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Citation for the original published paper (version of record):

Gärtner, N. (2026). A tool for screening groundwater ecosystem services at Swedish drinking-water sources. *Vatten*, 41: 55-62

N.B. When citing this work, cite the original published paper.

A tool for screening groundwater ecosystem services at Swedish drinking-water sources

Ett verktyg för screening av grundvattnets ekosystemtjänster vid svenska dricksvattentäkter



Nadine Gärtner¹

¹Chalmers University of Technology, Department of Architecture and Civil Engineering, 41296 Göteborg, nadine.gartner@chalmers.se

Abstract

Groundwater protection enjoys broad public support, yet implementation is often constrained by competing land uses and the need to justify trade-offs transparently. Ecosystem services offer a useful framework for structuring these discussions, but systematic screening is still uncommon because relevant information is dispersed across sources and time-consuming to compile. This paper presents a practitioner-oriented screening tool that automates the retrieval and processing of open national geodata for any user-defined area in Sweden and uses the results to pre-populate a groundwater ecosystem services assessment. Users define an area of interest by drawing on an interactive map or by uploading a boundary file. The tool produces an Excel output that summarises provisioning, regulating, and cultural services associated with the selected area, and exports GeoPackage layers for follow-up analysis and communication. Services that cannot be inferred from open data are completed through a brief guided questionnaire. The result is a repeatable screening workflow that can be completed in about 15 minutes.

Keywords: drinking water, ecosystem services, groundwater, GIS

Sammanfattning

Grundvattenskydd har ett brett stöd i samhället, men genomförandet av åtgärder begränsas ofta av konkurrerande markanvändning och behovet av att motivera avvägningar på ett transparent sätt. Ekosystemtjänster erbjuder ett användbart ramverk för att strukturera sådana diskussioner, men systematisk screening är fortfarande ovanlig eftersom relevant information är spridd över flera källor och tar lång tid att sammanställa. Denna artikel presenterar ett praktikernära screeningverktyg som automatiserar hämtning och bearbetning av öppna nationella geodata för valfritt användardefinierat område i Sverige och använder resultaten för att förfylla en bedömning av grundvattenrelaterade ekosystemtjänster. Användaren definierar ett intresseområde genom att rita i en interaktiv karta eller genom att ladda upp en grännsfil. Verktyget genererar ett Excel-underlag

som sammanfattar försörjande, reglerande och kulturella tjänster kopplade till det valda området och exporterar GeoPackage-layer för vidare analys och kommunikation. Tjänster som inte kan härledas från öppna data kompletteras genom en kort, vägledad enkät. Resultatet är ett repeterbart screeningflöde som kan genomföras på cirka 15 minuter.

Nyckelord: dricksvatten, ekosystemtjänster, grundvatten, GIS

Introduction

Establishing and updating drinking-water protection areas is a recurring task for local authorities and water suppliers. The aim is to safeguard groundwater quality and quantity while enabling ongoing land use, development, and economic activity. This requires clear decisions on where restrictions are necessary, which activities can continue, and what trade-offs different protection levels entail.

One way to support these decisions is to describe, in a structured way, what the groundwater system provides to people and the environment, and how these benefits change under alternative management options. Ecosystem services (ES) frameworks offer a common terminology for doing so and for making trade-offs comparable across sectors (Daily et al., 2009; Honey-Rosés & Pendleton, 2013). However, routine use in planning remains limited. Comprehensive ES assessments are often too time- and data-intensive, and many practitioner organisations lack the capacity to carry them out consistently (Olander et al., 2017). As a result, ES considerations are frequently treated as supplementary rather than embedded in protection planning.

To reduce this barrier, we developed Water System Services (WSS), a practitioner-oriented subset of ecosystem services tailored to Swedish drinking-water sources (Gärtner et al., 2022), and later refined it to a groundwater-specific WSS sublist. Still, even a streamlined list does not solve the main bottleneck: compiling and processing supporting evidence. Many indicators require practitioners to locate suitable datasets, curate them, and perform site-specific spatial analyses. Practitioners end up repeating the same steps for each site, often with different data availability, which makes the process hard to apply consistently. These constraints are particularly relevant for

small and medium-sized supplies, where protection planning rarely includes systematic ES screening and where groundwater-related services may remain less visible than surface-water services.

This article presents a lightweight application that reduces the workload of groundwater ES screening by automating the extraction of selected indicators from openly available Swedish geodata. Users delineate an assessment area in an interactive map or upload an existing boundary. The tool then queries and processes relevant datasets, summarises results, and pre-populates a structured reporting template. Services that cannot be supported by available datasets are flagged for user input, so that local knowledge can be documented in a consistent format. By reducing the workload of compiling indicators, the tool makes it easier to include groundwater ES in day-to-day drinking-water protection work.

