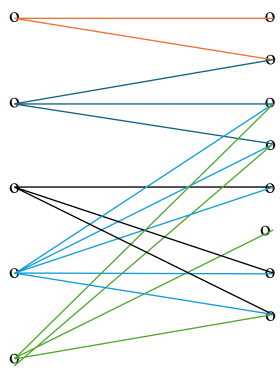
2. **Stormwater management** is identified as a high priority for climate adaptation, with flood mitigation and erosion prevention emphasized. The EIA also notes that surface water quality is generally poor, which, from an outside perspective, raises the questions whether current or future development projects could integrate or prepare for water treatment solutions, such as stormwater retention ponds along major roads.

3. **Groundwater supply** is considered to have relatively low priority, since the availability of water from Lake Vättern and local aquifers is currently sufficient. This perspective, however, raises questions regarding long-term sustainability and whether changing national security considerations of emergency management and civil defence could affect future priorities.

4. **Soil and water quality** concerns are linked to agricultural activities, new infrastructure development, and legacy mining operations, all of which pose risks of contamination to soil, surface water, and, over time, groundwater.

5. Finally, **material provision** is addressed implicitly through discussions of active mining and large infrastructure projects. While mining activities require careful consideration of contamination risks, they are also highlighted as economically significant, creating incentives to maintain or expand extraction activities. Quarrying for Material provision can, on the other hand, also pose dangers to groundwater aquifers which calls for consideration in relation to the municipality's reliance on groundwater resources.

Table 2: Key themes in CP and EIA linked to potentially relevant GS.

Key themes		**Potentially related GS**
Buildability		Bearing capacity
		Resistance to erosion
Stormwater management		Regulation of water quantity
		Regulation of water quality
Material provision		Provision of geomaterials for construction
		Provision of mining minerals
Groundwater supply		Provision of groundwater extraction
		Regulation of soil and bedrock chemistry
Soil and water quality		

5.1.2 Key challenges and priorities from previous contact with municipality

Assessment of the earlier workshop W0 with Askersund municipality resulted in three prioritized planning challenges, which were frequently mentioned:

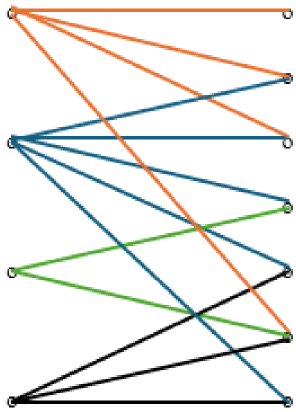
Buildability: identifying areas that are physically suitable for construction. Late discoveries of limitations regarding buildability or difficult ground conditions were said to contribute to stagnating development or to substantially increased construction costs.

Flooding- and stormwater management: determining where water-related problems can be avoided already in early planning stages. Poor management and increased runoff volumes were noted as both a financial challenge and a potential risk to groundwater levels.

Soil and water contamination: understanding which areas may be unsuitable for development despite otherwise favourable conditions. Contaminated land poses health risks, increases remediation costs and risks compromising groundwater quality.

Among these topics, the strongest consensus concerned stormwater management, followed by buildability and contamination issues. Additional concerns were conveyed verbally, notably regarding **material provision**, specifically the conflict between the extraction of natural gravel for concrete production and the protection of glaciofluvial deposits as a drinking water source. Based on this material, seven GS were identified as most relevant for addressing the municipality's challenges and are presented in Table 3.

Table 3: Prioritized challenges from W0 linked to potentially relevant GS.

Prioritized challenges		Possibly related GS, suggested by author
Buildability		Regulation of stress and strain
		Regulation of erosion
Flooding and Stormwater management		Regulation of water quantity
		Regulation of groundwater quality
Contamination		Provision of construction material
		Regulation of soil and bedrock chemistry
Material provision		Provision of groundwater

5.1.3 GS selection in preparation for Webinar

Insights from the CP, EIA, W0 and following discussion, combined with extended research value, resulted in the following list of nine GS to present at the Webinar.

GS prioritized for the Webinar:

The subsurface's ability to…

1. …regulate surface load,
2. …regulate load over caves and tunnels,
3. …regulate erosion,
4. … (not) emit substances or radiation harmful to human health,
5. …treat stormwater through infiltration,
6. …infiltrate stormwater,
7. …facilitate extraction of groundwater,
8. …provide geological construction material, and
9. …provide mineral resources for mining.

5.1.4 Results from Municipality meeting 1 - Webinar

This subchapter presents the results from the webinar where representatives from the Municipality of Askersund discussed the nine prioritized GS to evaluate their perceived relevance and potential usefulness in local planning practice. Three representatives from the municipality participated: one comprehensive planner (A), one GIS engineer (B) and one spatial planning architect (C). Three key questions structured the discussion, and following sections present a summarised version of the participant responses.

Question 1: Have we missed any important aspect or subsurface issue?
All participants gave the unanimous answer "*no*". Some follow-up discussion explored whether certain aspects, such as subsurface energy extraction or cultural services, might be relevant. The general response was that, while such topics could be of interest, other issues among the presented GS appeared more pressing and directly connected to municipal planning needs. It was also noted that two of the three participants (the planning architect and the GIS engineer) were new to the GS concept, which made it difficult for them to fully assess potential missing aspects without more time for reflection and familiarity with the framework.

Question 2: Are any of the proposed GS less relevant?
Several services were deemed less directly applicable to the municipality's current planning work, including the subsurface's ability to:

- facilitate the extraction of groundwater,
- provide geological construction materials, and
- provide mineral resources for mining.

Participants found it difficult to see how these services could be practically integrated into ongoing municipal processes. In addition, one participant (B) found that the services *regulate surface load* and *regulate load over caves and tunnels,* were of uncertain relevance, though this view came primarily from a participant whose role was more peripheral to practical planning tasks.

Some reservations were expressed regarding drinking water services, as representatives from the environmental department, who might have a greater insight into this topic, were not present. While current aquifers are protected and supply is stable, drinking water could become more significant in the future in relation to reserve capacity or emergency preparedness, under, for example, climate change scenarios.

One participant (B) also raised a broader point about the usability of map material. It was noted that complex, multi-layered maps can be difficult for municipal officers to interpret and compare. Simplified materials that merge information into fewer, more comprehensible layers were preferred for providing overviews of key issues.

Question 3: Which three maps would be most usable?
The participants identified the following GS as most useful for their municipal work:

- the subsurface's ability to regulate erosion,
- infiltrate stormwater, and
- (not) emit substances or radiation harmful to human health.

These were regarded as most directly connected to the municipality's prominent planning challenges: buildability, stormwater management, and contamination. Participants emphasized that these topics are highly relevant both in the CP and in subsequent detailed development planning stages.

Additional discussion concerned the types of contamination data currently available and their use in planning. It was explained that Askersund does not maintain its own datasets but uses materials provided by Länsstyrelsen. Contaminated areas are currently considered in the CP mainly by referencing previously identified sites, with further assessments conducted during detailed development planning. Radon is also considered at the CP stage, although the data sources were considered uncertain. Data on gamma radiation were reported as available from SGU.

Cultural services were briefly discussed but regarded as sufficiently covered by existing material. The meeting concluded with reflections on how geosystem service maps could best complement existing planning materials. Opinions differed regarding map design: Participant C preferred separate maps for each GS, while Participants A and B saw advantages in both separate and thematic maps (e.g., "Buildability" or "Stormwater Management"), depending on the intended audience, use and whether the maps would be used digitally or in print. Regardless of format, all participants agreed that colour gradients effectively communicated variations in GS potential. While external communication could also be a valuable secondary function, the project aims primarily to develop a tool for internal use between municipal planners.

Additional notes:
Two GS were not specifically discussed: the subsurface's ability to *treat stormwater through infiltration* and the ability to provide substitutes for natural gravel in concrete by addressing the service *provision of geological construction materials*.

5.1.5 Condensation into a Final List of GS

The discussions during the webinar largely confirmed the conclusions drawn from the CP, the EIA and W0. One distinct finding was that interest in the themes *Goundwater Supply* and *Material Provision* was noticeably low. An important contextual factor though, was the participants' limited prior experience with the geosystem services (GS) concept. Due to staff turnover, none of the attendees had participated in the previous workshop W0, and only one participant (A) had encountered the GS concept before. This may have contributed to a focus on more familiar, established themes, while reconsidering newer ones (as drinking water and material supply) could be more difficult within a short meeting format.

Based on the meeting outcomes, while also considering the limited representation during the meeting and a more risk-oriented perspective, it was decided to still focus on four thematic areas: '*Buildability*', '*Flooding and stormwater management'*, '*Groundwater supply'* and '*Material provision'*. Although the drinking water supply had received little attention in both the CP and the meeting discussions, it was still regarded as essential given society's dependence on reliable water resources and the growing risks posed by climate change and competing land uses. Moreover, the intersectoral trade-off between groundwater protection and material extraction made this theme particularly interesting from a research perspective.

The theme *Soil and water quality* was also considered relevant. However, uncertainties regarding data and how to practically map various types of contaminants, including radiation, made the task exceed the project scope. Instead, it was determined to regard general contamination risk as a suitability parameter within other GS rather than a service on its own.

When it came to the choice of map design, it was decided to adopt the same procedure as in the M-case and create individual GS maps rather than combined thematic ones. This is due to the risk for cluttering while allowing more flexibility, data transparency and intersectoral usage.

In the end, the result was based on five key factors: municipal preferences, risk perspective, data availability, broader research value and limitations of the scope. The outcome was five specific GS, presented in Table 4. The following subchapters provide a more detailed description of each service along with its presumed relevance for Askersund.

Table 4: List of selected GS along with specific use, benefits and related themes

General Geosystem Service	**Specific Geosystem Service**	**Specific use**	**Benefit**	**Related theme(s)**
Regulation of water quantity	Infiltration and Retention of Stormwater	Natural flooding mitigation	Lowered flooding risks Reduced costs and property damage due to flooding	Stormwater management Groundwater supply Buildability
Provision of groundwater	Provision of Groundwater	Extraction on municipal scale	Access to fresh water	Groundwater supply Material provision
Regulation of stress and strain.	Bearing Capacity	Surface construction	Prevented costs due to soil subsidence etc	Buildability
Regulation of erosion	Resistance to Erosion	Construction	Prevented costs due to landslides etc	Buildability Stormwater management
Provision of construction materials	Provision of Rock Aggregate	Production of crushed aggregate for concrete	Local access to concrete aggregate	Material provision Groundwater supply

5.1.5.1 Infiltration and Retention of Stormwater

Climate change is expected to bring heavier and more intense rainfall, increasing pressure on stormwater systems and raising the risk of flooding and property damage. Although stormwater management is currently an established part of spatial planning, it is often addressed too late, which can lead to the loss of natural infiltration areas and create a need for costly technical solutions to replace them.

The Geosystem Service Infiltration and retention of stormwater helps reduce flooding by allowing water to infiltrate and be retained locally, which mitigates the risks of overloading drainage systems. A map of this service highlights areas with high natural infiltration potential; areas that may be important to preserve or to utilise in planning to reduce the need for post-construction stormwater measures.

5.1.5.2 Provision of Groundwater

Sweden, including Askersund, has traditionally enjoyed stable access to high-quality raw water, but several emerging factors may challenge this in the future. Climate change risks altering precipitation patterns, increasing summer droughts, and affecting water quality through warmer temperatures and ecological changes. At the same time, a heightened national security context has raised questions about the resilience of essential resources. Together, these developments suggest that future access to high-quality water may become less predictable than today.

The Geosystem Service Provision of groundwater reflects the subsurface's ability to store and allow for the extraction of groundwater from natural aquifers. A map of this service would therefore highlight areas with potential to serve as municipal-scale groundwater sources, information that may help strengthen long-term water security and reduce pressure on other vulnerable water supplies.

5.1.5.3 Bearing Capacity

Construction projects depend heavily on subsurface stability, yet modern engineering techniques and competing interests sometimes make it tempting to build in areas that are not naturally well-suited for bearing heavy loads. This can lead to unexpected costs, delays, or technical complications—issues that might have been avoided through better early awareness of ground conditions.

The GS Bearing Capacity reflects the natural ability of the subsurface to support buildings and other constructions without causing subsidence, landslides or other forms of structural failure. A map of this service would therefore highlight areas with naturally high bearing capacity. By incorporating this information early in the planning process, it may be possible to steer development toward more suitable locations or to better anticipate necessary foundation measures. This could help reduce avoidable costs and improve the accuracy of project budgets.

5.1.5.4 Resistance to Erosion

The ground's buildability depends not only on the load-bearing capacity but also on its sensitivity to erosion, the process by which water, wind, or other agents remove soil or sediment. Over time, this process can undermine sites that initially appear suitable. Since erosion is particularly relevant near water bodies or on slopes, it can be a considerable concern since these locations are often valued for scenic or recreational purposes.

The Geosystem Service Resistance to erosion reflects the ability of the ground to withstand this process, with focus on erosion induced by water. A map of this service would highlight areas where erosion is unlikely due to favourable soil composition and slope gradients, while areas with signs of high erodibility or evidence of past erosion, such as ravines, would indicate lower potential. The aim would be to support planning by identifying locations where the risk of landslides or settlement is lower, complementing other considerations such as surface load capacity.

5.1.5.5 Provision of Rock Aggregates

Concrete remains a major component in many building and infrastructure projects, with ballast being one of its primary ingredients. Transporting these materials over long distances can be logistically complex and generate significant emissions, so local production is desirable. Production of ballast is a specialized process with strict quality requirements to ensure predictable product properties, such as workability and curing time (härdningstid), which in turn place quality demands on the ballast. Historically, natural gravel from glaciofluvial deposits was commonly used, as it often met these requirements. However, this practice has raised environmental concerns, particularly regarding the disruption of groundwater aquifers. Natural gravel extraction is now commonly restricted and substituted with alternative materials.

An alternative to natural gravel is to produce crushed aggregate from bedrock. While this approach reduces reliance on natural gravel, it introduces its own infrastructure, energy demands and especially requires access to bedrock with suitable properties. The Geosystem Service Provision of bedrock reflects the availability of such bedrock for crushed concrete aggregate production. A map of this service would indicate areas where appropriate bedrock exists locally, supporting early-stage planning and helping to identify potentially sustainable alternatives in the material supply chain.

5.2 Final indicators and indicator data sources

Table 5 below shows an overview of the indicators which were used for the GS-mapping. More thorough information regarding the indicator parameters and data sources is provided in Appendix A-1.

Table 5: Summary of Selected GS and indicator parameters used to produce Geosystem Service potential maps in QGIS.