Ecosystem services relevant to groundwater sources in Sweden

Ecosystem services (ES) describe the benefits that ecosystems provide to people (Haines-Young & Potschin-Young, 2018). To support practical use in Swedish drinking-water protection planning, we previously operationalised the Common International Classification of Ecosystem Services (CICES) version 5.1 into a simplified, practitioner-oriented set of Water System Services (WSS) (Gärtner et al., 2022). The aim was not to replace ES concepts, but to translate them into a short list of service classes that are plausible at drinking-water sources and can be described with concrete indicators. In this article, we use the groundwater-specific WSS refinement, which reflects typical groundwater uses, regulating functions, and cultural values linked to aquifers and groundwater-dependent environments. For clarity,

Table 1. Sweden-specific list of groundwater water system services (WSS), structured according to the Common International Classification of Ecosystem Services (CICES) hierarchy (Division, Group, and Class), with an indication of how each class is assessed in the screening tool. Codes: D = pre-filled automatically from open datasets using direct indicators; P = pre-filled automatically using a proxy indicator; Q = completed via the guided questionnaire (present / not present / unknown) and optional notes.

	Division	Group	Class	Code	
Provisioning Services	Biomass (aquatic)	Genetic Material	Genetic material from all organisms	Q	
			Municipal and private water supply, for humans	D	
	Water	Water for drinking	Drinking water for animals	P	
			Reserve water source	Q	
			Irrigation	D	
		Water for non-drinking purpose	Cooling	Q	
			Water used as a material, e.g. process water	D	
			Geothermal energy	D	
		Energy	Groundwater and surface water as an energy source	D	
			Storage of heat and coolness	Q	
Regulating Services			Transformation of biochemical or physical inputs to ecosystems	Through living processes	Q
				Through dilution	Q
	Through filtration	Q			
	Through sequestration	Q			
	Through storage or accumulation	Q			
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	Erosion control	Q	
			Flood protection	Q	
			Prevention of subsidence	D	
			Drought attenuation	P	
			Fire protection	P	
Lifecycle maintenance, habitat and gene pool protection	Pest and disease control	Maintaining populations and habitats	Q		
		Pest and disease control	Q		
		Controlling the chemical quality of freshwater	Q		
		Regulation of global climate	Q		
		Regulation of local temperature and humidity	P		
Cultural Services	Direct, in-situ and outdoor interactions that depend on presence in the environmental setting	Physical and experiential interactions with natural environment	Activities promoting health, recuperation or enjoyment through active, immersive, passive or observational interactions	P	
			Intellectual and representative interactions with natural environment	Scientific investigation, creation of traditional ecological knowledge, education, training	D
		Indirect, remote, often indoor interactions that do not require presence in the environmental setting	Spiritual, symbolic and other interactions with natural environment	Culture or heritage	Q
				Aesthetic experiences	Q
	Other biotic or abiotic characteristics that have a non-use value	Existence, bequest or option value	Religious, sacred or symbolic meaning	P	
			Entertainment or representation	Q	

the WSS class is treated as the unit of assessment and reporting: each class corresponds to one service, and the terms are used interchangeably.

The groundwater WSS list is organised into provisioning, regulating, and cultural services following the CICES hierarchy (Table 1). The structure distinguishes between benefits that are directly extracted and used, benefits that arise from physical and biogeochemical functions, and benefits that are valued through experience or non-use. Across the three divisions, 32 groundwater WSS classes may be relevant

at a given source, but their importance varies by hydrogeological setting, land use, and societal context.

Method

Tool structure

The groundwater WSS tool is a local Streamlit app distributed via a GitHub repository. Streamlit is a Python framework for building lightweight interactive web apps that run locally and open in a standard web browser. The repository includes a README with step-by-step instructions for installing Python,