Specific GS	**Specific use**	**Capacity parameters**	**Ori**	**Adj**	**Accessibility parameters**	**Ori**	**Adj**	**Suitability parameters**	**Ori**	**Adj**
Infiltration and Retention of stormwater	Natural flooding mitigation.	Permeability	I	A	Impermeable surfaces	I	A	Contamination	I	
		Unsaturated zone thickness	I	A						
		Soil depth	I	A						
Provision of groundwater	Extraction on municipal scale.	Water extraction capacity	I		Protected areas	I	A	Contamination	I	
					Existing construction/activity	I	A	Ethics	I	A
Bearing capacity	Surface construction.	Terrain class	II	A	Protected areas	III		-		
		Precautionary areas	III							
Resistance to erosion	Construction.	General soil erodibility	I		Existing construction and installations	III		-		
		Precautionary areas	III							
Provision of rock aggregate	Crushed concrete aggregate production.	General rock quality for concrete aggregate	III	A	Soil depth	I		Competing interest: groundwater	III	
					Protected nature	I	A			
					Existing construction/activity	I	A			

Note: The **Ori**-markers (I-III) represents the origin of the indicator parameters: I - Previously proposed in Lundin-Frisk (2025); applied earlier in the M-case. II - Previously proposed in Lundin-Frisk et.al, (2025); first applied in the A-case. III - Not previously proposed; first applied in the A-case. The **Adj**-marker (A) indicates that content in the translation scheme for the parameter has been adjusted to fit Askersund's conditions.

5.3 Final GS Maps – data sources and commentary

After services had been selected and prioritized, maps that illustrated the geosystem services-potential were produced in QGIS and the following subchapters describe the resulting maps. For each GS, one image showing two maps was presented: one *G-map* showing geophysical potential G, and one *E-map* showing effective potential E. Both map types use the same base potential G, but the E-maps include a selection of overlaying attributes for accessibility and suitability, which reduces the base potential in certain areas. The potential-classification corresponds to indicators capacity classes on the scale from D/0 (No or limited potential), C/1 (Some potential), B/2 (Moderate potential), A/3 (Highest potential). Areas covered by water surfaces were considered inaccessible.

For each GS, the respective maps are supplemented with a brief description of the indicator parameters, accessibility and suitability attributes, and data sources. For the G-maps, a calculated municipal area percentage of each level of potential is also presented. More detailed information regarding indicators, data sources, and the QGIS workflow is provided in Appendix A1-A3.

5.3.1 Maps for 'Infiltration and Retention of Stormwater'

Figure 3 presents the two GS-potential maps that illustrate the subsurface's capacity to infiltrate and retain stormwater for natural mitigation of flooding events (see Appendix A-1 for further details). Geophysical potential G is based on three indicator parameters: *Permeability*, determined by soil type, where coarser materials allow higher infiltration; *Unsaturated zone thickness*, representing the available storage volume in the soil; and *Soil thickness*, as insufficient soil depth limits infiltration regardless of soil quality. The data products used were 'Genomsläpplighet', 'Brunnar' and 'Jorddjupsmodell', all provided by SGU. Based on estimations of sufficient stormwater storage volume, see Appendix A1, the threshold for Unsaturated zone thickness was set to 0.3 m, and for Soil thickness to 1.5 m.

The G-map shows that a large share of the municipality (44%) falls within the potential class C (Some potential). About 27% is classified as B (Moderate potential), occurring mainly as scattered patches or larger areas toward the municipal outskirts. Only 9% is classified as A (High potential), concentrated in three distinct NW–SE-oriented zones. Central areas and the surroundings of Lake Vättern predominantly show class C potential. Less than 1% of the area was unclassified.

The effective potential E incorporates additional overlays for accessibility and suitability attributes. Accessibility reductions occur where infiltration is inhibited due to *impermeable surfaces* such as buildings, roads, railways, and paved activity areas. Areas that are difficult to change are classified as inaccessible, class D, while areas where it may be possible to improve infiltration are classified as class C, limited accessibility. Areas that are not inhibited are left unclassified in the overlay layers, with the E-map showing the potential from the G-map.

Overall, impermeable surfaces are relatively sparse in the municipality, with the largest concentrations in Askersund Town, the smaller surrounding settlements, and along major transport routes. Suitability constraints reflect areas where infiltration is technically possible but may pose risks to the surrounding environment. In this assessment, *contaminated sites* are the primary limiting factor, as infiltration could potentially mobilize pollutants. These are shown as 300x300 m areas, classified as either C or D. The data products used for accessibility and suitability parameters were 'Topografi10' by SGU and 'LST Potentiellt förorenade områden (EBH)' by Länsstyrelsen.

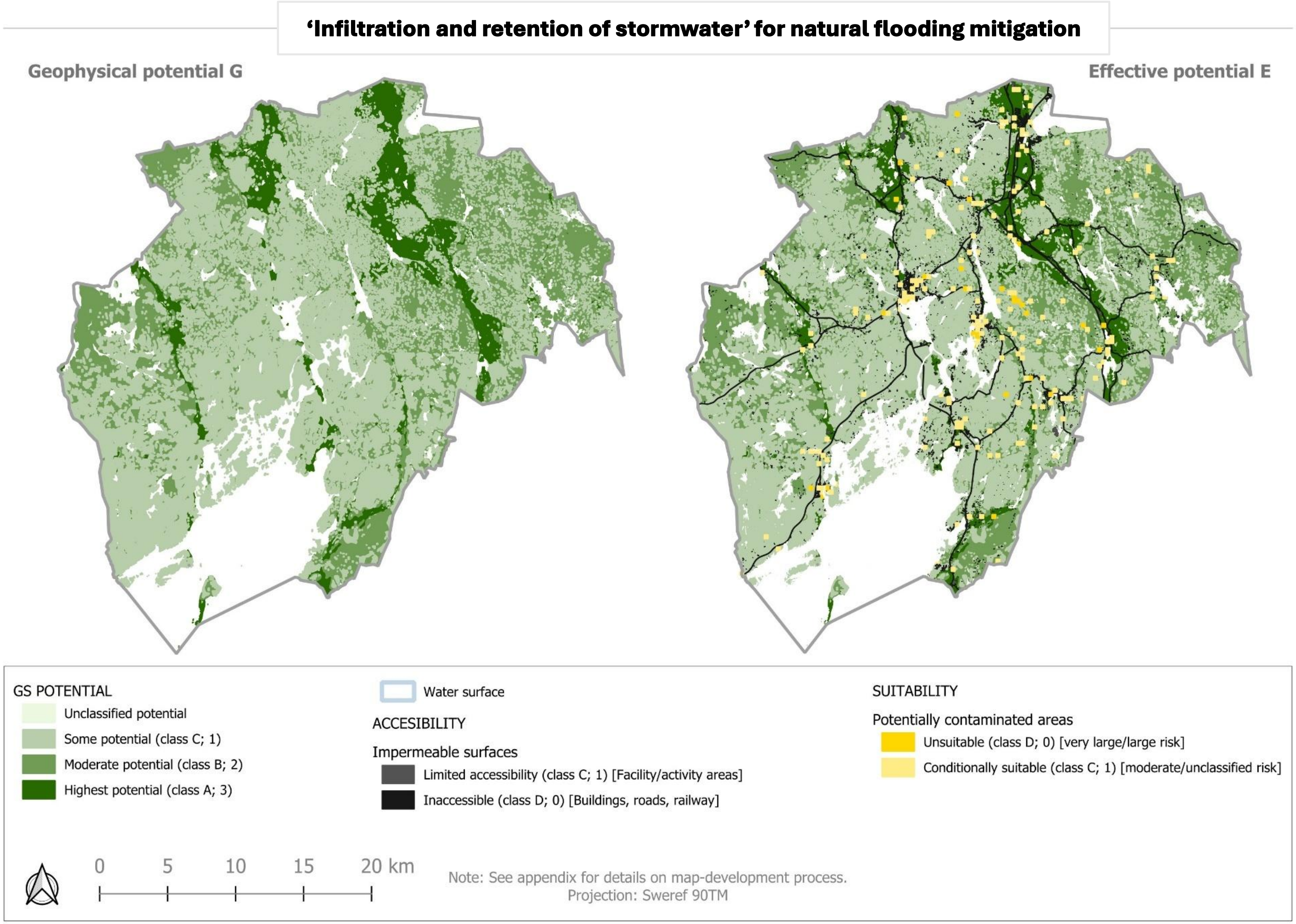


Figure 3: GS-potential maps for the geosystem service 'Infiltration and Retention of Stormwater' in Askersund. Left map: Geophysical potential G. Right map: Effective potential E.

5.3.2 Maps for ‘Provision of Groundwater’

Figure 4 presents the two GS-potential maps of the service ‘Provision of groundwater’ for extraction on municipal scale. The geophysical potential G is based on a single indicator: *extraction capacity*. This capacity depends on factors such as soil permeability, soil thickness, bedrock fracturing and the presence of impermeable layers. The data comes from SGU’s product ‘Grundvattenmagasin’, which merges these factors into a single parameter with four extraction-capacity levels. These levels were translated directly into GS-potential classes with minor adjustments (see Appendix A-1).

Since favourable conditions for groundwater extraction partly overlap with those for infiltration, the G-map shows similar NW–SE-oriented zones as the infiltration maps. However, because the SGU product focuses on major aquifers, the groundwater potential map consists mainly of land with limited potential except for a few distinct high-potential units. Within the total municipal area, about 1% falls into class C (some potential), 5% into B (moderate potential), and 1% into A (high potential). Considering only aquifer areas, roughly 15% are class C, 72% class B, and 12% class A. The highest-potential areas are mainly located in the northern part of the municipality.

The effective potential E includes accessibility and suitability constraints. The presented accessibility reductions stem from legally *protected areas* (e.g., nature reserves, national interest areas, water protection zones) and *existing land uses* that may hinder groundwater development. Farmland constitutes a major limitation, covering considerable parts of the available aquifers and additional restrictions occur around lakes within areas for water-or nature protection.

Suitability factors address areas where groundwater use may pose environmental or ethical concerns, such as *potentially contaminated sites* and *cemeteries*. None of the aquifers appear completely free from potential contamination sources, but include few indications of very severe contamination. The two largest northern aquifers include areas of both moderate/unclassified and high risk as well as cemeteries. Depending on factors such as location, hydraulic conditions and pollutant characteristics, these areas may still be usable but call for caution in the planning process.

The layers for accessibility and suitability are based on several different data products: 'Skyddade områden; Art och habitatsdirektivet' and 'Riksintresse för friluftsliv och naturvård', from EPA, 'Topografi10' from SGU and 'LST Potentiellt förorenade områden (EBH)' from Lantmäteriet.

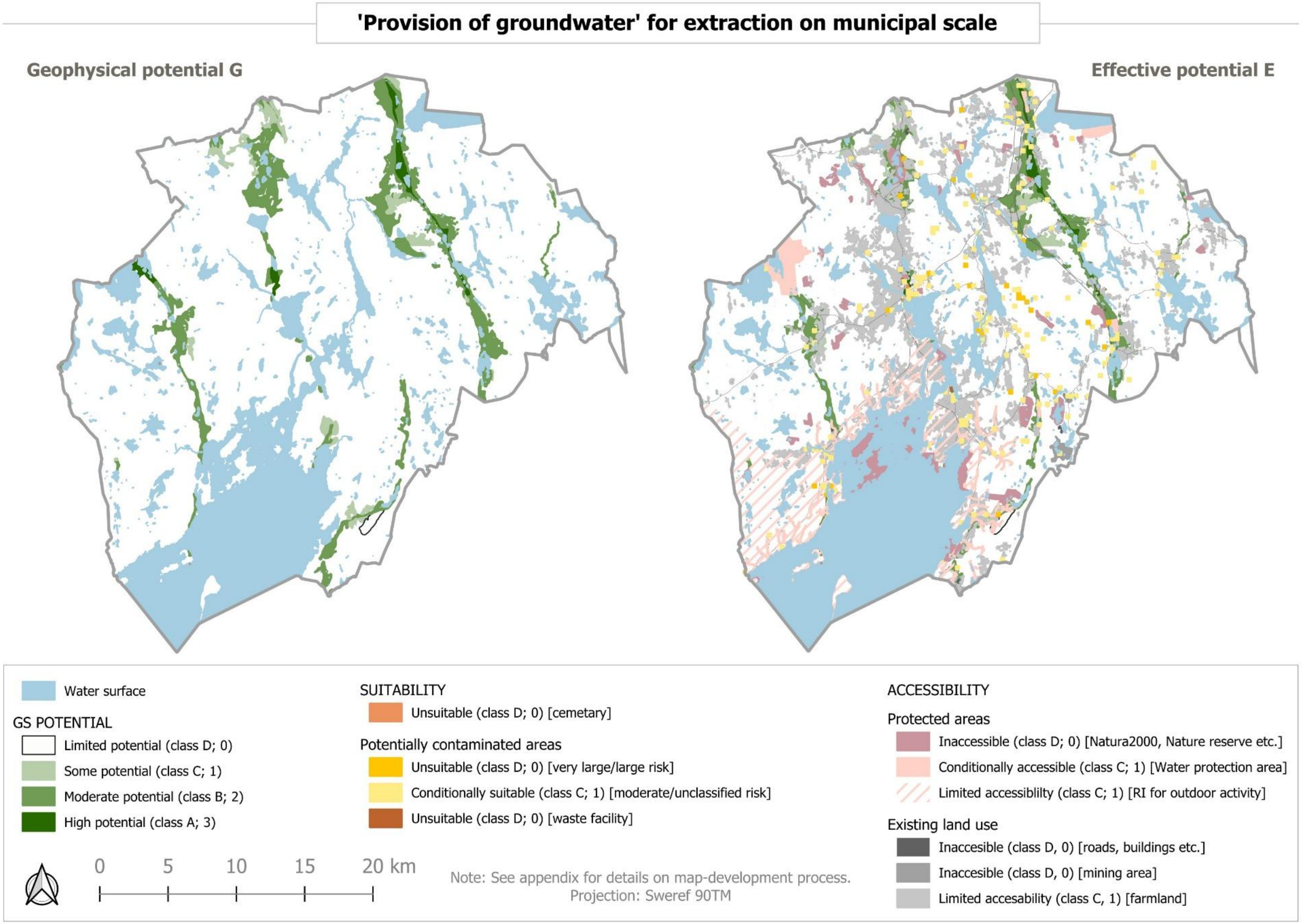


Figure 4: GS-potential maps for the geosystem service 'Provision of groundwater' in Askersund.. Left map: Geophysical potential G. Right map: Effective potential E.

5.3.3 Maps for 'Bearing Capacity'

Figure 5 presents the two GS-potential maps for the GS 'Bearing capacity' regarding surface constructions which aim to illustrate the subsurface's ability to bear surface load. This service depends on properties such as soil density and compaction, grain-size distribution, water content, internal friction and cohesion. It is also affected by erosion processes, where material gradually removed and thereby reduces the load-bearing capacity. In attempt to consider all these factors, the geophysical potential G is based on two indicator parameters: *Terrain class*, which links soil-type data to bearing capacity according to the capacity classes presented in Lundin (2025), and *precautionary areas*, which reduce the potential in zones identified as particularly sensitive to erosion. The data products used were 'Jordarter 1:25 000–1:100 000', 'Jordskred och raviner', and 'Förutsättningar för skred i finkornig jordart', all provided by SGU. For further details, see Appendix A-1.

The G-map shows that most of the municipality (64%) falls into class A (highest potential). About 17% is classified as C (some potential), while only 1% is classified as B (moderate potential). High-potential areas are widely distributed across the municipality, whereas lower-potential zones are mostly concentrated in central land areas, north of Lake Vättern and around other water bodies.