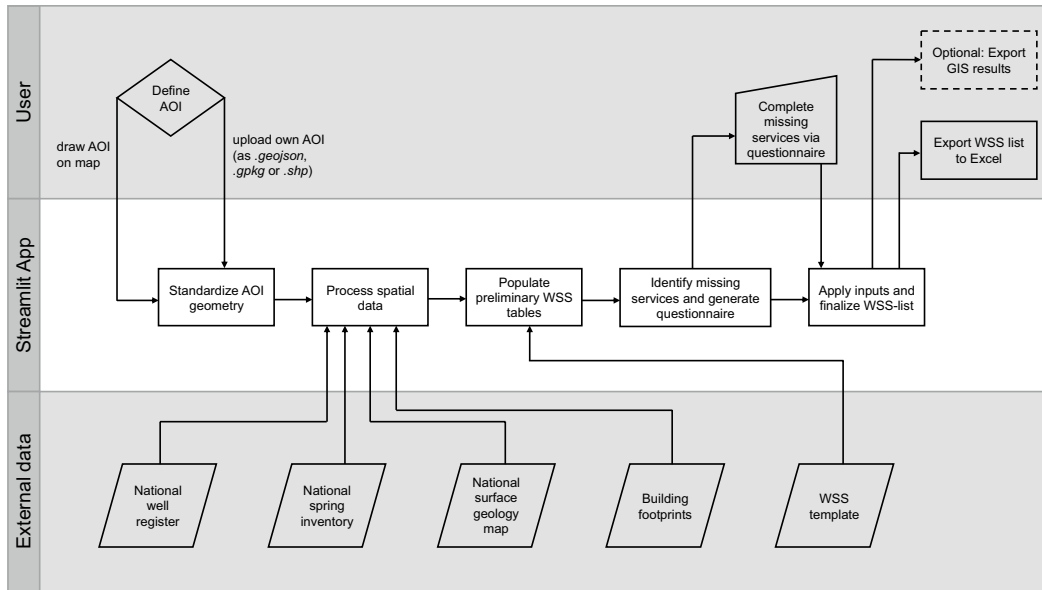


Figure 1. Swimlane flowchart summarizing the workflow of the groundwater WSS assessment tool, from AOI definition to generation of the finalized WSS list and exported results.

setting up the required libraries, and running the app. The overall workflow is summarised in the swimlane flowchart (Figure 1). After launch, the user defines an assessment area (AOI) either by drawing it directly on the map or by uploading an existing boundary (GeoPackage, GeoJSON, or a zipped Shapefile). The tool then retrieves the most recent available geodata from national agency sources and uses these data to populate the Sweden-adapted WSS list where feasible. Services with clear, dataset-based indicators are filled in automatically, together with brief text describing the underlying evidence (for example counts of household wells, heat pumps, or type of springs within the AOI).

However, not all services can be inferred from national datasets. Some depend on site-specific conditions or non-material values that require local knowledge and, in some cases, a field visit. For these services, the tool guides the user through a short questionnaire and also allows direct edits in the WSS tables. The user can indicate whether a service is present, not present, or unknown, and add a brief supporting note. The final column in Table 1 (D/P/Q) indicates whether each WSS class is pre-filled from datasets (D, P) or completed via the questionnaire (Q). The final output is a single Excel file that com-

bins the automatically derived information with user input in a transparent and consistent assessment record. In addition, all assessed WSS that are present can be exported as GeoPackage layers for further visualisation and analysis in standard GIS software.

Data

The tool combines national open geodata with user-provided inputs for a defined area in Sweden (Table 2). The analysis boundary is defined by an area of interest (AOI) drawn in the app or uploaded by the user (GeoJSON, GeoPackage, or zipped Shapefile) and is used for all spatial queries and clipping.

Spatial datasets are sourced from the Geological Survey of Sweden (SGU) and OpenStreetMap. SGU well data (Brunnar; GeoPackage) provide well locations and purpose codes and are used to characterise groundwater uses within the AOI, reported as counts by use category (for example drinking-water supply, private household wells, irrigation, process water or observation wells) and as a basic classification of geothermal installations and ground source heat pumps. SGU spring data (Källor; GeoPackage) provide spring locations and attributes (for example aquifer type, spring type, flow class, and discharge setting) and are

Table 2. Overview of datasets and inputs used by the groundwater WSS tool (Sweden)

Data type	Dataset (provider)	Format	Role in the tool	Output / indicator produced
Area of interest (AOI)	User-drawn polygon or uploaded AOI	GeoJSON / GPKG / Shapefile	Defines analysis boundary and clipping extent	AOI geometry (used for all clipping and queries)
Wells	SGU open data: Brunnar	GeoPackage	Identifies groundwater uses based on well purpose codes and attributes	Counts by use category (e.g., drinking water supply, private household wells, irrigation, process water, observation wells); GSHP vs bedrock geothermal classification
Springs	SGU open data: Källor (springs)	GeoPackage	Identifies presence and characteristics of springs within AOI	Spring count and spring attribute summary (id, aquifer type, spring type, flow class, discharge setting) and optional link to WSS classes
Soils	SGU open data: Jordarter 25k–100k	GeoPackage	Screens for clay occurrence relevant to subsidence susceptibility	Clay polygons clipped to AOI; buildings-on-clay count
Buildings	OpenStreetMap via OSMnx	Vector footprints	Estimates exposure to subsidence-relevant conditions (buildings intersecting clay)	Number of buildings and number intersecting clay polygons
Water system services (WSS) list	WSS Excel template (based on CICES, Sweden-adapted list)	Excel	Defines the service classes and assessment fields	Service table with “Present?” and “Services in the case study” fields
Expert judgement / local knowledge	User input (questionnaire and edits)	Manual entry in app	Completes services that cannot be inferred from national open datasets	“Present?” and short description for unassessed services; contextual notes