Accessibility constraints relate to various types of protected nature, including data from the products 'Skyddade områden: Art- och habitatsdirektivet', 'Riksintresse för friluftsliv och naturvård' (EPA), and 'Topografi10' (SGU). The most prominent restrictions appear near water bodies, for example, around the Tiveden forest and the northern archipelago of Lake Vättern. Despite these restrictions, most of the municipal area remains accessible.

Suitability factors were not applied for this GS. Since the suitability of constructing on bearing surfaces depends on project-specific conditions (e.g., scale, purpose) as well as political considerations, it was deemed beyond the scope of this assessment.

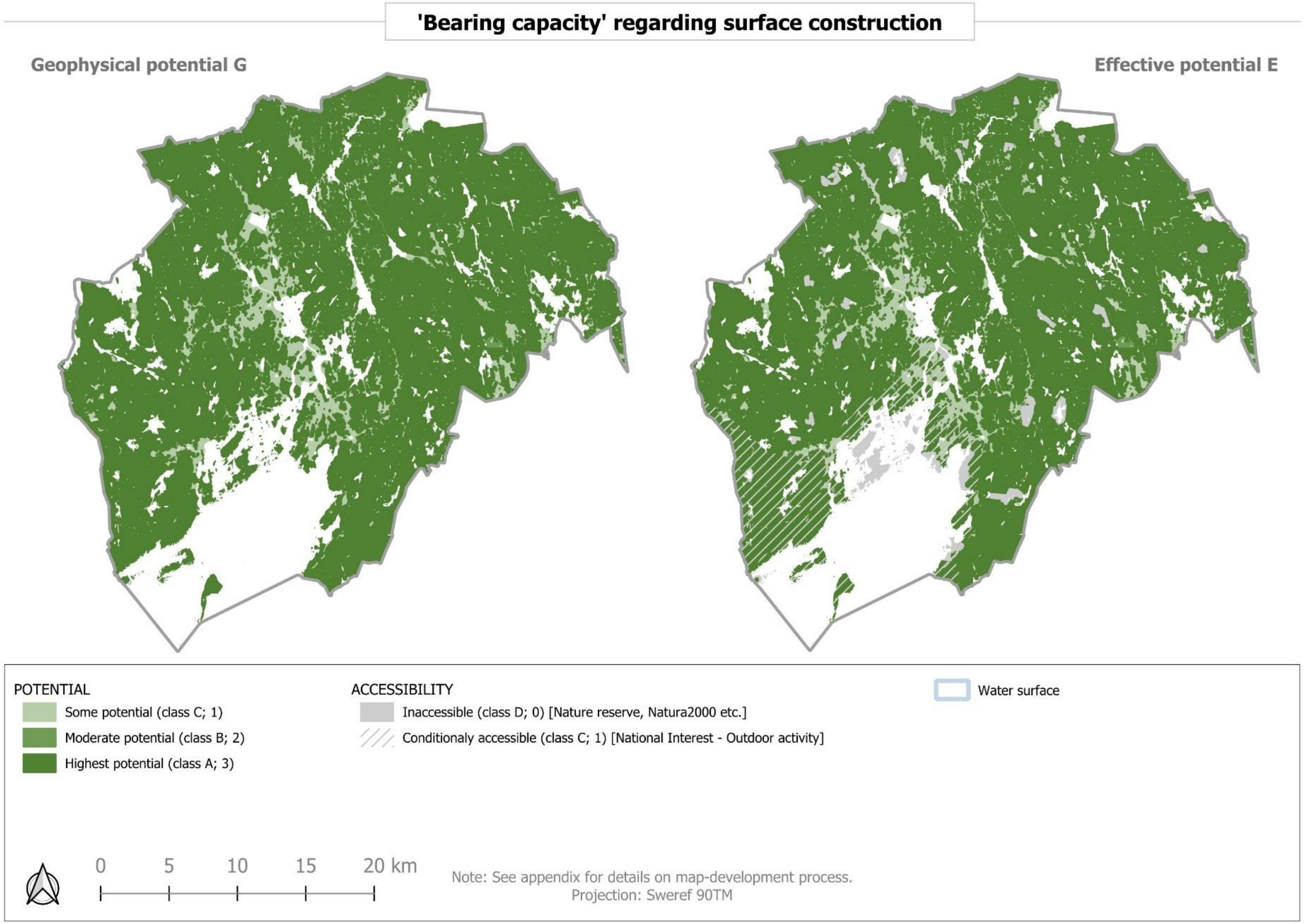


Figure 5: GS-potential maps for the geosystem service 'Bearing capacity' in Askersund.. Left map: Geophysical potential G. Right map: Effective potential E.

5.3.4 Maps for 'Resistance to Erosion'

Figure 6 presents the two maps illustrating the GS 'Resistance to erosion' regarding construction. This service is closely related to the load-bearing service but focuses specifically on the prevention of eroding processes. To represent this, the maps were produced using an approach similar to the one for bearing capacity. Here, soil types are linked to erosion-resistance potential through the indicator *erosivity class* presented in Lundin-Frisk (2025). As in the bearing-capacity assessment, the soil data are complemented with the attribute *precautionary areas*, which includes existing ravines and areas identified as potentially unstable due to soil-type characteristics combined with terrain slope. The datasets used were 'Jordarter 1:25 000–1:100 000', 'Jordskred och raviner', and 'Förutsättningar för skred i finkornig jordart', all provided by SGU. See Appendix A-1 for details.

According to the G-map, most of the municipality (55%) is classified as class A (highest potential). Approximately 22% falls into class B (moderate potential), often following the same NW–SE-oriented zones seen in previous maps with particularly large areas in the northeastern part of the municipality. Only about 2% is classified as class C (some potential), corresponding primarily to the precautionary areas. These include ravines, erosion-prone shore zones and areas where erodible soil types coincide with critical slope angles. Such areas are often located near water bodies but also appear as extensions of moderate-resistance zones across the landscape.

For the effective potential-map, suitability factors were consciously excluded due to their strong dependence on project-specific characteristics and political decision-making. Accessibility restrictions were hard to determine as well. In the end they were limited to consider *existing constructions and installations* that would be difficult to relocate. That included major transport corridors, buildings, cemeteries, waste facilities and schoolyards. In theory these factors do not limit erosion resistivity itself but it limits the access to land available for new construction that would otherwise benefit from the service. Accessibility data were derived from SGU's 'Topografi10' dataset.

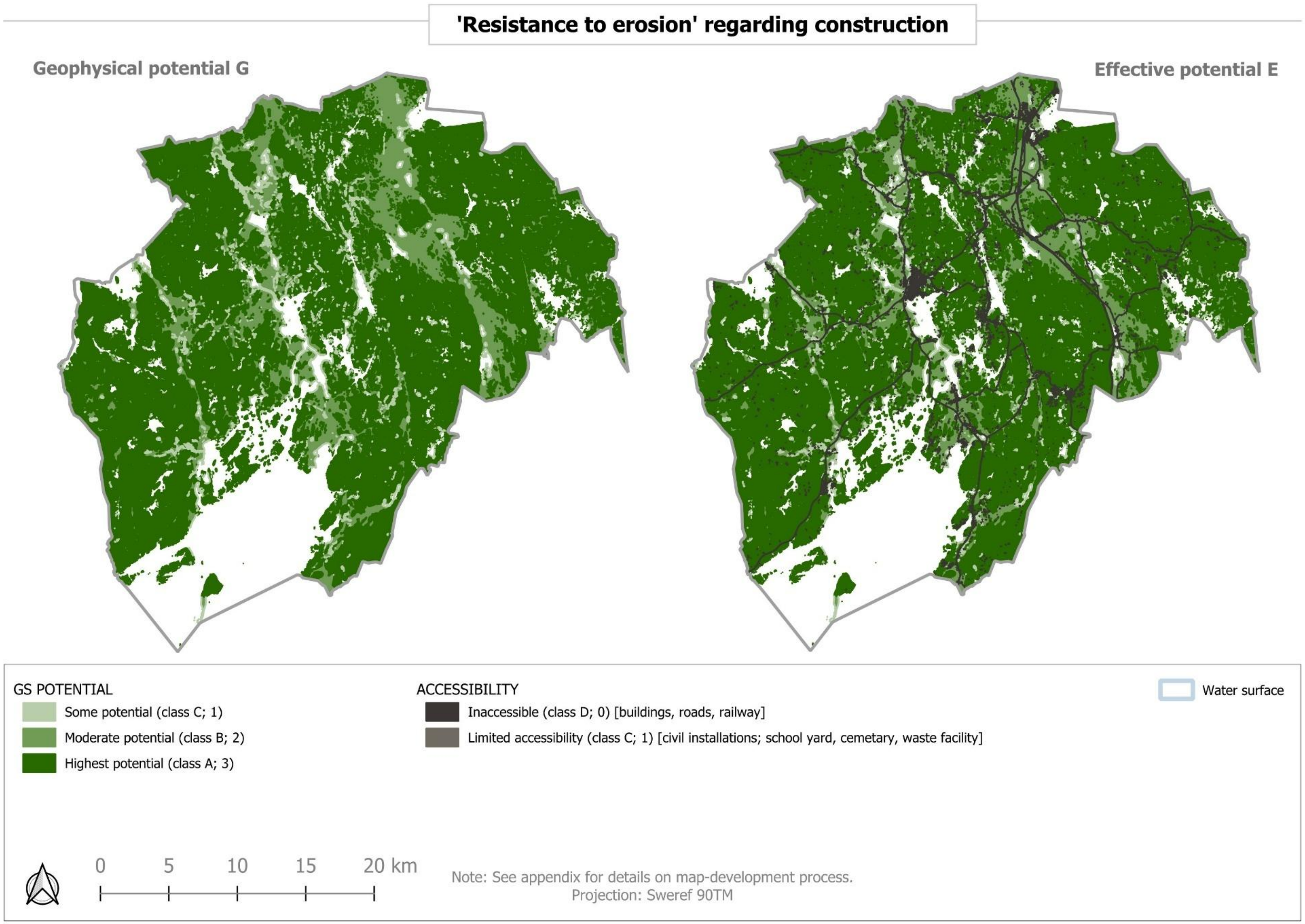


Figure 6: GS-potential maps for the geosystem service 'Bearing capacity' in Askersund. Left map: Geophysical potential G: Right map: Effective potential E.

5.3.5 Maps for 'Provision of Rock Aggregate

Figure 7 presents the two maps illustrating the Geosystem Service 'Provision of rock aggregate' for concrete production. The geophysical potential G is based solely on the parameter *bedrock quality for concrete aggregate production*. In principle, this quality depends on several factors such as mica content, sulphide content, activity index (AI), and alkali–silica reactivity (ASR). However, because comprehensive high quality data was not available for Askersund municipality, the assessment instead uses *bedrock quality class* as an indicator, linked bedrock data to potential through the general quality classes presented in Mortensen (2018). The dataset used was SGU's 'Berggrund50'.

The G-map shows that most mapped bedrock (73%) falls into class B (moderate potential). Both class A (high potential) and class C (some potential) each cover less than 1% of the area. A substantial share of bedrock (27%) could not be classified using the general system in Mortensen (2018), increasing the degree of uncertainty. In addition to GS-potential, the G-map also identifies the location of existing stone quarries. Most of these are located within class B areas, although a few occur in unclassified zones as well.

In the E-map, the effective potential E incorporates both accessibility and suitability attributes. Accessibility is influenced by *soil depth*, where depths greater than 5 m are considered limiting. This constraint applies to roughly one quarter of the municipality, particularly in the northeastern part. *Existing structures and civil installations* (e.g., buildings, infrastructure, cemeteries, schoolyards and waste facilities) further restrict accessibility and are mostly concentrated around settlements and transport corridors.

As suitability factors primarily relate to *competing interests* they are classified as conditionally suitable. These include areas of national interest for outdoor recreation and zones relevant for groundwater supply. The latter coincide with the NW–SE-oriented areas previously identified for groundwater provision as well as the nature-rich surroundings of Lake Vättern and the Tiveden forest. It can also be noted that at least four of the noted quarry sites lie within conditionally suitable areas.

The data products used to construct the E-map were 'Jorddjupsmodell', 'Topografi10', and 'Grundvattenmagasin' from SGU, alongside 'Skyddade områden: Art- och habitatsdirektivet' and 'Riksintresse friluftsliv och naturvård' from the EPA.

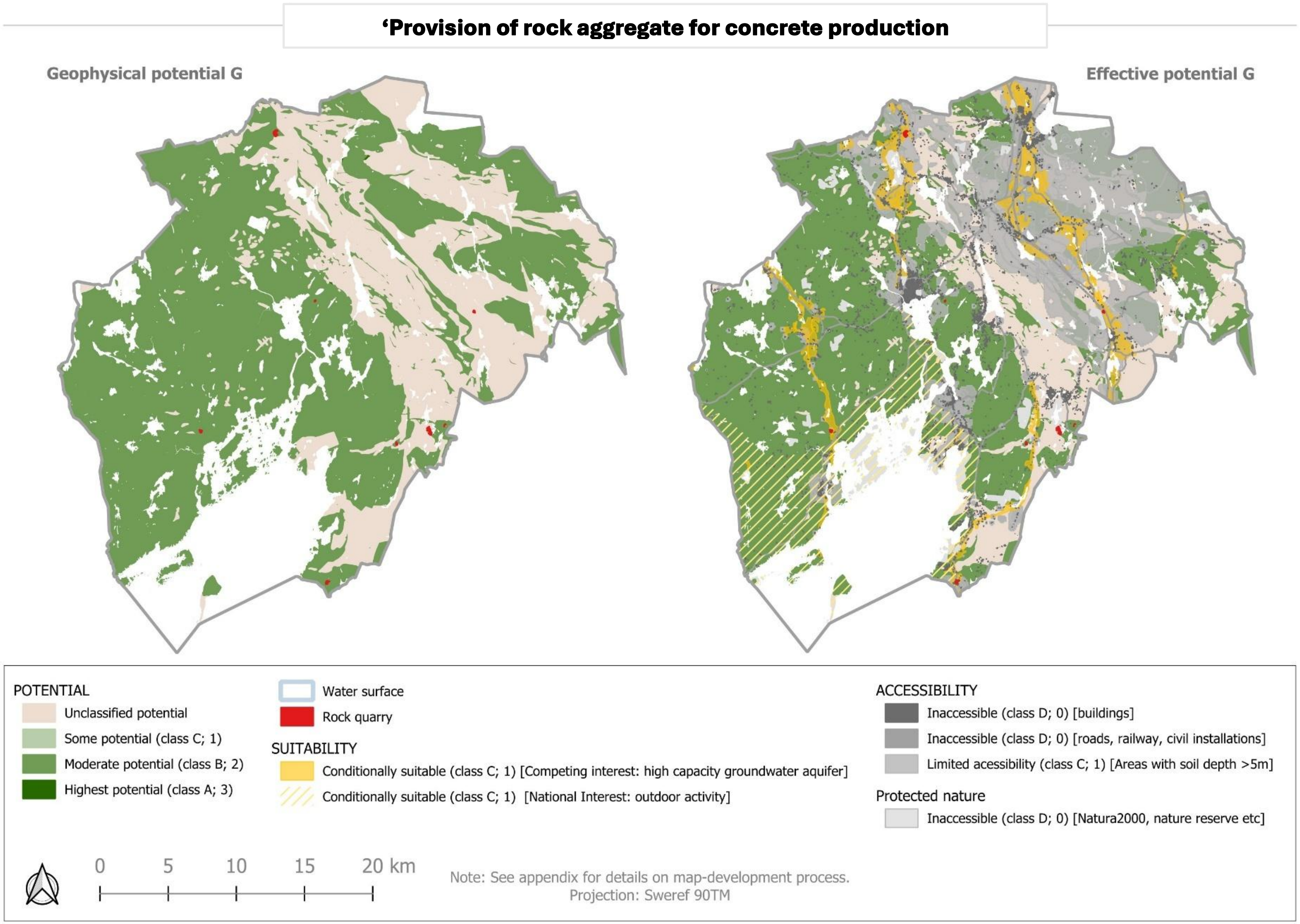


Figure 7: GS-potential maps for the geosystem service ‘Provision of rock aggregate’ in Askersund. Left map: Geophysical potential G: Right map: Effective potential E.