summarised as spring counts and attribute distributions within the AOI.

Subsurface conditions are screened using SGU Quaternary deposits mapping (Jordarter 25k–100k; GeoPackage), which is used to identify clay occurrence relevant to subsidence susceptibility. Building footprints are retrieved from OpenStreetMap via OSMnx. The assessment structure is provided by a Sweden-adapted WSS Excel template mapped to CICES classes, the Common International Classification of Ecosystem Services. Site-specific information can be added through a short in-app questionnaire and direct table edits, recorded as present, not present,

or unknown together with brief contextual notes.

Application interface

The application is organised as a guided, map-based workflow that takes the user from AOI definition to an exportable WSS assessment. After launch, the app runs locally and opens in a standard web browser. The interface has two main parts: an interactive map for defining the assessment area and a set of tables and forms for completing the WSS list. The AOI is defined either by drawing a polygon directly on the map or by uploading an existing boundary file, and the selected AOI is used for all subsequent processing

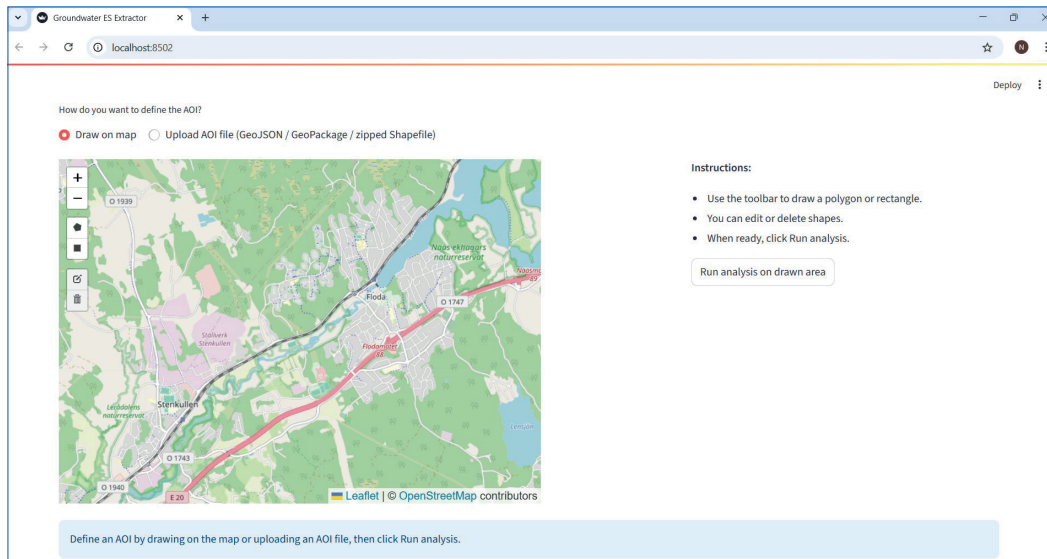


Figure 2. Area-of-interest (AOI) selection view of the groundwater WSS tool, where users define the assessment boundary by drawing directly on the interactive map or by uploading an AOI file before running the analysis.

steps (Figure 2).

After the automated extraction and pre-filling, the WSS tables are shown in the interface in spreadsheet format. Services that cannot be populated automatically are handled through a short questionnaire. For each service, the user records whether it is present, not present, or unknown and can add a brief supporting note (Figure 3). This separates services that are absent from services that are simply not supported by the available datasets. Completing the screening record in the tool typically takes around 15 minutes (automated pre-filling plus the short questionnaire), depending on AOI size and the user’s familiarity with local conditions. Services can be marked as unknown,

which flags them for follow-up rather than being resolved during screening.