5.4 Results from Municipality Meeting 2 – Workshop

Following chapter presents the results from the evaluating workshop that was held with end-users in Askersund. It contains details regarding the workshop session, a compilation of the participants' feedback and in-depth evaluations of all the maps.

5.4.1 Workshop details and feedback compilation

The evaluation workshop with representatives from the Municipality of Askersund was structured around four key questions, and a summary of the results is presented in Table 6-9. A summary of the final verbal reflections from the workshop is also provided at the end.

As the workshop was conducted in Swedish and the responses were written informally on separate notes, the comments have been translated into English and slightly condensed to provide a clearer and more cohesive overview. In some cases, the responses have also been reorganised to better match the questions they address, as the content did not always correspond to the note colour used.

The participants represented a range of professional backgrounds related to spatial planning, and during the workshop, they were divided into two discussion groups, each with two assisting research representatives from Chalmers or SGU added.

Group 1:
Spatial Planning Architect
GIS Engineer
Environmental Inspector
Assisting researcher, student (Chalmers)
Assisting researcher, examiner and supervisor (Chalmers)

Group 2:
Head of Development
Comprehensive Planner
Land and Development Engineer
Assisting researcher, supervisor (Chalmers)
Assisting researcher, supervisor (SGU)

Table 6: Responses to discussion questions in Workshop 1 regarding GS-potential maps for 'Infiltration and Retention of Stormwater'.

			Group 1	Group 2
Infiltration and Retention of Stormwater for natural flooding mitigation	**Q1**	**a) What information can you interpret from the map?** **b) Does the map provide any new information?**	The resolution may be too low. More detail would be needed in built areas, especially for detailed development planning.	b) Yes, the information is presented in a more continuous, large-scale format than previous material, which may be useful in various planning stages, e.g., the comprehensive plan.
	Q2	**a) How do you think the map could have been used in early planning stages?** **b) Do you think the map is a relevant complement to existing planning material? Why?**	Could potentially guide the need for a stormwater assessment. Relevant for local stormwater management and suitability assessments for individual wastewater systems (where moderate infiltration capacity is desirable for natural water treatment).	Interesting when combined with cloudburst management. Useful to combine with elevation data.
	Q3	**Do you have any suggestions for improvement?**	Need to be able to see how a given potential value was derived — for example, by clicking a point in a digital map (risk that information is lost when layers are processed).	Remove the category "unclassified"
	Q4	**Any other reflections?**	How can the maps be updated when new data becomes available? Digital maps? Predefined GIS processing workflow?	(No comments noted)

Table 7: Responses to discussion questions in Workshop 1 regarding GS-potential maps for 'Provision of groundwater'.

			Group 1	Group 2
Provision of groundwater for drinking water extraction on municipal scale	**Q1**	**a) What information can you interpret from the map?** **b) Does the map provide any new information?**	(No comments noted)	a) The connection between neighbouring areas through subsurface groundwater flows. a) Flow structures and areas clearly suitable/unsuitable for various activities or installations. b) With new visualization, yes.
	Q2	**a) How do you think the map could have been used in early planning stages?** **b) Do you think the map is a relevant complement to existing planning material? Why?**	Somewhat unclear how it can be practically used. Potentially relevant when developing entirely new areas with shared infrastructure and high water demand. Likely relevant for water and wastewater planning (no VA representative present to confirm), and for emergency preparation.	The map can ideally cover a larger area to support cross-boundary planning.
	Q3	**Do you have any suggestions for improvement?**	Possibly interesting to include data on radon levels in groundwater. National interest areas for nature conservation should be included.	Potentially hazardous activities should be included, e.g., industrial sites. Quarries should be included.
	Q4	**Any other reflections?**	Different questions become relevant in different parts of the municipality. Local planners would benefit from being able to generate these maps themselves, e.g by using databases with relevant indicators.	The material exists, but it's good to have it accessibility-classified. Generally, the layers are helpful as they reduce the need for qualified on sight-interpretation of soil properties.

Table 8: Responses to discussion questions in Workshop 1 regarding GS-potential maps for 'Bearing capacity'.

			Group 1	Group 2
Bearing capacity regarding surface construction	Q1	**a) What information can you interpret from the map?** **b) Does the map provide any new information?**	Bearing capacity in relation to roads and logistics.	(No comments noted)
	Q2	**a) How do you think the map could have been used in early planning stages?** **b) Do you think the map is a relevant complement to existing planning material? Why?**	May be useful in the comprehensive planning stage and potentially reducing work needed later in detailed development planning. A good complement, although the required resolution is an important consideration which will vary. Currently hard to determine the scale of application.	(No comments noted)
	Q3	**Do you have any suggestions for improvement?**	Gradation of the GS-potential scale with hands-on examples: e.g., road construction, single-family house, multi-story building complex. Integration/transparency of metadata (including which combined indicator parameters underlie the GS-potential values).	Clearer explanation of what the different scale levels mean in practice. Not necessarily bad to highlight "difficult" or "expensive" areas as unsuitable. Add separate layers for: • multi-story buildings • single-family houses/slab-on-grade foundations or industrial buildings • areas that are problematic regardless of type of construction.
	Q4	**Any other reflections?**	Nybro Municipality is an example of an area that has experienced subsidence due to construction on poor ground conditions. This type of mapping might have helped prevent such incidents.	Low-potential areas could be differentiated more using indexed topography.

Table 9: Responses to discussion questions in Workshop 1 regarding GS-potential maps for 'Resistance to erosion'.

			Group 1	Group 2
Resistance to erosion regarding construction	Q1	**a) What information can you interpret from the map?** **b) Does the map provide any new information?**	Combines several different datasets.	(No comments noted)
	Q2	**a) How do you think the map could have been used in early planning stages?** **b) Do you think the map is a relevant complement to existing planning material? Why?**	Could potentially be used as a complement for planning decisions and save time by early guiding.	(No comments noted)
	Q3	**Do you have any suggestions for improvement?**	Improvements could include more information; internal or site-specific.	Needs to be combined with information on high-flow risks in order to identify hazards.
	Q4	**Any other reflections?**	There should be a way to comment on the accuracy/resolution of the maps (a general issue).	(No comments noted)

Table 10: Responses to discussion questions in Workshop 1 regarding GS-potential maps for 'Provision of rock aggregate'.

			Group 1	Group 2
Provision of rock aggregate ..for concrete production	**Q1**	**a) What information can you interpret from the map?** **b) Does the map provide any new information?**	Uncertain about this dataset, as it concerns areas outside of the participants' own knowledge areas. New information regarding access to stone combined with quarry locations and groundwater considerations.	Unclassified areas coincide with zones of mineralisation (including sulphides, which indicate low bedrock quality) and old mines.
	Q2	**a) How do you think the map could have been used in early planning stages?** **b) Do you think the map is a relevant complement to existing planning material? Why?**	Could be relevant to connect with mass-management plans.	The large extent of unclassified areas is problematic. b) To be useful, the maps require clearer underlying data. In planning, it is difficult to protect values that are not clearly established.
	Q3	**Do you have any suggestions for improvement?**	Current data quality is too low: before use, the dataset should be supplemented with results from proper bedrock quality investigations. Consider access to infrastructure, for logistics. All protected nature areas, including water protection zones, should be classified as inaccessible. Introduce buffer zones around settlements (noise, traffic, visual impacts).	Better raw data. Narrow the indicators so that "highest potential" areas become smaller and more precise.
	Q4	**Any other reflections?**	(No comments noted)	Bedrock availability is not a shortage in Askersund so the service is not specifically relevant. Useful for specific infrastructure projects.

General map reflections:

- The maps provide a hands-on tool to communicate comprehensive information, for example to decision-makers and politicians with little or no planning experience.
- Caution is advised regarding public use: the data is coarse and there is a risk that users may overinterpret fine-scale details.
- Future development could focus not only on improving the maps themselves but also on the processes used to produce them, such as standardised workflows or databases of indicators.

Workshop reflections from assisting researchers:

- The workshop provided efficient arrangement with enough time for reflections and well-functioning material.
- The workshop provided targeted discussions that kept focus on the topics.

5.4.2 Evaluation of Map Readability, Usefulness and Potential Improvements

This section covers evaluations of the Askersund maps which is based on end-user input from the workshop. Focus has been on assessing the maps' readability, usefulness and potential improvements.

5.4.2.1 Evaluation of Map for 'Infiltration and Retention of Stormwater'

According to the workshop participants, the stormwater infiltration map seemed to provide a new and more comprehensive planning tool compared to existing material. The spatial resolution was generally considered too coarse for detailed development, which, however, was expected given that the maps were designed for a larger scale. Except for the resolution issue, the readability of the map was considered good.

The feedback on usability was generally positive. Participants saw clear potential for applying it in early stages of stormwater management, for example, to identify areas that may require more in-depth investigation during detailed planning. Additional potential applications were also discussed, such as supporting permit assessments for individual wastewater treatment systems, which also rely on soil infiltration. While this also relates to another geosystem service (water quality regulation) the challenge lies in visualizing the two at once, as the services' potential varies under different infiltration conditions. (For flooding mitigation, more infiltration is usually better, while quality regulation requires more moderate infiltration to provide enough time for treatment.)

During the workshop, mainly two suggestions for improvements were raised: to remove unnecessary information from the legend, but foremost to add elevation data as a way to clarify where water is likely to accumulate or drain. This was an interesting idea, where the next step would be to find such data. One option is the LiDAR-dataset (laser-scanned topography data) distributed by Lantmäteriet, though it should be noted that the dataset can be heavy to process. Cloudburst assessments could also be a possible complementary source, since they often integrate information on elevation, soil types and rainfall characteristics.

One aspect that received no feedback during the workshop was the choice of parameter limits for the unsaturated zone and soil depth. A likely explanation is that these parameters were incorporated into the GS-potential calculation and therefore not directly visible on the map. Even though they were described in the accompanying documentation the limited time made it hard for the participants to consider these types of in-depth aspects.

The chosen threshold values may not be fully representative as they were based on groundwater well data of highly variable quality, and the calculations were roughly derived from a single one-hour rainfall event. The data was also interpolated linearly, while groundwater table levels in reality are difficult to simulate because they depend on a range of interconnected hydrogeological conditions. The chosen methodology was determined to be good enough for evaluating the mapping principle during the workshops. However, the selected values may not be appropriate for operational use in comprehensive planning and would require more consideration for that context.

For further improvement of similar maps, it would be recommended to include analysis of longer rainfall series for more representative precipitation values and consider work such as Haitjema and Mitchell-Bruker (2005). It could provide guidance on when groundwater levels follow topography and when they remain relatively stable. At the moment, however, it is not clear to what extent these added details would improve the map's usability in practice.

5.4.2.2 Evaluation of Map for Provision of Groundwater

For the groundwater map, no comments were made regarding readability, suggesting that the workshop participants found it easy to interpret. In terms of usability, the map was recognized as a good way to visualise the interconnection of different areas through shared geological formations, such as aquifers. Although the current map is restricted to the municipal boundary, an extended regional version was seen as a potentially valuable communication tool for cross-boundary planning.

The participants were already familiar with the underlying aquifer data, but the map offered a clarifying perspective of how areas connected to aquifers may be more or less suitable and accessible for various constructions or activities. It was also suggested that the map might prove useful in detailed water and wastewater planning, including emergency planning, although no firm conclusions were drawn since the relevant department was not represented during the workshop.

Potential improvements of the map included integrating radon data and adding accessibility or suitability parameters related to potentially hazardous sites (e.g., industrial areas), quarries, and national interest areas for nature conservation. These requests are considered feasible, but how easy they would be to implement depends on data availability and quality.

5.4.2.3 Evaluation of Map for Bearing Capacity

For the Bearing capacity map, no major concerns were raised about readability, suggesting that the map was generally easy to interpret. In terms of usability, participants found the concept appealing and noted that a more refined version could help prevent issues such as settlements in later planning stages. However, in its current form, the map was considered too diffuse, mainly due to its coarse resolution and large scale, and would require adjustments before it could be used in practice. The inclusion of precautionary zones related to erosion was received positively, as these added helpful context without causing confusion.

Regarding map improvements, participants made a notation regarding low-potential areas. They thought the map could be more useful if these zones were more clearly differentiated, since they are often attractive for development. One suggested measure was to integrate topographic information, for which the same LiDAR dataset that was proposed for the Stormwater infiltration and retention map in could be used.

Remaining improvements focused mostly on clarifying how the GS-potential classes translate into real-world construction examples (e.g. suitability of areas for road building, single-family housing, or locations that should be avoided regardless of structure type). While this request is understandable, the development of such classifications would require careful consideration. Clear labels may give users the impression that the map provides definitive answers, even though it only indicates potential. Nevertheless, if this uncertainty is properly communicated, adding clearer class descriptions might still be an effective way to improve the map's practical applicability.

5.4.2.4 Evaluation of Map for Resistance to Erosion

For the Resistance to Erosion map, no concerns were raised about readability. Regarding usability, participants saw potential in the map but emphasized that erodibility alone provides limited insight for buildability challenges unless it is combined with information on where water actually flows. As a result, the primary suggestion for improvement was to integrate the map with data on areas exposed to high flow or concentrated runoff.

Combining erodibility with water-flow information appears both sensible and feasible. Such data may already exist or be possible to produce as part of cloudburst risk assessments. If the data is available such an integration would likely improve the map's relevance for early-stage planning.

5.4.2.5 Evaluation of Map for Provision of Rock Aggregate

The readability of the rock aggregate map was considered poor. The large unclassified areas made the map feel unreliable and unclear. Some participants could interpret these areas as low-quality bedrock because they happened to know they overlapped with mineralisation zones and former mines, but this is not knowledge all users would share. For the classified areas, the poor quality of data and translation schemes also made most of the map appear as "Moderate potential," and some participants even misread the colour for "Highest potential". All these factors combined risk making the map misleading.

In its current form, the map's usability was assessed as low. Missing or uncertain data makes it difficult to motivate actions since the cause is not clearly verified. Additionally, bedrock availability has not been a major constraint in Askersund, which reduces the local relevance. However, it was noted that the map may still be interesting for specific infrastructure projects where the demand for concrete aggregates is high.

To make this map usable, necessary improvements include obtaining better-quality data and then reworking the potential classification to allow clearer distinctions between moderate and high potential. If large parts of the map still fall within one category, a more differentiated colour scheme may also be needed.

6 DISCUSSION

This chapter discusses more general results of the study. It covers gained insights regarding GS-mapping in general but also critical aspects of the applied project process. Reflections on the study's general applicability and suggestions for future studies are also included.

6.1 General Mapping Insights

Throughout the project, a range of general mapping-related questions emerged, many of which were also highlighted during the workshop. This chapter addresses the most prominent ones.

6.1.1 Maps As Communication Tools

The workshop responses largely aligned with the project's initial intentions regarding the use of GS maps as communicative tools. Participants highlighted that the maps provide early-stage overviews of relevant data, enabling users to initiate discussions and address potential conflicts before more extensive assessments are undertaken. The simple visual format was particularly appreciated, as it allows stakeholders to gather around a table and engage with the material even without in-depth geological knowledge.

6.1.2 Map Extent

One aspect that had been considered earlier and was also exemplified during the workshop was that municipalities are not isolated units within the landscape. This was illustrated by aquifers that, in the groundwater map, were cut off at the municipal boundary. To avoid such issues and to enhance cross-regional usefulness, the idea was raised to extend the mapping area beyond municipal borders. While the appropriate extent will vary by case and printed maps may require larger formats, this small measure appears both simple and valuable.

6.1.3 Resolution and Scale

During the workshop resolution and scale emerged as other recurring themes. Feedback from the stormwater infiltration and retention map underscored that no single map would meet the needs of all users: if the resolution is too low, some users will find the details invisible and if it is too high, some may develop unwarranted confidence in uncertain parts of the data.

Addressing this issue requires considering both what is technically possible (e.g., data availability and quality) and what is desirable for users (e.g., printed vs. digital formats, simple static maps vs. multi-layered interactive interfaces with zoom and explanatory notes). A key takeaway is that the map's purpose must be clearly defined and consistently communicated, from the choice of geosystem services to the formulation of workshop questions and final evaluation and use.

Another reflection was that given the interdisciplinary nature of these maps, there is a risk of striving for multifunctionality by attempting to address for example multiple soil functions or planning needs within a single product. In some cases, functions overlap (e.g., infiltration for water treatment and flood mitigation), which can make it tempting to broaden the applicability. However, a highly useful tool for one well-defined user group is often preferable to a mediocre, or even misleading, tool for many. This makes it essential to not compromise the map's primary purpose.

6.1.4 Caution Regarding Public Use

One specific workshop insight concerned the context in which these maps should be used. Due to their ability to simplifying detailed information meanwhile appearing highly detailed there is a risk of over-interpretation. Especially if they are displayed publicly. It may therefore be wise to limit their use to internal planning processes unless accompanied by sufficient explanation and safeguards.

6.1.5 Data Transparency

Data transparency was another recurring topic during both map development and workshop discussions. The question is how to make data traceable without cluttering the map or overwhelming users. Digital maps could provide clickable metadata for specific areas, enabling deeper insight without visual overload. Printed maps, however, lack this functionality, requiring alternative approaches such as clearer labelling or supplementary documentation, similar to what was provided during the workshop. Although the optimal solution will depend on the context, transparency remains essential, both to prevent misplaced confidence and to strengthen trust in the underlying data.

6.1.6 Practical Aspects of Data and Map Production

Several practical considerations also emerged:

- **Updates**
  This issue was discussed thoroughly during the workshop. Since underlying datasets change over time, maps require periodic updates. With the current methodology, updates must be performed manually by re-processing relevant layers, which may become time-consuming. However, if the maps are designed for comprehensive planning, which has a slower cycle than, for example, detailed development plans, they may remain useful even with longer intervals between updates.

- **Automation and web-based tools**
  The topic of digitalisation was raised both prior to and during the workshop. To date, the methodology has primarily focused on production of analogue maps, but from a broader perspective, online services could also be an option. Automated digital platforms offer advantages such as self-updating and synchronisation with underlying databases. However, the more processing steps involved, the harder such synchronization becomes.

- **Standardized workflows.**
  This was not particularly mentioned during the workshop but became evident during the map development in QGIS. In its current state, the map production process can be difficult to follow due to a lack of consistency. Standardized naming conventions and synchronized workflows could therefore be a way to support efficient updates and reuse of material.

6.2 Discussion of Method

This section reflects on certain methodological choices that have significantly influenced the results of the study. Particular focus is set on effects due to the chosen study site, data-related limitations and the design of workshops and webinars.

6.2.1 Choice of Study Site

The selection of Askersund as the study site had already been done when the project started, and the decision was influenced by practical considerations such as accessibility, existing contacts and expressed interest from the municipality. The hypothesis was that the choice of setting would have relevance on the input parameters compared to previous studies, for example, by providing different geological and socio-economic conditions. In short, the study supports the hypothesis; a new context did provide other data and local priorities.

Throughout the study in Askersund, regular contact with the municipality was maintained through both preparations, the webinar and the workshop. However, participation in general was quite limited and feedback regarding comprehensive planning specifically, was largely shaped by one single planner. As a result, the findings reflect this individual perspective to a considerable extent. On the other hand, are the total number of planners in Askersund small and this individual is the only one with the explicit role of "Comprehenive Planner". Therefore, the results may still be considered representative for that municipality. Had a similarly small group been used in Malmö, the risk of insufficient representativeness would have been greater. On the other hand, the small scale does not provide too much insight regarding the views of comprehensive planners in general. The positive responses from other type of planners suggests potential for broader application but such conclusions would be better supported through comparative analysis of similarities and differences between for example the Askersund and Malmö cases.

6.2.2 Practical Considerations in Webinars and Workshops

Since the webinar and workshop provided the foundation for many of the results, it becomes an interesting point of methodological analysis. One important consideration is the representativeness of participants. The limited number of participants constrained the discussions, creating a hindrance as well as an advantage. While a broader group could capture more perspectives, it would risk diverging from the topic. A more homogenous group would make it easier to derive representative conclusions for a specific group of users, while losing some interdisciplinary input. Which one to prefer is hard to say in general, but one conclusion is that participant selection directly influences the results of this type of study and should therefore be carefully considered. One possible approach would be to divide the process into multiple sessions: one initial workshop focused narrowly on comprehensive planning needs, followed by later sessions aimed at adapting the material for broader or more multifunctional use once a solid core product has been established.

Another topic is the study's absence of formal workshop methodology. Although this relates to an extensive scientific field, this study did not investigate any conventional workshop methodologies. However, this does not mean the process was unstructured; significant effort was devoted to preparation and planning. This included delimiting the material to provide sufficient background without overwhelming participants, clarifying the project's purpose and expected outcomes for both participants and the author, and carefully formulating questions to guide discussions toward relevant topics and avoid unnecessary digressions. While more time could have been spent on methodological pre-studies, this would likely have required trade-offs elsewhere due to the project's limited timeframe, without necessarily leading to better results.

The number of GS to select was also a critical study consideration. In total, five geosystem services were selected, combining those prioritized by the municipality with others that showed research relevance and potential. This number proved appropriate for the workshop format: it allowed varied discussion without overwhelming participants or losing focus. They were few enough to be addressed within the available time, and the absence of comments regarding missing services suggests that the selection was still perceived as sufficient.

Given the few services included, it is reasonable to ask whether the workshop could be extended to cover a larger number. As the material this time was entirely new to participants, future workshops with greater prior familiarity might accommodate more services within the same timeframe. However, observations from the workshop showed that the maps examined first received the most attention, while later discussions became more limited and focused mainly on improvement-related issues rather than basic understanding. This suggests that longer workshops would not necessarily yield responses of equal depth or quality.

6.2.3 Data Quality and Uncertainties

Data quality presents another significant limitation. Geological data generally involves significant uncertainties due to its subsurface and often historical nature. Many datasets used in the study are compiled stepwise by different actors with varying objectives and levels of accuracy, resulting in data that may be outdated or inconsistent. Interpolation poses another risk, as it can encourage assumptions about spatial continuity that may not be sufficiently supported. Some datasets are also dynamic but rely on momentary measurements, potentially producing misleading results. One such example is the groundwater data used for estimates of the unsaturated zone in the Stormwater infiltration and retention map.

Inconsistencies in data collection can also lead to visual artefacts, such as unnaturally sharp boundaries between areas with contrasting classifications. For example, in the Stormwater infiltration and Retention map a large square area classified as sandy moraine appears adjacent to areas classified as bedrock. This produces an abrupt line in the map that are not necessarily wrong but unlikely reflects the actual conditions.

Finally, contamination data (EBH) posed a particular challenge. While it represents contaminated sites as points, it provides limited information about spatial extent. Contaminant spread is influenced by numerous uncertain factors, including groundwater flow and transport properties, making detailed delineation beyond the scope of this study. However, for comprehensive planning purposes, representing contamination as isolated points would be even more misleading. The adopted grid-based approach serves as a compromise. Although still a coarse approximation, it avoids conveying false precision and clearly communicates that the mapped areas indicate zones of concern rather than definitive contamination extents and likely requires further investigation.

6.3 Applicability of Results

This study has investigated the mapping methodology under the conditions of Askersund. A natural question, however, is to what extent the results are applicable to other contexts. Three factors that may vary are map purpose, the set of geosystem services considered, and the municipal setting.

Regarding the maps' purpose, the findings suggest that GS maps have potential beyond the applications examined in this study. Given the relatively minor adjustments required to shift the focus from resilience planning in the M-case to comprehensive planning, there appears to be good potential for applying the methodology in other contexts where geosystem services are relevant. Such contexts may include certain stages of detailed development planning or for use as supporting material in communication with decision-makers. While the maps themselves are purpose-specific, the underlying methodology appears more broadly generalisable.

In terms of the selection of GS, the mapping approach has so far proven capable of handling a range of services, provided they can be linked to indicators based on quantifiable and classifiable data. The main challenges identified relate not to the methodology itself, but to limited data availability or insufficient data quality for certain services.

Finally, regarding the municipal setting, the methodology has been tested in two deliberately different municipalities and has functioned well in both cases. Differences in local conditions primarily influenced the selection of services rather than the overall mapping approach, and services common to both municipalities could be mapped using similar types of indicators. That said, such transferability cannot be assumed in all contexts. Municipalities with substantially different environmental conditions may require additional or alternative parameters. In northern regions, for example, soil frost could be a critical factor influencing infiltration capacity, potentially affecting the results.

6.4 Future Studies

Future research may want to focus on refining the maps based on the improvement suggestions identified in this study. It could also be interesting to observe how planners would actively use the revised maps in real operational planning tasks. It could also be valuable to examine the operational functionality of the revised maps, for example by providing planners access to them and then observing how the maps are used in everyday planning practice. It could also be beneficial to explore ways to facilitate the production of additional and more costume made maps. Standardized GIS workflows could streamline the map production, improve transparency, and enable more efficient updates, especially if they were combined with online map services. In parallel, establishing accessible databases of indicators and translation schemes would allow individual planners to construct maps tailored to their specific purposes and preferences, increasing flexibility and local relevance.

7 CONCLUSION

This study has successfully applied the indicator-based mapping methodology developed in the M-case (Lundin-Frisk, 2025) to produce geosystem service (GS) potential maps adapted to the conditions of Askersund municipality. Through assessments of municipal needs, available data and broader research relevance, five geosystem services were prioritised: 'Infiltration and retention of stormwater' for natural flood mitigation, 'Provision of groundwater' for extraction on municipal scale, 'Bearing capacity' regarding surface construction, 'Resistance to erosion' regarding construction and 'Provision of rock aggregate' for concrete production.

The intention was to apply indicators and datasets in line with the original methodological framework. This approach proved effective in most cases; however, certain maps required methodological adjustments. For example, the rock aggregate map required development of new quality classifications to be able to use available data. After adapting indicator parameters accordingly, the services were mapped in the GIS software QGIS. The resulting maps were evaluated by end users, providing insights into perceived usability as well as hands-on suggestions for improvement.

The project takeaways can be summarised as follows:

- The methodology was applicable to the rural municipality of Askersund.

- Experienced challenges regarded mainly availability of data and translation schemes for chosen GS.

- Despite limitations and areas for refinement, the evaluation of the maps yielded generally positive results.

- The findings indicate that GS-potential maps can function as a valuable complement to comprehensive planning, particularly as communicative support material in early planning stages.

- Key themes for broader applicability include:
    - Data quality, -uncertainty, and -transparency.
    - Practical considerations for workshop-based evaluation.
    - Opportunities to facilitate better map production and -updating processes.
    - Importance of defining clear purpose and target groups.

- The results are considered representative of comprehensive planners in Askersund municipality. It suggests potential for broader application in comprehensive planning in other municipalities but due to the study's limited scale further comparative research would be required to strengthen such conclusions.