Tool validation

As an initial validation, the workflow was applied to two drinking-water source areas that had already been assessed. For Skallsjö (Västra Götaland), the same AOI boundary as in the groundwater ecosystem services screening reported in Gärtner et al. (2022) was used, and the same set of groundwater WSS classes was obtained. The same consistency check was then carried out for a second case in Skåne (Nedrabý), with the same outcome. Overall, these checks provide an initial confirmation that the automated screening

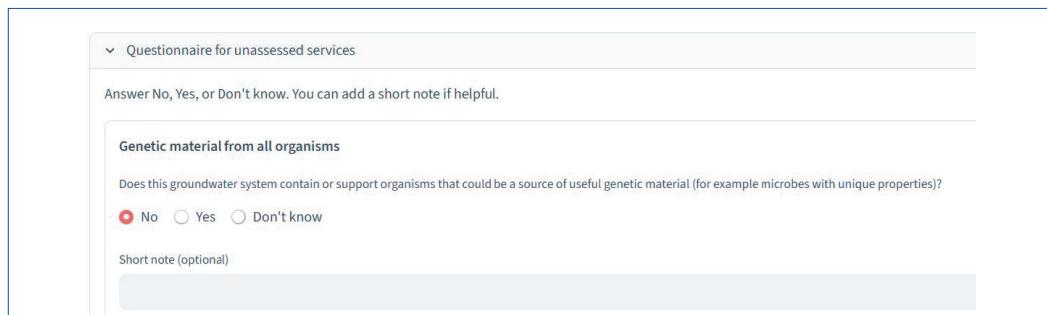


Figure 3. Excerpt of the questionnaire for unassessed services, where users record whether a WSS is present, not present, or unknown and optionally add a brief supporting note.

aligns with expected outputs for known cases. Broader evaluation across additional sites and users is a logical next step.

Tool Output

The tool produces an Excel workbook that serves as the main assessment record for the selected AOI. The workbook contains three worksheets corresponding to provisioning, regulating, and cultural services. Each row represents one WSS class and follows the same structure: classification fields (division, group, and CICES reference) and two assessment fields indicating whether the service is present in the AOI and a short description of the supporting evidence. Depending on the service, the description is either an automatically generated summary based on the input datasets or a brief user-provided note. The result is a compact, checklist-style overview of groundwater-related services within the AOI.

In addition to the Excel workbook, the tool exports GeoPackage files for services with a spatial representation in the AOI. These files contain the clipped features used to support the assessment and are stored as separate layers for direct use in standard GIS software (for example QGIS or ArcGIS) for mapping and follow-up analyses. The two outputs are complementary: the Excel workbook documents the assessment in a structured table, while the GeoPackages provide the underlying geospatial features.

Results and Discussion

The tool reduces the transaction costs of groundwater WSS screening by bringing the required datasets and the reporting structure into a single workflow. Instead of repeatedly searching for datasets, downloading files, clipping layers, and compiling indicators for each new site, it produces a ready-to-use assessment record from a user-defined AOI. This shifts effort away from repeated data handling and towards documenting the case-specific interpretation of results.

An additional advantage is data currency. Because the tool retrieves data directly from the original providers at runtime, the assessment is based on the most recent available versions rather than on locally stored copies. This reduces the risk of working with outdated inputs and supports more comparable screening

across sites, provided that data sources and retrieval dates are recorded in the output.

Two limitations are important to keep in mind. First, ecosystems and water sources are dynamic and vary over space and time (Snäll et al., 2021). The current screening is static and local, and it does not capture regional or global services such as carbon sequestration or global climate regulation. Spill-over effects across scales are often poorly represented (Vári et al., 2021), which can lead to underestimation of the full set of services linked to a drinking-water source. Second, the output is intended as a biophysical screening and documentation step, not as an endpoint for decision-making. Economic valuation is typically recommended after the biophysical assessment (Grizzetti et al., 2016), and the WSS screening can provide structured input to cost–benefit analysis when comparing protection measures and their social profitability (Sjöstrand et al., 2018).

A logical next step is a browser-based deployment so that practitioners can run the workflow without local installation. This would lower a practical barrier in organisations where installing software is restricted, where downloaded code is treated with caution, or where users are not comfortable running command-line tools. The trade-off is reduced transparency and flexibility: a hosted tool is harder to inspect and customise and may be perceived as a black box. Maintaining trust would therefore require clear documentation, versioning, and continued access to the underlying code, even if the interface is delivered through a web browser.

Incorporating ecosystem services into water management has been described as a recent step in the evolution of the field (Grizzetti et al., 2016), yet ES approaches have also been criticised as difficult to translate into governance and management practice (Cook & Spray, 2012). A lightweight screening workflow helps close this implementation gap by translating ES concepts into a routine protection-planning task with a consistent output record.

Data availability: The tool is available via GitHub: github.com/WellWellWhatNow/-/WSS

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