8 REFERENCES

Boverket. (2019). *Områdesbestämmelser*. Retrieved September 22 from https://www.boverket.se/sv/PBL-kunskapsbanken/lov--byggande/provning_lov_fb/inom_ob/ob/

Boverket. (2022). *Detaljplanering*. Retrieved September 22 from https://www.boverket.se/sv/samhallsplanering/sa-planeras-sverige/kommunal-planering/detaljplanering/

Boverket. (2024). *Översiktsplanen*. Retrieved September 22 from https://www.boverket.se/sv/PBL-kunskapsbanken/oversiktsplan/oversiktsplanen/

Buckley, A., & Field, K. (2011). Making a Meaningful Map. *ArcUser*, *Fall 2011*. https://www.esri.com/news/arcuser/0911/files/arcuser55/arcuser55.pdf

Carlsson, C., Hedfors, J., & Fransson, A.-M. (2020). *ekoGeokalkyl för byggbarhet och ekosystemtjänster* (U2-2016-07). https://www.diva-portal.org/smash/get/diva2:1502581/FULLTEXT01.pdf

Chalmers University of Technology. (2021). *UNDER: Geosystem services underneath for sustainable communities and improved spatial planning practices*. Retrieved October 13 from

Chalmers University of Technology. (2025). *Geosystem Services to Support Planning and Management of the Subsurface*. Retrieved November 20 from https://research.chalmers.se/en/publication/548829

Delmastro, C., Lavagno, E., & Schranz, L. (2016). Underground urbanism: Master Plans and Sectorial Plans. *Tunnelling and Underground Space Technology incorporating Trenchless Technology Research*, *55*, 103-111. https://doi.org/10.1016/j.tust.2016.01.001

Ekholm, E., & Hallin, G. (1980). *Översiktlig naturinventering av Askersunds kommun (utom Tiveden)*. Askersunds kommun: Länsstyrelsen i Örebro län, Retrieved from https://www.lansstyrelsen.se/download/18.8cd5a1b19362fb4fc21afd/1732536138859/1980:3%20%C3%96versiktlig%20naturinventering%20av%20Askersunds%20kommun%20(utom%20Tiveden),%20exklusive%20kartbilaga.pdf

Ekonomifakta. *Askersund*. Retrieved December 10 from https://www.ekonomifakta.se/regional-statistik/din-kommun-i-siffror/askersund/

Esri. *What is GIS?* Retrieved December 10 from https://www.esri.com/en-us/what-is-gis/overview

Fox, N., Graham, L. J., Eigenbrod, F., Bullock, J. M., & Parks, K. E. (2020). Incorporating geodiversity in ecosystem service decisions [Article]. *Ecosystems and People*, *16*(1), 151-159. https://doi.org/10.1080/26395916.2020.1758214

Gray, M., Gordon, J. E., & Brown, E. J. (2013). Geodiversity and the ecosystem approach: The contribution of geoscience in delivering integrated environmental management [Article]. *Proceedings of the Geologists' Association*, *124*(4), 659-673. https://doi.org/10.1016/j.pgeola.2013.01.003

Grima, N., Jutras-Perreault, M.-C., Gobakken, T., Ole Ørka, H., & Vacik, H. (2023). Systematic review for a set of indicators supporting the Common International Classification of Ecosystem Services. *Ecological Indicators*, *147*. https://doi.org/10.1016/j.ecolind.2023.109978

Haitjema, H. M., & Mitchell-Bruker, S. (2005). Are water tables a subdued replica of the topography? *Ground Water*, *43*(6), 781. https://research.ebsco.com/linkprocessor/plink?id=d7646d69-0c40-3781-b8b0-ec437ff82fca

Jochen, S. (2025). *Cartography*. Springer Nature Switzerland. https://research.ebsco.com/linkprocessor/plink?id=ac481a1a-c74d-33ae-bba5-f0f6ff144691

Lamé, F., & Maring, L. (2014). *Into Dutch Soils*. The Netherlands: Rijkswaterstaat Retrieved from https://iplo.nl/publish/pages/220025/into_dutch_soils.pdf

Lundin-Frisk, E. (2025). *Geosystem Services to Support Planning and Management of the Subsurface* (Publication Number 5770) [Doctoral dissertation, Chalmers University of Technology]. Chalmers University Publications Electronic Archive. Chalmers. https://doi.org/10.63959/chalmers.dt/5770

Lundin-Frisk, E., Ericsson, L. O., Lindgren, P., Melgaço, L., Mossmark, F., Taromi Sandström, O., Svahn, V., Söderqvist, T., Volchko, Y., de Lourdes Melo Zurita, M., & Norrman, J. (2025). Geosystem services from the subsurface: A literature review and a proposed set of indicators

tailored to a Swedish setting [Article]. *Environmental and Sustainability Indicators*, *26*, Article 100609. https://doi.org/10.1016/j.indic.2025.100609
Lundin-Frisk, E., Volchko, Y., Sandström, O. T., Söderqvist, T., Ericsson, L. O., Mossmark, F., Lindhe, A., Blom, G., Lång, L. O., Carlsson, C., & Norrman, J. (2022). The geosystem services concept – What is it and can it support subsurface planning? [Review]. *Ecosystem Services*, *58*, Article 101493. https://doi.org/10.1016/j.ecoser.2022.101493
Municipality of Askersund. (2016). *Översiktsplan för Askersunds kommun 2015-2025*. Municipality of Askersund Retrieved from https://www.askersund.se/download/18.5d207894188bda3ec891888/1686919699324/%C3%96versiktsplan%20Askersunds%20kommun%202015_2025.pdf
Municipality of Askersund. (2024a). *Askersunds kommuns översiktsplan 2040 - Samrådsversion*. Retrieved from https://www.askersund.se/download/18.6703f2da199a32001e07d20/1760001498347/Askersunds%20kommuns%20%C3%B6versiktsplan%202040%20samr%C3%A5dsversion.pdf
Municipality of Askersund. (2024b). *Översiktsplan för Askersunds kommun - Miljökonsekvensbeskrivning samråd*. Structor Miljöpartner AB, Structor Miljöteknik AB Retrieved from https://www.askersund.se/download/18.2fb0a5c2191e4fccc1e10ed6/1727434853471/Milj%C3%B6konsekvensbeskrivning%20f%C3%B6r%20samr%C3%A5d%20av%20%C3%B6versiktsplan%20f%C3%B6r%20Askersunds%20kommun.pdf
Nordström, S. (2017). *Storstadsutveckling – behov av undermarksplanering* (2017:11). SGU. https://resource.sgu.se/produkter/sgurapp/s1711-rapport.pdf
Norrman, J., Ericsson, L. O., Markstedt, A., Volchko, Y., L Nilsson, K., & Sjöholm, J. (2020). *New dimensions in Swedish planning - An investigation of subsurface planning and geosystem service* (214). https://www.befo.se/wp-content/uploads/2024/10/befo_rapport_214_web.pdf
Palino, G., & Sparks, E. (2024). *QGIS: An Introduction to an Open-Source Geographic Information System*. Mississippi State University. Retrieved December 10 from https://extension.msstate.edu/publications/qgis-introduction-open-source-geographic-information-system
SMHI. *Närkes klimat*. Retrieved December 10, from https://www.smhi.se/kunskapsbanken/klimat/klimatet-i-sveriges-landskap/narkes-klimat
Sourd, G. L., & Ricker, B. (2025). Cartography for global sustainable development agendas: informing public policies with geospatial information and knowledge for people, places and planet*. *International Journal of Cartography*, *11*(3), 428-457. https://doi.org/10.1080/23729333.2025.2532942
Plan- och bygglag (2010:900), (2010).
Tarozzo Kawasaki, M. L., Thomas, L., Hackauf, U., van der Krogt, R., Visser, W., & van Oosterom, P. (2025). Integrating subsurface data into urban planning for climate adaptation using land administration domain model part 5 [Article]. *Survey Review*. https://doi.org/10.1080/00396265.2025.2539606
Van Ree, C. C. D. F., & Van Beukering, P. J. H. (2016). Geosystem services: A concept in support of sustainable development of the subsurface [Article]. *Ecosystem Services*, *20*, 30-36. https://doi.org/10.1016/j.ecoser.2016.06.004
Volchko, Y., Norrman, J., Ericsson, L. O., Nilsson, K. L., Markstedt, A., Öberg, M., Mossmark, F., Bobylev, N., & Tengborg, P. (2020). Subsurface planning: Towards a common understanding of the subsurface as a multifunctional resource [Article]. *Land Use Policy*, *90*, Article 104316. https://doi.org/10.1016/j.landusepol.2019.104316
Vähäaho, I. (2016). An introduction to the development for urban underground space in Helsinki. *Tunnelling and Underground Space Technology incorporating Trenchless Technology Research*, *55*, 324-328. https://doi.org/10.1016/j.tust.2015.10.001
Zhou, Y., & Zhao, J. (2016). Assessment and planning of underground space use in Singapore. *Tunnelling and Underground Space Technology incorporating Trenchless Technology Research*, *55*, 249-256. https://doi.org/10.1016/j.tust.2015.12.018

APPENDIX A: GIS and Indicator Specifications

This appendix contains additional information regarding used indicator parameters, data sources and QGIS procedures.

A-1 Specifications of Map Indicators and Datasets

Sections below show specifications for each GS-map in the study.

A-1.1 QGIS Specifications - Infiltration and Retention of Stormwater

All data sources used in the maps regarding 'Infiltration and Retention of stormwater are summarised in Table A1.

Table A1: Data Used in QGIS Maps for Infiltration and retention of Stormwater.

Specific GS	**Parameter(s)** c – capacity s – suitability a – accessibility	**Data Product**	**Used data subproducts**	**Licence**	**Data product source**
Infiltration and retention of stormwater for natural flooding mitigation	c: Permeability	Genomsläpplighet	All	CC0 1.0	SGU
	c: Unsaturated zone thickness	Brunnar	All	CC0 1.0	SGU
	c: Soil depth	Jorddjupsmodell	All	CC0 1.0	SGU
	a: Impermeable surfaces	Topografi10	Anläggningsområde, Byggnadsverk, Kommunikation	CC BY 4.0	SGU
	s: Contamination	LST Potentiellt förorenade områden (EBH)	All	CC BY 4.0	Länsstyrelsen

The GS-potential in these maps were based on three parameters: permeability, unsaturated zone depth and soil thickness. The permeability parameter is represented by soil type data from SGU's product 'Genomsläpplighet' which is based on 'Jordarter 1:25 00-1:100 000' (see section A-2.2). The product gives a simplified picture of the soil permeability in the area based on the soil's grain size. The data is initially divided into four capacity classes: 'low', 'moderate', 'high' and 'not evaluated' which could be almost directly translated into capacity classes for GS-potential. Some minor adjustments were done with regard for previous GS research (Lundin-Frisk, 2025) and the final classes are presented below in Table A2.

Table A2. Indicator translation scheme: from the parameter permeability to GS capacity class.

Lithology	**Lithology (Swedish)**	**Permeability class** (Genomsläpplighet, SGU)	**Previous GS capacity classes** [(Lundin-Frisk, 2025) / (Lundin-Frisk et al., 2025)]	**GS capacity class** (suggested by author)
Flood-plain deposit sand	Älvsediment, sand	3	Only available for Flood-plain deposit, silt--gravel: [2/2] and sand-boulder: [2/2]	Highest potential – A(3)
Flood-plain deposit clay--silt	Älvsediment, ler--silt	1	Only available for Flood-plain deposit silt--gravel [2/2] and sand-boulder [2/2]	Some potential – C(1)
Igneous bedrock	Urberg	2	Only available for different types of igneous rocks of which Urberg belongs to, but all classified the same: [missing/1]	Some potential – C(1)
Peat	Torv	1	1	Some potential – C(1)
Flood-plain deposit sand	Svämsediment, sand	3	Only available for Flood-plain deposit, sand--boulder)[2/2]	Highest potential – A(3)
Flood-plain deposit clay--silt	Svämsediment, ler--silt	1	1	Some potential – C(1)
Flood-plain deposit coarse silt--fine sand	Svämsediment, grovsilt--finsand	2	[missing/missing]	Moderate potential – B(2)
Washed deposit gravel	Svallsediment, grus	3	3	Highest potential – A(3)
Silt	Silt	1	1	Some potential – C(1)
Sandy till	Sandig morän	2	Only available for Till: [1/2]	Moderate potential – B(2)
Post-glacial silt	Postglacial silt	1	1	Some potential – C(1)
Post-glacial sand	Postglacial sand	3	3	Highest potential – A(3)
Post-glacial clay	Postglacial lera	1	1	Some potential – C(1)
Post glacial fine sand	Postglacial finsand	3	[missing/missing]	Highest potential – A(3)
Bog peat	Mossetorv	1	Only available for Peat: [1/1]	Some potential – C(1)
Till	Morän	2	[1/2]	Moderate potential – B(2)
Clay--silt	Lera--silt	1	[missing/missing]	Some potential – C(1)
Swamp peat	Kärrtorv	1	Only available for Peat: [1/1]	Some potential – C(1)
Washed deposit shingle	Klapper	3	3	Highest potential – A(3)
Glaciofluvial deposits, sand	Isälvssediment, sand	3	Only available as Glaciofluvial deposits [3/3]	Highest potential – A(3)

Glaciofluvial deposits, gravel	Isälvssediment, grus	3	Only available as Glaciofluvial deposits [3/3]	Highest potential – A(3)
Glaciofluvial deposits	Isälvssediment	3	3	Highest potential – A(3)
Muddy clay	Gyttjelera (eller lergyttja)	1	[missing/missing]	Some potential – C(1)
Mud	Gyttja	1	1	Some potential – C(1)
Glacial silt	Glacial silt	1	1	Some potential – C(1)
Glacial clay	Glacial lera	1	1	Some potential – C(1)
Glacial coarse silt	Glacial grovsilt--finsand	3	[missing/missing]	Highest potential – A(3)
Shifting sand	Flygsand	3	[missing/missing]	Moderate potential – B(2)
Bedrock	Berg	2	Only available for all igneous rocks: [missing/1]	Some potential – C(1)

The indicator parameter Unsaturated zone thickness was determined by well data for groundwater level measured from the surface (the inverse of the unsaturated zone). Stormwater infiltration becomes limited if the zone thickness is too small to store enough water, so an estimation of the required water volume was done to approximate a minimum thickness (eq1). The calculations are based on a dimensioning precipitation of 50 mm/h, which corresponds to SMHI's approximate value for a 100-year rain in southwestern Sweden 2011-2040. Based on the calculated values in Table A3, the minimum limit for Unsaturated zone was set to 0.3m.

$$Uz = (D * t) / p \qquad \text{(eq 1)}$$

Uz: unsaturated zone thickness
D, dimensioning precipitation: 50 [mm] = 0,05 [m]
t, duration: 1 h
p, approximated soil porosity for permeable soils in the area

Table A3: Calculated Uz for different soil types.

Soil Type	**p (-)**	**Uz (m)**
Silty till	0.2	0.25
Sand	0.3	0.17

The parameter Soil thickness also limits the infiltration capacity. The data layer for this parameter was based on data from the SGU product 'Jorddjupsmodell', which gives a rough picture of the soil coverage thickness. The data is provided as points but is still not raw. It has been calculated through interpolation of field data received from, e.g. drillings and supported by information derived from surface layers, which makes the data quality very uncertain. The limiting minimum depth was approximated to 1.5 m.

Accessibility parameters included Impermeable surfaces derived from Lantmäteriet's dataset Topografi10: 'Anläggningsområden', 'Byggnadsverk' and 'Kommunikation'. Classifications are shown in Table A4, and for more information regarding the datasets, see section A-2.3.

Table A4: Indicator translation scheme: Accessibility parameters for Infiltration and retention of Stormwater

Accessibility parameter	**GS accessibility class (Author's suggestion)**
Buildings	Inaccessible - D (0)
Big roads	Inaccessible - D (0)
Railway	Inaccessible - D (0)
Motorsports facility	Limited accessibility - C (1)
Ball sports field	Limited accessibility - C (1)
Tennis field	Limited accessibility - C (1)
Sports facility	Limited accessibility - C (1)
Ice field	Limited accessibility - C (1)
Waste facility	Limited accessibility - C (1)
Running track	Limited accessibility - C (1)

The only suitability parameter used was Potentially Contaminated Areas based on the product 'LST Potentiellt förorenade områden (EBH)', see A-2.1 for more information.

The processing in QGIS involved mainly the use of the tools *Clip* and *Dissolve* to delimit areas and combine polygons according to specific attributes. To visualize point data as areas, *IDW interpolation* was used, followed by *vectorize* and removal of areas with depth less than liming values for soil depth and unsaturated zone respectively. The different capacity parameters were *merged stepwise* as described in section A-3. Line data for roads and railways were displayed as areas by adding *buffers* of 10m and 15m.

A-1.2 QGIS Specifications - Provision of Groundwater

All data used for the maps regarding 'Provision of groundwater' are summarized in Table A5.

Table A5: Summary of data used in QGIS maps for 'Provision of groundwater'.

Specific GS and use	Parameter(s) c – capacity s – suitability a – accessibility	Data Product	Used data subproducts	License	Data product source
Provision of groundwater for extraction on municipal scale	c: Water extraction capacity	Grundvattenmagasin	All	CC0 1.0	SGU
	a: Protected areas	Skyddade områden: Art- och habitatsdirektivet	Natura2000	CC0 1.0	EPA
		Riksintresse friluftsliv och naturvård	All	CC0 1.0	EPA
		Skyddade områden: Vattenskyddsområde	All	CC0 1.0	EPA
		Topografi10	Naturvård	CC BY 4.0	SGU
	a: Existing construction/activity	Topografi10	Anläggningsområde, Byggnadsverk, Kommunikation	CC BY 4.0	SGU
	s: Contamination	LST Potentiellt förorenade områden (EBH)	All	CC BY 4.0	Länsstyrelsen
	s: Ethics	Topografi10	Anläggningsområde	CC BY 4.0	SGU

These maps were primarily based on aquifer data from SGU's 'Grundvattenmagasin'. This dataset identifies major groundwater aquifers, mainly linked to glaciofluvial deposits and sedimentary bedrock. Within the study area, however, no significant bedrock aquifers were identified. The product contains information at both an overview scale (1:250 000) and, in some areas, a more detailed scale (1:50 000). The dataset provides an attribute groundwater extraction capacity in predefined intervals, which were translated into GS-potential levels according to Table 6.

Table A6. Indicator translation scheme: from the parameter water extraction capacity to GS-potential.

Extraction capacity (from 'Grundvattenmagasin')	GS capacity class (Lundin2025)
Unknown	No or limited potential - D (0)
<1 l/s	Some potential - C (1)
1–5 l/s	Moderate potential - B (2)
5–25 l/s	Moderate potential - B (2)
25–250 l/s	Highest potential - A (3)

The suitability parameters Potentially contaminated sites were primarily represented using rasterized 'EBH' data (see Chapter A-2.1). Waste facility areas were included for similar reasons, and cemeteries were added due to both pathogenic concerns and ethical considerations. These features were sourced from Lantmäteriet’s 'Topografi 10' (1:10 000). Suitability classifications (excluding EBH) are shown in Table A7.

Table A7. Suitability parameters (excl. EBH) for groundwater extraction.

Suitability parameter	**Suitability class (Author’s suggestion)**
Waste facility	Unsuitable - D (0)
Cemetery	Unsuitable - D (0)

Accessibility parameters included legally protected areas and existing, conflicting land use (summarised in Table A8). Protected areas cover sites designated by Swedish law for cultural, ecological, or recreational value. 'Topografi 10' provides nature reserves and natural memorial areas (naturminnesområden), while the Swedish EPA datasets 'Skyddade områden: Art- och habitatsdirektivet' and 'Riksintresse för friluftsliv' supply Natura 2000 areas and national interests for outdoor recreation (the latter mapped at a general level). See chapter A-2.3 – A-2.5 for more details.

Water protection areas ('Skyddade områden: Vattenskyddsområden') for surface water were also included, since constructing extraction facilities in such zones would require special permits.

Existing land use affecting accessibility includes areas occupied by activities or structures difficult to relocate, such as mining sites, major roads, and buildings, as well as conflicting land uses like agriculture. All were derived from 'Topografi10', see A-2.3.

Table A8. Indicator translation scheme: Accessibility parameters for groundwater extraction.

Accessibility parameter	**GS accessibility class (Author’s suggestion)**
Natura2000	Inaccessible - D (0)
Nature reserve	Inaccessible - D (0)
Nature memorial area	Inaccessible - D (0)
Animal protection area	Inaccessible - D (0)
Water protection area	Conditionally accessible - C (1)
National interest for outdoor activity	Limited accessibility - C (1)
Mining area	Inaccessible - D (0)
Buildings	Inaccessible - D (0)
Big roads	Inaccessible - D (0)
Farmland	Conditionally accessible - C (1)

The data processing in QGIS was performed mainly using *Clip* to remove unnecessary data and *Dissolve* to combine data polygons according to attributes, e.g. extraction capacity.

A-1.3 QGIS Specifications - Bearing Capacity

All data used for the maps of ‘Bearing capacity’ are summarized in Table A9.

Table A9: Data used in QGIS maps for ‘Bearing capacity.

Specific GS and use	Parameter(s) c – capacity s – suitability a – accessibility	Data Product	Used data subproducts	Licence	Data product source
Bearing capacity regarding surface construction	c: Terrain class	Jordarter 1:25 000 – 1:100 000	Capacity classing according to Lundin2025	CC0 1.0	SGU
	c: Precautionary areas	Jordskred och raviner	All	CC0 1.0	SGU
		Förutsättningar för skred i finkornig jordart	Strandnära aktsamhetsområden Efterarbetade aktsamhetsområden	CC0 1.0	SGU
	a: Protected areas	Skyddade områden: Art- och habitatsdirektivet	Natura2000	CC0 1.0	EPA
		Topografi10	Naturvård	CC BY 4.0	SGU
		Riksintresse friluftsliv och naturvård	All	CC0 1.0	EPA

The maps were mainly based on Terrain class (Lithology) data from SGU’s dataproduct ‘Jordarter 1:25 000 – 1:100 000’, see A-2.1. The attribute of interest for translation into GS-potential was ‘jg2_tx’ which corresponds to Lithology or Terrain class, see Table A10. Added to Terrain class was data from two more products. First SGU’s ’Förutsättningar för skred I finkornig jordart’ which describes areas with fine grained soil types which shows higher risk of landslides, see A-2.5. The attribute of interest from this product was ‘aktsamhetsområden’, precautionary areas, which all were classified with GS capacity class C;1. The other added data product was ‘Jordskred och raviner’ which shows landslides traces in the terrain including ravines. For this product all registered areas were defined as precautionary areas and classified with GS capacity class C;1.

Table A10. Indicator translation scheme: from the parameter Terrain class to GS-potential.

Terrain class / Lithology	**Terrain class / Lithology (Swedish)** (from ‘jg2_tx’)	**GS capacity class** (Lundin-Frisk et al., 2025) C(lowest) - A(highest)	**Closest available substitute** C(lowest) - A(highest)	**GS capacity class** (Author’s suggestion)
Bog-peat	Mossetorv	missing	Torv (C)	1
	Flygsand	missing	Sand (A) Silt (C)	2
Glacifluvial deposit coarse silt—fine sand	Glacial grovsilt--finsand	missing	Glacial silt (C) Glacial sand (A)	2
Mud	Gyttja	C		1
Postglacial sand	Postglacial sand	A		3

Flood-plain deposit clay--silt	Svämsediment, ler--silt	C		1
Flood-plain deposit coarse silt--fine sand	Svämsediment, grovsilt--finsand	missing	Silt	1
Washed deposit shingle	Klapper	A		3
Post glacial clay	Postglacial lera	C		1
Bedrock	Berg	missing	Urberg (A)	3
Silt	Silt	C		1
Flood-plain deposit sand	Svämsediment, sand	missing	Svämsediment sand--block (A)	1
Washed deposit gravel	Svallsediment, grus	A		3
Flood-plain deposit, clay--silt	Älvsediment, ler--silt	missing	Svämsediment ler--silt (C)	1
Postglacial fine sand	Postglacial finsand	missing	Postglacial sand (A) Postglacial silt (C)	2
Glaciofluvial deposit, gravel	Isälvssediment, grus	missing	Glacifluvial deposit (A)	3
Glaciofluvial deposit, sand	Isälvssediment, sand	missing	Glacifluvial deposit (A)	3
Flood-Plain deposit, sand	Älvsediment, sand	missing	Flood-Plain deposit, sand--boulder (A)	3
Bedrock	Urberg	A		3
Sandy till	Sandig morän	A		3
Muddy clay	Gyttjelera (eller lergyttja)	missing	Gyttja (C) Lera (C)	1
Swamp peat	Kärrtorv	missing	Torv (C)	1
Glaciofluvial deposit	Isälvssediment	A		3
Glacial clay	Glacial lera	C		1
Fill material	Fyllning	A		3
Peat	Torv	C		1
Glacial silt	Glacial silt	C		1
Till	Morän	A		3
Postglacial silt	Postglacial silt	C		1
Clay--silt	Lera--silt	missing	Clay (C) Silt (C)	1

Accessibility parameters data used included variations of protected areas. The product Topografi10 – 'Naturvård' covered nature reserves, nature memorials (naturminnesområden) and animal protection areas. Next, the EPA product 'Skyddade områden: Art- och habitatsdirektivet (Natura2000, SCI, SAC)' provided Natura2000 areas; the EU for protection program for species and nature types. EPA also provided areas for national interest regarding outdoor activity. An overview of accessibility classifications is shown in Table A11.

Table A11. Indicator translation scheme: Accessibility parameters for bearing capacity.

Accessibility parameter	**GS accessibility class (Authors suggestion)**
Natura2000	Inaccessible - D (0)
Nature reserve	Inaccessible - D (0)
Nature memorial area	Inaccessible - D (0)
Animal protection area	Inaccessible - D (0)
National interest for outdoor activity	Limited accessibility - C (1)

The processing in QGIS was preformed mainly using *Clip* and *Dissolve* to limit area and combine polygons according to specific attributes. The ravine information was provided as line data and was therefore provided a *Buffer* of 50m for show of areal extent. The different capacity parameters were *merged stepwise* as described in section A-3.

A-1.4 QGIS Specifications - Resistance to Erosion

All data used for the maps regarding 'Resistance to erosion' are summarized in Table A12.

Table A12: Data used in QGIS maps for 'Resistance to erosion'.

Specific GS and use	**Parameter(s)** c – capacity s – suitability a – accessibility	**Data Product**	**Used data subproducts**	**Licence**	**Data product source**
Resistance to erosion regarding construction	c: General soil erodibility	Jordarter 1:25 000 – 1:100 000	Capacity classing according to Lundin2026	CC0 1.0	SGU
	c: Precautionary areas	Jordskred och raviner	All	CC0 1.0	SGU
		Förutsättningar för skred i finkornig jordart	Strandnära aktsamhetsområden Efterarbetade aktsamhetsområden	CC0 1.0	SGU
	a: Existing construction and installations	Topografi10	Byggnadsverk, Kommunikation, Anläggningsområden	CC BY 4.0	SGU

These maps were primarily based on erosivity classed soil type data. The data product used was 'Jordarter 1:25 000 – 1:100 000', attribute of interest was jg2_tx and the erosivity classes were based on values from the dataset 'Stranderosion och geologi', referred to in Lundin2026. However, since a detailed assessment of erosivity was available in the datasets for precautionary areas, 'Förutsättningar för skred I finkornig jordart' and 'Jordskred och raviner', these was used to differentiate the risk areas even more. It was done by upgrading lithologies originally classified as Some potential C;1 to Moderate potential B;2, leaving only precautionary areas as to represent lowest level C;1. Table A13 shows the erosivity classifications of lithologies. The included datasets are described in more detail in section A-2.1, A-2.6 and A-2.7,

Table A13: Indicator translation scheme: from the parameter Erosivity class to GS-potential:

Lithology	**Lithology (Swedish)** (jg2_tx)	**Erosivity class** (SGU, 'Stranderosion och geologi')	**GS capacity class** (Author 's suggestion)
Peat	Torv	Some erosion susceptibility	Moderate potential – B (2)
Glacial silt	Glacial silt	Some erosion susceptibility	Moderate potential – B (2)
Glacial coarse silt—fine sand	Glacial grovsilt--finsand	Potentially high erosivity	Moderate potential – B (2)
Clay--silt	Lera--silt	Some erosion susceptibility	Moderate potential – B (2)
Mud	Gyttja	Potentially high erosivity	Moderate potential – B (2)
Till	Morän	Low erosion susceptibility	Highest potential – A (3)
Flood-plain deposit clay--silt	Svämsediment, ler--silt	Some erosion susceptibility	Moderate potential – B (2)
Sandy till	Sandig morän	Some erosion susceptibility	Highest potential – A (3)
Shifting sand	Flygsand	Potentially high erosivity	Moderate potential – B (2)
Bog peat	Mossetorv	Some erosion susceptibility	Moderate potential – B (2)
Postglacial clay	Postglacial lera	Some erosion susceptibility	Moderate potential – B (2)

Filling	Fyllning	Low erosion susceptibility	Highest potential – A (3)
Postglacial silt	Postglacial silt	Potentially high erosivity	Moderate potential – B (2)
Glacial clay	Glacial lera	Some erosion susceptibility	Moderate potential – B (2)
Flood-plain deposit, clay--silt	Älvsediment, ler--silt	Potentially high erosivity	Moderate potential – B (2)
Glaciofluvial deposit, sand	Isälvssediment, sand	Potentially high erosivity	Moderate potential – B (2)
Flood-plain deposit, sand	Svämsediment, sand	Some erosion susceptibility	Moderate potential – B (2)
Flood-plain deposit, sand	Älvsediment, sand	Some erosion susceptibility	Moderate potential – B (2)
Washed deposit, coarse silt—fine sand	Svämsediment, grovsilt--finsand	Some erosion susceptibility	Moderate potential – B (2)
Washed deposit, gravel	Svallsediment, grus	Some erosion susceptibility	Moderate potential – B (2)
Silt	Silt	Potentially high erosivity	Moderate potential – B (2)
Glaciofluvial deposit, gravel	Isälvssediment, grus	Some erosion susceptibility	Moderate potential – B (2)
Igneous Bedrock	Urberg	Low erosion susceptibility	Highest potential – A (3)
Glaciofluvial deposit	Isälvssediment	Potentially high erosivity	Moderate potential – B (2)
Postglacial sand	Postglacial sand	Potentially high erosivity	Moderate potential – B (2)
Bedrock	Berg	Low erosion susceptibility	Highest potential – A (3)
Postglacial fine sand	Postglacial finsand	Potentially high erosivity	Moderate potential – B (2)
Swamp peat	Kärrtorv	Some erosion susceptibility	Moderate potential – B (2)
Muddy clay	Gyttjelera (eller lergyttja)	Potentially high erosivity	Moderate potential – B (2)
Shingle	Klapper	Low erosion susceptibility	Highest potential – A (3)

Accessibility parameters for the erosion resistivity map are presented in Table A14 and covers buildings, facilities or activity areas that are considered very or quite hard to reposition. This includes data from Topografi10 regarding 'Byggnadsverk, 'Kommunikation' and 'Anläggnignsområden', see section A-2.3.

Table A14. Indicator translation scheme: Accessibility parameters for erosion resistance map.

Accessibility parameter	**GS accessibility class (Authors suggestion)**
Buildings	Inaccessible - D (0)
Big roads	Inaccessible - D (0)
Railway	Inaccessible - D (0)
School yards	Limited accessibility - C (1)
Cemetery	Limited accessibility - C (1)
Waste facility	Limited accessibility - C (1)

The processing in QGIS was preformed mainly using *Clip* and *Dissolve* to limit area and combine polygons according to specific attributes. The different capacity parameters were *merged stepwise* as described in section A-3. Line data roads and railways were displayed as areas by adjusting *stroke thickness*.

A-1.5 QGIS Specifications - Provision of Rock Aggregate

All data used for the maps regarding 'Provision of Rock Aggregate' are summarized in Table A15.

Table A15: Data used in QGIS maps for 'Provision of rock aggregate'.

Specific GS and use	Parameter(s) c – capacity s – suitability a – accessibility	Data Product	Used data subproducts	License	Data product source
Provision of bedrock for crushed concrete aggregate production	c: General rock quality for concrete aggregate	Berggrund 1:50 000-1:250 000	General quality classing according to Mortenssen2018	CC0 1.0	SGU
	a: Soil depth	Jorddjupsmodell	All	CC0 1.0	SGU
	a: Protected nature	Skyddade områden: Art- och habitatsdirektivet	Natura2000	CC0 1.0	EPA
		Topografi10	Naturvård	CC BY 4.0	SGU
	a: Existing construction/activity	Topografi10	Byggnadsverk, kommunikation, anläggningsområden	CC BY 4.0	SGU
	s: Competing interest: groundwater	Riksintresse friluftsliv och naturvård	All	CC0 1.0	EPA
		Grundvattenmagasin	All	CC0 1.0	SGU

These maps for were based on bedrock data from the SGU bedrock product 'Berggrund 1:50 000 – 1:250 000'. It describes geological units found at the ground surface and is based on geological field observations combined with analyses and geophysical data. Since the inventories has been in progress since the 60s the quality of data varies considerably.

To translate bedrock types into GS-potential, the report Mortensen2018 was used as reference. It describes general quality classes for concrete along with bedrock type examples so these in turn could be assigned suitable GS-potential, see Table A16.

Table A16: Indicator translation scheme: from the parameter Bedrock quality class to GS-potential:

Quality class (Mortensen2018)	**Rock type examples (Swedish)** (Mortensen2018)	**Corresponding rock types represented in Askersund (Swedish)** (Bedrock 1:50 000-1:250 000)	**Capacity classes** (Author's suggestion)
Generally suitable for most types of usage - class 1	Kambrisk Sandsten Alksten Leuko-Graniter Glimmerfattiga Granitoider Omkristalliserade Jämnkorniga Granitoider	Kalksten	Highest Potential – A (3)
Generally suitable for several types of usage - class 2	Granitoider, Gabbro Diabas Diorit I Allmännhet, Sandsten	Diabas Granit Tonalit-Granodiorit Gabbroid-Dioritoid Sandsten Syenitoid-Granit Kvartsit Monzodiorit-Granodiorit	Moderate Potential – B (2)
Generally suitable for some types of usage - class 3	Myoliter Kvartsiter Högstrålande Graniter Sulfidimpregnerade Bergarter Glimmerrika Bergarter Ljusa Vulkaniska Bergarter Porösa Sandsten, Basalt	-	Some Potential – C (1)
Generally unsuitable - class 4	Skiffer (Särskilt Alunskiffer) Vittrade Bergarter Kritkalsten Med Mycket Flinta	Glimmerskiffer	No Potential – D (0)
Unclassified	-	Vacka Karbonatsten, Marmor Basisk Eller Mafisk Bergart Konglomerat Granofels Amfibolit Dacit-Ryolit Paragnejs Skiffer Ultrabasisk Intrusivbergart Kvartsarenit	Unclassified

Suitability parameters are summerised in Table A17 and include EPA data for National interest for outdoor activity (see section A-2.5) but also data for groundwater conflicting groundwater aquifers. (Used datasets originate from the SGU product 'Grundvattenmagasin' which have been GS-classified with highest or moderate potential for groundwater extraction on municipal scale).

Table A17. Indicator translation scheme: Suitability parameters for Rock aggregate provision map'.

Suitability parameter	**Suitability class (Authors suggestion)**
Competing interest: high-capacity groundwater aquifer	Conditionally suitable - C (1)
National interest for outdoor activity	Conditionally suitable - C (1)

Accessibility parameters are presented in Table A18 along with their indicator classifications. One major accessibility parameter for the bedrock map was a limitation of soil depth, set to 5m. For this task, data from the SGU product 'Jorddjupsmodell' was used, which provides a very rough picture of the soil coverage. The data is provided as points but is still not raw. It has been calculated through interpolation of field data received from e.g. drillings and supported by information derived from surface layers which makes the data quality very unsure. Accessibility also covered Natura2000-areas from 'Skyddade områden: Art- och habitatsdirektivet (Natura2000, SCI, SAC)' by EPA. Added to that were data regarding nature protection, buildings, infrastructure and various civil installations provided from subproducts in 'Topografi10' by Lantmäteriet: 'Naturvård', 'Kommunikation' and 'Anläggningsområden' (see section A-2.3 and A-2.4 for more information.) Locations for existing rock quarries was also added.

Table A18. Indicator translation scheme: Accessibility parameters for Rock aggregate provision map.

Accessibility parameter	**GS accessibility class (Authors suggestion)**
Buildings	Inaccessible - D (0)
Big roads	Inaccessible - D (0)
Railway	Inaccessible - D (0)
School yards	Inaccessible - D (0)
Cemetery	Inaccessible - D (0)
Waste facility	Inaccessible - D (0)
Natura2000	Inaccessible - D (0)
Nature reserve	Inaccessible - D (0)
Nature memorial area *(Naturminnesområde)*	Inaccessible - D (0)
Nature memorial point *(Naturminnespunkt)*	Inaccessible - D (0)
Animal protection areas	Inaccessible - D (0)
Soil depth > 5m	Limited accessibility - C (1)

The processing in QGIS was preformed mainly using *Clip* and *Dissolve* to limit area and combine polygons according to specific attributes. To visualize the depth data as areas, *IDW interpolation* was used followed by *vectorize* and removal of areas with depth less than 5m. Larger limiting areas as groundwater aquifers and limited soil depth were visualized with 60% *opacity*. Cemeteries, waste facilities and school yards were provided *buffers* of 200m, respectively 20m for roads, 30 m for railway and 50m for nature memorial points.

A-2 Reoccurring Datasets and Assumptions

Some data products reoccurred during the mapping process. These are described below.

A-2.1 LST Potentiellt förorenade områden (EBH)

One commonly used dataset was 'LST Potentiellt förorenade områden (EBH)', which provides point data from Länsstyrelsen regarding identified or suspected contamination. However, the dataset does not include information on the spatial extent of contamination, making both visual interpretation and further analysis challenging. To address this, the EBH points were aggregated into a 300 × 300 m grid, with each cell classified for suitability based on the number and severity of contamination points it contained (see Table A19).This approach offers a more interpretable indication of potential contamination influence, although the actual impact areas may be either larger or smaller than the chosen grid size.

Data processing in QGIS was performed using *Rasterize* to generate the grid and *Count Points in Polygon* to summarise the number of EBH points per cell.

Table A19: GS-classification of EBH contamination data.

Contamination assessment	(in Swedish)	Suitability class
>= 1 instances of 'very large risk of adverse impact (risk class 1)'	>= 1 instans av 'stor risk för påverkan (risk-klass 1)'	Unsuitable - D (0)
>= 1 instances of ' large risk of adverse impact (risk class 2)'	>= 1 instans av 'stor risk för påverkan (risk-klass 2)'	Unsuitable - D (0)
>= 1 instances of 'moderate risk of adverse impact (risk class 3)'	>= 1 instans av 'måttlig risk för påverkan (risk-klass 3)'	Conditionally suitable - C (1)
>= 2 instances of 'recorded but not classified risks of adverse impact (risk class E)	>= 2 instans av 'Rapporterad men ej klassificerad risk för påverkan (risk-klass E)'	Conditionally suitable - C (1)

A-2.2 Jordarter 1:25 000 – 1: 100 000

This dataset shows the spatial extent of soil types, grouped together depending on lithology and grain composition that is found about 0.5 m below the soil surface. It is intended to support various subsurface assessments from contamination spread to buildability and is the foundation for several map services provided by SGU. The product contains information on scales between 1:25 000 and 1: 100 000 which makes the data quality varied.

A-2.3 Topografi10

Topografi10 is provided by Lantmäteriet and consist of several subproducts including buildings, land use types, roads, hydrography etc. The product is recommended for use on scale 1:1000-1:20 000.
One reoccurring subproduct of Topografi10 is ‘Naturvård’. It covers areas protected due to nature values for example nature reserves, nature memorials (naturminnesområden) and animal protection areas. The data has been collected in cooperation with Naturvårdsverket EPA and the areas are measured with GPS-technology with high considered geographical precision.

Another used subproduct is ‘Anläggningsområde’, areas for certain facilities or activities. This data is gathered through photogrammetric measurements in air photos combined with manual editing by the municipalities. The data is described with generally high thematic accuracy.

The subproducts ‘Byggnadsverk’ and ‘Kommunikation’ represents buildings and different types of communication modes such as variations of roads, railways etc. ‘Byggnadsverk’ stems from Grundläggande Geografisk Data (GGD) and editing cooperation with municipalities. ‘Kommunikation’ is based on the extensive national database NVDB (Nationell vägdatabas). For visual clarity of the road mapping, this project has only used data for roads that were considered larger, including: ‘Mötesfri väg’, ‘landsväg’, ‘övergripande länk’, ‘huvudagata’ and ‘landsväg liten’.

A-2.4 Skyddade områden: Art och habitatsdirektivet

Next, the EPA product ’Skyddade områden: Art- och habitatsdirektivet (Natura2000, SCI, SAC)’ provided Natura2000 areas; the EU for protection program for species and nature types. The EPA also provided areas for national interest regarding outdoor activity, though these areas are registered with lower geographical precision.

A-2.5 Riksintressen för friluftsliv

This EPA product presents areas that hold national interest for outdoor activity. The geographical positions are approximate and should always be complemented with descriptive documentation. The product was brought up to date during 2024.

A-2.6 Förutsättningar för skred i finkornig jordart

SGU’s ’Förutsättningar för skred I finkornig jordart’ describes areas with fine grained soil types which shows higher risk of landslides. The information is based on an estimation algorithm dependent on soil type, terrain data and a critical slope of 10%. One part of the dataset ‘Stränders eroderbarhet’ also considers areas close to shores of water bodies larger than 10 000 m^2. Due to the combination of different datasets caution is recommended in areas where only maps in small scales as 1:50 000 are available.

A-2.7 Jordskred och raviner

‘Jordskred och raviner’ from SGU shows morphological traces in the terrain after landslides with addition of ravines deeper than 3m in loose soils. The areas have been identified by image-recognition based on material from Elevation data from Lantmäteriet (GSD-Höjddata, grid 2+) and SGU’s soil type databases. Approximated position errors are 30 m.

A-3 Stepwise Merge of Multiple Capacity Parameters

To combine GS-potential from multiple capacity parameters into one single layer, a stepwise procedure was used to decrease GS-potential in areas where other parameters cause a limit. In this case all overlaying parameters had binary GS-potential values (0 or 1), which made the procedure straight forward. The description below summarises the procedure and gives a practical example from mapping of the service 'Provision of Rock Aggregate

1. Start from one parameter Layer (Layer 1) that is classified according to GS-potential
   Ex: Start with the GS-classified layer for the parameter Bedrock Quality.
2. Add a new GS-classified parameter Layer (Layer 2) on top.
   Ex: Add the GS- classified layer for Soil Depth on top, where some areas are graded as Limited accessibility – C(1) and the rest are unclassified.
3. Create a new layer (Layer 3) that matches areas where Layer 2 shows lower potential than Layer 1.
   Ex: Use tool 'Select by feature' to select areas where Soil depth is <5 and export the selected areas to a new layer named e.g. "*SoilDepthMin5".*
4. Create a duplicate of Layer 1 (Layer 4) but where Layer 3 has been used as template to cut out 'holes' in it.
   Ex: Use tool 'Symmetrical difference' with SDMin5 as template to create a new layer named e.g. SDMin5_Symdif
5. Now, create a duplicate of Layer 4 (Layer 5), but where the holes are filled in with areas assigned with the same potential that originally caused limitation.
   Ex: Use tool 'Union' to unify SDMin5_Symdif and SDMin5. Manually fill in GS-potential values in the added areas.

The result is a layer identical with the Bedrock Quality layer (Layer 1) but with GS-potential lowered to Limited accessibility – C(1) in areas where soil depth is less than 5m.

In cases more than two parameters are in play, the procedure is repeated with Layer 5 functioning as the new Layer 1.

APPENDIX B: M-case Reference Project

The methodological framework that underpins this project originates from Lundin-Frisk's case study conducted in Malmö Municipality (Lundin-Frisk, 2025). This is a coastal municipality, situated in region of Skåne at the southern tip of Sweden and spatially dominated by Sweden's third largest city Malmö with approximately 365 000 inhabitants.

In the study, here referred to as the M-case, GS-maps for Geophysical and Effective GS potential were developed to support the city's climate resilience planning and considered six different GS: 'Regulation of coastal erosion', 'Use of heat and cold from the subsurface', 'Infiltration and retention of stormwater', 'Access to underground space', 'Use of groundwater', and 'Production of geomaterials'. Lundin's methodology was organised into five main steps, as follows.

Step 1 involved introducing the GS concept to stakeholders in the participating municipality, carried out through a pre-webinar (LWeb1) and the first workshop (LWS1). This stage served to establish a shared understanding of the concept GS and gain local insight of the municipality's conditions and requirements.

Step 2 focused on the selection of relevant geosystem services. Lundin approached this by initially screening the comprehensive list of GS categories presented in (Lundin-Frisk et al., 2022). This screening was supplemented with insights gathered during Workshop 1 (LWS1) and desk studies. The final selection of services was guided by three key considerations: the thematic challenges facing the municipality, the availability of local knowledge, and the degree to which established solutions already existed for those challenges.

In Step 3, indicators and data sources were selected, and the geosystem service maps were produced. Indicator selection was based on the extensive list compiled in (Lundin-Frisk et al., 2025), but indicators were also adapted and modified to reflect Malmö's specific geological and spatial conditions while utilising available spatial datasets. Data collection was carried out using established national databases, including SGU, MSB, Lantmäteriet, and the EBH-database, among others.

The production of the GS maps was done with the software QGIS and consisted of four technical sub-steps which liked the geophysical environment to each selected service through the use of indicators. First, a calculation grid was created, which later enabled the sensitivity analysis conducted in Step 5. Second, the geophysical service potential was estimated for each grid cell. Third, the effective service potential, representing the extent to which people could use the service, was assessed. Finally, the maps for both geophysical and effective potential were rendered.

Step 4 involved testing and refining the developed maps. End-user feedback was collected during a preparatory webinar (LWeb2) and a second workshop (LWS2), after which the maps were adjusted based on the input received.

In **Step 5,** the refined maps underwent sensitivity analysis and validation. Two types of sensitivity calculations were applied using the established map grid, aiming to assess the robustness of the results.

DEPARTMENT OF ARCHITIECHTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2026
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY