Interreg Alpine Space — Co-funded by the European Union — MARGIN

Output 1.1

Catalogue of fact sheets for the current state of groundwater management in Alpine cities

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MARGIN

MARGIN enables 5 cities in the Alpine Space to manage groundwater sustainability tackling effects of climate change and urbanization to foster city's climate-resilience. User-oriented, transnational tools and procedures will be established including risk analysis to monitor impacts on groundwater quantity, ecosystem and infrastructure, strategies and measures to cope with it and concepts to implement groundwater sustainability management into policy instruments at different administrative levels.

Output Information

Work Package: WP1 – City Groundwater Management Evaluation

Title: Catalogue of fact sheets for the current state of groundwater management in Alpine cities

Code: Output 1.1

Description: The catalogue of fact sheets describes current data handling, on-site management and adaption strategies, as well as country-specific/regional regulations and policies regarding present groundwater risks and adaptation measures in the pilot cities. The fact sheets outline lacks, barriers and requirements for a groundwater sustainability management, identified via stakeholder interaction. A general approach for this assessment is deviated from outcomes and lessons learned in the pilot cities.

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Version 1.0

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1 Introduction

The Catalogue of Fact Sheets provides a comprehensive overview of current data handling, on-site management, and adaptation strategies, as well as country-specific and regional regulations and policies regarding groundwater risks and adaptation measures in the pilot cities. The fact sheets outline existing gaps, barriers, and requirements for sustainable groundwater management, identified through stakeholder interaction. A general and transferable approach for assessing groundwater sustainability is derived from the outcomes and lessons learned in the pilot cities.

For each pilot city, the fact sheets describe:

- the current status of data handling, governance structures, and regulatory frameworks,
- identified gaps, barriers, risks, and further requirements for sustainable groundwater management, and
- possible future measures and strategies to enhance resilience.

The main objectives are to:

- raise awareness among local governments and administrations about groundwater-related challenges,
- provide best-practice examples, and
- establish a transferable methodology applicable to other cities beyond the pilot regions.

The output (Catalogue of Fact Sheets) and the deliverables complement each other closely:

- While the deliverables (D1.1.1, D1.2.1, D1.3.1) describe the methodological framework, general requirements, and identified problems or gaps, and include collections of results in tabular form,
- the output (Fact Sheets) presents the practical outcomes, summarizing findings, facts, and case-specific information in a concise and accessible format.

In detail:

- **D1.1.1** provides a *Catalogue of existing practices* for data acquisition and management related to groundwater in the pilot cities, including a general approach for assessing urban groundwater data situations.
- **D1.2.1** compiles *existing requirements, strategies, measures, and policies* for groundwater management, based on the city fact sheets and complemented by literature review results.

MARGIN is co-financed by the European Regional Development Fund through the Interreg Alpine Space programme. **See more about MARGIN at www.alpine-space.eu/project/margin.**

- **D1.3.1** presents a *Catalogue of existing national and regional regulations* relevant to groundwater management in the pilot cities, derived from document reviews and fact-sheet findings.

Together, these deliverables form the methodological and analytical foundation, whereas the Catalogue of Fact Sheets provides a summarized, city-specific output that visualizes and communicates the results in a transferable and practice-oriented way across all three levels - data, strategies/measures, and regulations.

2 EU Perspective

Groundwater plays a critical role in the European Union's water policy, particularly as a source of drinking water and a vital ecological resource. The EU has established a robust legal framework to ensure the sustainable management, pollution prevention and quality monitoring of groundwater across all Member States. These laws are binding and must be transposed into national legislation.

First, we can mention the **Water Framework Directive (WFD) - Directive 2000/60/EC** which represents the cornerstone of EU water law. This Directive requires Member States to achieve "good status" for all water bodies, including groundwater, establishes River Basin Management Plans (RBMPs), water monitoring and public participation. It mandates integrated water resource management. Furthermore, there is **Groundwater Directive – Directive 2006/118/EC** which is more specific to groundwater protection. The Directive aims to prevent or limit pollutants from entering groundwater. It is interesting that it requires a Member State to set threshold values for pollutants (e.g., nitrates, pesticides). Linked to the WFD, there is also the **Environmental Quality Standards Directive (EQSD)**. It sets out environmental quality standards (EQSs) for the presence in surface water[1] of certain substances or groups of substances identified as priority pollutants because of the significant risk they pose to or via the aquatic environment. Despite its focus on pollution control for surface water, it supports an integrated water management approach that includes groundwater.

A Watch List mechanism was established in 2013 to improve the available information on identifying the substances of greatest concern. Member States must monitor the substances on the list at least once per year for up to four years. The watch list was established in 2015 and updated in 2018, 2020, 2022 and again in 2025.

The Nitrate Directive - Directive 91/676/EEC aims to reduce water pollution from nitrates used for agricultural purposes and prevent any further pollution and it is connected to the WFD as well. It is also focusing on surface water but its aim to reduce nitrate pollution is protecting groundwater from nitrate infiltration as well.

The **Drinking Water Directive – Directive 2020/2184** ensures the safety and quality of drinking water sources. It sets strict chemical and microbiological standards, strengthens protection of water catchments, including groundwater and encourages risk-based approaches and public access to information. In addition, with **Urban Wastewater Treatment Directive – Directive 91/271/EEC** which protects groundwater indirectly by regulating sewage and stormwater, prevents leaching of pollutants into groundwater from untreated or poorly treated wastewater, encourages risk-based approaches and management of sewer systems, especially in urban areas.

[1] https://eur-lex.europa.eu/EN/legal-content/summary/environmental-quality-standards-applicable-to-surface-water.html#keyterm_E0001

The Water Reuse Regulation – Regulation EU 2020/741 on minimum requirements for water reuse sets out harmonised parameters to guarantee the safety of water reuse in agricultural irrigation, with the aim of encouraging this practice and helping to address droughts and water stress. It created minimum requirements for water quality and monitoring along with rules on risk management, for the safe use of reclaimed water for agricultural irrigation in the context of integrated water management.

Lastly, **Industrial Emissions Directive – Directive 2010/75/EU** applies to large-scale industrial activities as it requires permits that include groundwater protection measures (under IPPC regime), and it mandates monitoring and remediation in case of contamination.

Together, a comprehensive EU legal framework for groundwater protection is formed. They require Member States to monitor groundwater quality, quantity, prevent and reduce pollution and manage water sustainability.

3 Catalogue of Factsheets

The catalogue comprises at this state all gathered facts about the recent groundwater management in the pilot cities, considering data-handling, governance and regulations. The fact sheet will be updated and completed with other relevant aspects (strategies and measures, best practise etc.) during the project duration

The pilot cities are

- Linz, Austria
- Ljubljana, Slovenia
- Milan, Italy
- Munich, Germany

Each City Fact Sheet provides a concise yet comprehensive overview of the respective pilot city and its groundwater-related situation. The structure is designed to ensure clarity, comparability, and practical value across all cities.

- **Summary Fact Sheet**
  A one-page summary highlighting the key findings, main challenges, and essential insights for the city.
- **City – General Overview**
  A short presentation of the city, outlining its geographical, climatic, and hydrogeological context, as well as the specific framework conditions relevant for groundwater management.
- **City – Data Overview**
  A summary of the currently available groundwater-related data, including monitoring networks, data quality, accessibility, and existing data management practices.
- **City – Topics Overview**
  A table listing all identified groundwater-related challenges and their relative importance or ranking within the city.
- **City – Challenges Details**
  An in-depth assessment of each identified challenge, covering its relevance, governance structures, data-handling practices, existing gaps, ongoing or planned measures and strategies, and the regulatory framework.
- **Further Information**
  Additional resources, references, and links to relevant deliverables and documents for deeper insight into methodologies, detailed analyses, and supporting materials.

3.1 LJUBLJANA

Short overview

Hydrogeology

- thick alluvial sediment deposits
- unconfined, highly productive intergranular aquifer

Main usage of groundwater

- drinking water
- industrial
- geothermal heating and cooling

Data overview and handling practices

- The monitoring networks provide systematically collected data (GW level and chemical parameters)
- Groundwater and geothermal data are partly accessible through web portals
- ~150 GW geothermal systems

Measures & strategies and regulation & policies

- Sustainable Urban Strategy
- Local energy plan
- Drinking water protection zones
- Municipal Spatial Plan

Topics

- Thermal use of groundwater (management, interactions, sustainability)
- Groundwater quality and ecosystem health
- Rainwater Infiltration

Gaps

- The monitoring networks are not integrated into a single system
- Limited monitoring of groundwater temperature and thermal use
- Lack of tools to assess interactions of thermal groundwater uses
- No established methodology for groundwater ecosystem assessment

Ljubljana – General Overview

Extended description of the city

Description of the city

Ljubljana is the political, economic, educational, and cultural centre of Slovenia, with a population of 290,903 in 2024, which represents 13% of Slovenia's total population. It is also one of the most densely populated areas in the country, with a population density of over 1,760 inhabitants per km². A very high urbanization rate of around 90% is present in the central part of the city and is lower on its outskirts.

Extent and altitude

The Municipality of Ljubljana covers 275 km². It is located in the central part of the Ljubljana Basin, bordering the mountainous Alpine regions to the north, the Škofjeloško and Polhograjsko Hills to the west, the Posavsko Hills to the east, and the Dinaric Karst regions (Krim and Menišija) to the south.

The average altitude of Ljubljana is 299 m a.s.l. The highest point is Janški hrib 794 m a.s.l. and the lowest point is 261 m a.s.l at confluence of Sava and Ljubljanica river. In old city center the highest point is Ljubljanski grad (castle) with 366 m a.s.l.

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Climate

Ljubljana has a temperate continental climate, with frequent temperature fluctuations during winter that can persist for several days. July is typically the warmest month, while the lowest temperatures are recorded in January. Due to its location in the Ljubljana Basin, fog is common during the colder part of the year. The city also exhibits a pronounced urban heat island effect, experiencing significantly higher temperatures than nearby less urbanized or rural areas.

According to data from the Slovenian Environment Agency, the average annual temperature recorded at a meteorological station in the city has been rising over the past decades. The average annual temperature was 9.85 °C in the period 1971–1990, increasing to 11.2 °C in 1991–2010, and further to 12.2 °C between 2011 and 2024. Average annual precipitation has also increased notably, from 1,176.7 mm in 1971–1990 to 1,367.8 mm in 1991–2010, and 1,411 mm between 2011 and 2024.

The number of days with snow cover in Ljubljana has shown a clear declining trend over recent decades. In 1971–1990, the city recorded an average of 59 days with snow cover per year, dropping to 49 days in 1991–2010 and further to only 28 days in 2011–2024, which is over 50% less than in 1971–1990.

Pilot area information	
Pilot Area	Ljubljana
Country	Slovenia
Area (km^2)	275
Elevation	299
Inhabitants	290.903
Inhabitants/km^2	1.760
Level of urbanisation	90 %
Economy	Ljubljana is the economic center of Slovenia, hosting numerous national and international companies. The city has a strong service sector, particularly in finance, trade, and tourism.
Infrastructure	Ljubljana is an important transport hub, where major international motorways intersect, forming a crossroads of two key European corridors. The city is also a railway junction, with lines branching out in five to six directions, connecting Slovenia with neighbouring countries. The network of city public bus lines covers a large part of the central Ljubljana region.

Climatological settings	
Mean air temperature	9,85°C (1971-1990); 11,2°C (1991-2010); 12,2°C (2011-2024)
Annual rainfall	1176,7 mm (1971-1990); 1367,8 mm (1991-2010); 1411 mm (2011-2024)
Heating Degree Days	Approximately 1,800–2,100 HDD (setpoint 18 °C)- Osrednjeslovenska regija
Cooling Degree Days	Approximately 130–140 CDD (setpoint 22 °C)- Osrednjeslovenska regija
Length of heating season	mid-September to mid-May
Length of cooling season	June to September

Regional hydrogeological and geological characteristics

Ljubljana is in largest part located in an alluvial plane (Ljubljansko polje) which is part of the Ljubljana Basin. subsidence and gradual filling with alluvial material transported from alpine periglacial areas

Ljubljana is situated in the Ljubljana Basin, which was formed along the main neotectonic fault system. The area subsided over time and was gradually filled with alluvial material transported from Alpine periglacial regions. Ljubljansko polje area is composed of Pleistocene and Holocene fluvial sediments, which are highly permeable and contain large amounts of groundwater. The sediments are up to 100 m thick, and their basement consists of low-permeability Carboniferous shaly mudstone and sandstone. The water table is on average 25 m below the surface. The Ljubljansko polje aquifer is recharged mainly by the Sava River and partly by rainfall. The general groundwater flow direction is from northwest towards southeast, and the groundwater flow velocity is estimated at up to 20 m/day. The hydraulic conductivity of the aquifer is high (3×10^{-3} m/s to 10^{-2} m/s). The temperature of groundwater ranges between 10.6 and 14.6 °C. In the southwestern part of the city, perched aquifers are present, which influence rainwater infiltration and the transport of pollutants from the surface.

Groundwater usages

Groundwater is the sole source of drinking water in Ljubljana. The central water supply system is based on groundwater abstraction from five well fields: Šentvid, Kleče, Hrastje, Jarški prod, and Brest. The pipeline network extends 1,273 km, and in 2024 approximately 29.17 million m^3 of groundwater was pumped. In general, the pumped water is not technically treated; occasional chlorination is applied as a precautionary measure.

The thermal use of groundwater has been steadily increasing, particularly through its use in heat pump systems for the heating and cooling of buildings. This trend is driven by the high availability and stable thermal regime of the aquifer, which provides a reliable and energy-efficient source for shallow geothermal systems.

Ljubljana – Data Overview

Groundwater-related responsibilities in Ljubljana are distributed among multiple stakeholders. Data collection, management, and use are carried out by various municipal departments, public utilities, regional authorities, and research institutions, with certain datasets available through public databases. The following stakeholders are engaged in these processes:

Authorities

Municipality of Ljubljana (MOL). **The Department of Environmental Protection (OVO)** monitors the state of the environment and nature, manages related information systems, and prepares vulnerability studies, threat assessments, and environmental reports. It also evaluates the environmental impacts of planned interventions, oversees spatial planning implementation, and maintains a spatial information system with data on land use, spatial interventions, and relevant municipal regulations.

Companies with full or partial public ownership

The public company **JP VOKA SNAGA** carries out groundwater quality and quantity monitoring to ensure the drinking water supply.

National institutions

The Slovenian Water Agency (DRSV) performs administrative and development tasks in the field of water management.

The Slovenian Environment Agency (ARSO) serves as Slovenia’s central institution for monitoring, collecting, analyzing and evaluating environmental data, as well as forecasting natural phenomena and processes to reduce natural hazards to people and property. In this context, ARSO is also responsible for monitoring groundwater quality, quantity and climate data.

The National Institute of Biology (NIB) has an important role in the groundwater protection. It conducts groundwater research, connected with ecosystem and environmental protection.

The Geological Survey of Slovenia (GeoZS) conducts monitoring of groundwater for research purposes connected with groundwater trends, thermal use of groundwater and chemical status.

Groundwater data (groundwater monitoring, water permits and water protection areas) is available at web portals of Slovenian Environmental Agency and Slovenian Water Agency. A water permits for the thermal use of groundwater is available at EcoFund web site..

The following table summarizes the groundwater-related data availability in the pilot area of Ljubljana for the most relevant categories. For a complete and detailed version see Deliverable D1.1.1

Parameter	Short description	Data format	Responsible Organization
Climate data	ARSO provides climate data such as air temperature, precipitation, snow coverage, weather phenomena, air pressure	txt	ARSO
Groundwater level	Daily data for measuring stations which locations are shown on Atlas okolja	csv	ARSO
Location of groundwater monitoring points	Location of groundwater monitoring points and description, since when the station is operational and which data is measuring	Webgis (not available for download) + PDF with stations description	ARSO
	Location of groundwater monitoring points, some are the same as at Atlas okolja	Webgis (not available for download)	DRSV
Groundwater temperature	Daily data for measuring stations which locations are shown on Atlas okolja. Temperature data missing for some stations, depends of measuring sonds in wells	csv	ARSO
Groundwater protection	Polygons of water protection zones for Slovenia	Polygon data	DRSV
Groundwater chemistry	Water supply monitoring. Available PDF reports of chemical and microbiological analysis for water-plants	PDF	JP VOKA SNAGA

Sewage and water supply network data	Map of main sewage system and central water supply system	Webgis	MOL
Digital Elevation Model	Slovenia is covered with squares 1km^2. Each square is possible to download	txt	ARSO
Sustainable energy atlas	Map of Geothermal heat pump potential	Webgis (not available for download)	Borzen
Registered geothermal systems	List of registered heat pumps with energy efficiency	csv	Eco Fund

Ljubljana – Topics Overview

The table below synthesise the relevance for each topic analysed by the MRGIN project. Ranks are based integrating the findings from the stakeholder questionnaires and the insights derived from expert interviews.

Topic	**Relevance**
1. Groundwater extremes	Low (2)
1.1 High GW: Flooding cellars & Flooding of terrain	Average (3)
1.2 Low GW: Negative influence[2] on utilisations	Low (2)
1.3 Low GW: Land subsidence	Low (1)
2. Rainwater infiltration	High (4)
3. Thermal groundwater use	High (4)
3.1 Heat energy planning & Interference (Negative influence) management[3]	Very high (5)
3.2 Increasing groundwater temperatures through geothermal utilisations & Decreasing groundwater temperatures or too low temperatures	Average (3)
4 Groundwater quality and ecosystem health	High (4)
4.1 Ecosystem analysis	High (4)
4.2 Groundwater quality and temperature	Very high (5)

[2] Negative influences on utilisations may include impacts on pumping wells used for drinking water supply, industrial processes, or heat pum operations.
[3] Interference or restriction management

Ljubljana – Topics in Detail

1. Groundwater extremes – high groundwater levels **2. Rainwater infiltration**
Relevance Stakeholders identified flooding as a relevant problem in certain parts of the city, where low-permeability layers lie shallow below the surface. Another important cause of flooding is the limited infiltration and drainage capacity in urban areas due to surface sealing and the limited capacity of the sewage system. These floods are associated with extreme rainfall events. Rainwater infiltration and retention solutions are recognized as measures that can help mitigate urban flooding while enhancing groundwater recharge.

Governance
• MNVP (Ministry of Natural Resources and Spatial Planning)
  - Legislation and regulatory framework
  - Supervision and coordination of groundwater monitoring
  - Planning and implementation of groundwater protection measures
  - Preparation of River Basin Management Plans
• DRSV (Slovenian Water Agency) (responsible for the part concerning the responsibilities and activities of water infrastructure managers, and the concession-based manager of water infrastructure, in accordance with the Water Act (ZV-1))
  - Orders Flood hazard maps and flood risk maps
• ARSO (Slovenian Environment Agency) is a body of the Ministry for the Environment, Climate and Energy. Its mission is to monitor, collect, analyse and evaluate environmental data including GW monitoring.
• JP VOKA SNAGA (public utility company) is the company responsible for the public drinking water supply system, the wastewater drainage and treatment system as well as waste management system in the Ljubljana municipality.
• MOL, Oddelek za prostorsko načrtovanje (Municipality of Ljubljana, Department for Spatial planning released Odlok o občinskem prostorskem načrtu Mestne občine Ljubljana (Decree on the Municipal Spatial Plan for Municipality of Ljubljana).

Data-handling At the national level, groundwater level monitoring is established and managed by ARSO, with data available online through the Hidrolog database. For the measuring stations of the Ljubljansko polje aquifer, data can be downloaded in XLS or CSV format. Additional groundwater level monitoring is carried out by VOKA. These data are not publicly accessible but can be obtained upon request.

Gaps

- Lack of detailed maps of shallow, low-permeability layers that could be integrated into spatial planning and building construction plans
- Limited identification of areas suitable for stormwater and rainwater infiltration, as well as insufficient implementation of rainwater retention solutions
- Lack of effective enforcement to prevent extensive surface sealing in urban areas, which significantly reduces natural groundwater infiltration.

Measures & strategies

- River Basin Management Plan - (NUV III) Načrt upravljanja voda na vodnih območjih Donave in Jadranskega morja 2023-2027
- Disaster Risk Management Program in the City Municipality of Ljubljana 2023-2030
- Protection and Rescue Plan in the Event of Floods – City Municipality of Ljubljana
- Flood Risk Reduction Plan (2023-2027)

Regulations

- Water Framework Directive
- Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Text with EEA relevance)
- Floods Directive (Directive 2007/60/EC) 2022-2027
- Preliminary Flood Hazard Assessment of the Republic of Slovenia (2024)
- Decree on the Content and Method of Preparation of the Detailed Flood Risk Reduction Plan (Official Gazette of the Republic of Slovenia, No. 7/10)
- Rules on the Methodology for Determining Areas at Risk of Floods and Related Erosion from Inland Waters and the Sea, and on the Classification of Land into Risk Classesi (Official Gazette of the Republic of Slovenia, No. 60/07)
- Flood Risk Reduction Plan (Article 60.a of the Water Act (Official Gazette of the Republic of Slovenia, No. 67/02, 2/04 – ZZdrI-A, 41/04 – ZVO-1, 57/08, 57/12, 100/13, 40/14, and 56/15)

3 Thermal groundwater use

Relevance

The thermal use of groundwater for heating and cooling is an integral part of the city's strategy to achieve environmental and climate objectives, enhance the utilization of local resources, and strengthen energy resilience and efficiency. Consequently, the number of buildings using groundwater as a source for heating and cooling is increasing. However, neither the operation of geothermal systems nor their thermal impacts on groundwater are systematically monitored. This raises the risk that cumulative effects could adversely affect groundwater quality, cause interference between systems, and reduce their efficiency.

Governance

- Department for spatial planning MOL release Local Energy plan 2024-2030.
- Research permit (DRSV)
- Water consent (DRSV)
- Water permit (DRSV)
- Building permit (Spatial planning, OVO, Ministry)

Data-handling

- The web application (Water Atlas, 2025) provides an interactive platform for accessing spatial data and information on water permits for the thermal use of groundwater and the maximum permitted pumping rate, as well as permit expiry dates. (DRSV)
- A web portal (GeoPLASMA-CE, 2025) providing comprehensive information on geothermal potential with associated possibilities and regulatory or technical constraints for the implementation of geothermal systems.
- Eco Fund database: registered GWHP systems (RS)
- Sustainable energy portal – maps (BORZEN - implementation of the public utility service activity of the electricity market operator and the public utility service activity of the support center.) (https://borzen.maps.arcgis.com/apps/webappviewer/index.html?id=756ad50afb9240c58e95fc29d6f09170):
    - Surface temperature distribution of solid ground
    - Surface heat flux density
    - Thermal conductivity of upper geological layers
    - Volumetric heat capacity of rocks and soils
    - Potential for geothermal heat pumps
    - Most often unsuitable for large borehole heat exchanger fields

Gaps

- Currently, no numerical tools are used in the planning and permitting procedure, which would enable the simulation of the thermal impact of geothermal installations and their cumulative impact on groundwater.
- Public discussion and stakeholder engagement in planning and implementing facilities and infrastructure that could potentially impact groundwater are not well established.
- Limited availability of operational monitoring data of geothermal systems

Measures & strategies

- Awareness-raising and training for municipalities, planners, and installers are crucial to boost local uptake.
- LEK-MOL (Local energy plan – MOL) - Ensuring Diversification of Energy Sources – Shallow Geothermal Energy 2024-2030
- Mission 100 – Climate Neutral & Smart Cities

Regulations
There are no regulations which apply only for Ljubljana. Regulations for Geothermal use of groundwater are part of Energy and Construction act.

- Energy Act (no. 17/2014 – EZ-1)
- Water Act (Official Gazette of the Republic of Slovenia, Nos. 67/02, 2/04 – ZZdrI-A, 41/04 – ZVO-1, 57/08, 57/12, 100/13, 40/14, 56/15, 65/20, 35/23
- Water Framework Directive
- Environmental protection act (ZVO-2)
- Construction act (GZ-1)
- Decree on Water protection zones

4 Groundwater quality and ecosystem health

4.1 Ecosystem analysis

Relevance
Groundwater ecosystems are not included in monitoring and are in Slovenia (Ljubljana) generally overlooked in all directives and laws (which only highlight the importance of groundwater for groundwater-dependent habitats). It is therefore essential to develop a methodology for the assessment of groundwater ecosystems and to establish legislation that, in evaluating groundwater status, also incorporates the condition of groundwater ecosystems.

Data-handling

- Some data on groundwater fauna are available from scientific studies, but these data are limited and do not represent the entire Ljubljansko polje aquifer.
- There are no database and monitoring system for ecosystems.

Gaps

- Due to the lack of protocols and legally mandated monitoring, groundwater ecosystems are not assessed or observed for changes.

Measures & strategies

- Water Management Plans (NUV 2022–2027)
- Natura 2000 (include groundwater dependent ecosystems, not the ecosystems that are inside groundwater)

Regulations
No specific regulations, GW ecosystems are only mentioned in EU regulations.

- Environmental Impact Assessments (EIA/SEA)
- Water Framework Directive (WFD – 2000/60/EC)
- Habitats Directive (92/43/EEC)

4.2 Groundwater quality including temperature

Relevance
The groundwater quality, temperature and ecosystem health are of high relevance since groundwater is the main drinking water source for the city of Ljubljana. The water quality and temperature are regularly monitored by MOL and VOKA (municipality level) and by ARSO (national level), while other ecosystem indicators are investigated only through

research initiatives by university or research institutes. The agricultural activity, industrial spills, and urban land use are potential threat to the quality, temperature and ecosystem health.

Governance

- MNVP (Ministry of Natural Resources and Spatial Planning)
    - Legislation and regulatory framework
    - Supervision and coordination of groundwater monitoring
    - Planning and implementation of groundwater protection measures
    - Preparation of River Basin Management Plans
- DRSV (Slovenian Water Agency) performs professional, administrative and development tasks in the field of water management in accordance with the regulations governing water issues at the national level. The objective is to establish a water management system that enables integrated management.
- ARSO (Slovenian Environment Agency) is a body of the Ministry for the Environment, Climate and Energy. Its mission is to monitor, collect, analyse and evaluate environmental data including groundwater quality and temperature monitoring.
- JP VOKA SNAGA (public utility company) is the company responsible for the public drinking water supply system, the wastewater drainage and treatment system as well as waste management system in the Ljubljana municipality.
- MOL, Oddelek za prostorsko načrtovanje (Municipality of Ljubljana, Department for Spatial planning)

Data-handling

The data gathered 4 times yearly from ARSO national monitoring are stored in the ARSO database.

Since 1997, the City of Ljubljana (MOL) manages operational groundwater quality monitoring within the Ljubljansko polje and Ljubljansko barje aquifers, complementing national (ARSO) surveillance. Nutrient and emerging contaminant trends are followed (nitrates, pesticides, heavy metals, micro-pollutants) at municipal level.

Gaps

- The data from the monitoring are scattered between ARSO, MOL and research institutions.

Measures & strategies

- Sustainable Urban Strategy of the City Municipality of Ljubljana 2014–2030
- Regulation on Drinking Water Supply
- Municipal Spatial Plan Ordinance for the City of Ljubljana

Regulations

Regulations are on EU, Slovenia and Ljubljana scale. Mostly are regulations in monitoring and limited values of pollutants and nitrates in drinking water.

- Water Framework Directive (WFD, 2000/60/EC): requires river basin management plans and monitoring programs.
- Groundwater Directive (2006/118/EC, amended by 2014/80/EU): provides specific criteria for groundwater quality
- National Environmental Protection Act (ZVO-2): water quality monitoring and protection duties are mandated to ARSO (Slovenian Environment Agency)
- National Waters Act (ZV-2): implements EU directives into national water law
- National Rules on Groundwater Status Monitoring (Official Gazette RS, no. 13/21, amended 44/22 – ZVO-2): prescribe monitoring programs, parameters (e.g. physicochemical, nitrates, pesticides, heavy metals, organic solvents), and methodologies to assess groundwater chemical status in compliance with EU regulations
- Decree on the Protection of Waters against Pollution Caused by Nitrates from Agricultural Sources (Official Gazette No. 113/2009): implements the Nitrates Directive via national rules limiting nutrient surplus and pesticide application to protect groundwater especially in agricultural zones
- Ordinance on the Supply of Drinking Water in the City Municipality of Ljubljana (Official Gazette RS, 59/2014): Organization and conditions of mandatory public water supply service, including operational rules for local and central supply systems; assigns public authority for issuing internal municipal opinions on water-related permits (e.g. for groundwater abstraction, small reservoirs, and construction projects)
- Ordinance on Amendments and Supplements to the Ordinance on the Municipal Spatial Plan of the City Municipality of Ljubljana – Implementation Part." (Official Gazette RS, 59/2022): Ljubljana's Municipal Drinking Water Protection Zones are designated alongside national-level zones
- Decree on Groundwater Immission Monitoring

Ljubljana – Further Information

Contact information

- City of Ljubljana (tjasa.polajnar@ljubljana.si)
- Geological Survey of Slovenia (Mitja.Janza@GEO-ZS.SI, Nika.PisekSzillich@GEO-ZS.SI)
- National Institute of Biology (Natasa.Mori@nib.si, Ziva.Vehovar@nib.si)

Institutional Websites of Stakeholders

- City of Ljubljana https://www.ljubljana.si/sl/mestna-obcina/
- Geological Survey of Slovenia https://www.geo-zs.si/
- National Institute of Biology https://www.nib.si/
- Slovenian Environment Agency https://meteo.arso.gov.si/
- Slovenian Water Agency https://www.gov.si/en/state-authorities/bodies-within-ministries/slovenian-water-agency/
- Public company for water supply, wastewater treatment and waste management services in Ljubljana https://www.vokasnaga.si/en

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- Municipal Spatial Plan Ordinance for the City of Ljubljana (Občinski prostorski načrt Mestne občine Ljubljana – OPN MOL) https://www.ljubljana.si/sl/mestna-obcina/mestna-uprava-mu-mol/oddelki/oddelek-za-urejanje-prostora/obcinski-prostorski-nacrt-mestne-obcine-ljubljana-opn-mol/
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3.2 LINZ

Short overview

Hydrogeology

- Two interconnecting groundwater bodies: Welser Heide and Linzer Feld, composed of glacial / alluvial deposits
- Good groundwater availability (over 3.7 m^3/s), minimal seasonal groundwater fluctuations

Main usage of groundwater

- Drinking water
- Irrigation/Industrial
- Geothermal heating

Data overview and handling practices

- Water Information System (WIS) provides information on water rights data and groundwater relevant parameters.
- eHYD provides hydrological information from monitoring stations (approx. 250 wells).
- H_2O Database offers public groundwater quality data (38 wells).

Measures & strategies and regulation & policies

- Comprehensive groundwater monitoring network and analytical tools.
- Integrated regulatory framework: Federal water rights law, provincial regulations and technical standards.
- Integrated drinking-water and climate adaptation policies for droughts and floods.

Topics

- Thermal Groundwater Use.
- Groundwater Quality and Ecosystem Health.
- Groundwater Level Extremes.
- Rainwater infiltration.

Gaps

- Digital Infrastructure is limited and infrequent data updates may delay timely data access.
- Coordination and Governance Deficiencies as fragmented institutions that may block effective data sharing. Some datasets have restricted access.
- No information on GW ecology.

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Linz – General Overview

Extended description of the city

Linz, Austria's third-largest city and capital of Upper Austria, has a current population of approximately 213,557 inhabitants. The population density is approximately 2 200 inhabitants/km². Urbanization rate is about 60 %, reflecting a growing urban concentration. The larger metropolitan area, also called Upper Austrian Central Area, which includes of Linz-Wels-Steyr, is home to roughly 500.000 inhabitants, making it one of the most important socio-economic hubs of the country.

Extent and altitude

Linz covers an area of 96 km².The city extends 18.6 km north-south and 12.3 km east-west and is positioned along both sides of the Danube River. Located at an elevation of 263 m above sea level in the center, Linz sits within the Linzer Becken (Linz Basin). The city's terrain varies considerably. North of the Danube, in the Urfahr district, Linz is bounded by the Pöstlingberg (539 m), the Lichtenberg (927 m) and the hills of the Mühlviertel. The Pipieterkogel (567 m) is the highest peak still within the city limits.

Climate

Linz demonstrates a continental climate significantly affected by urbanization and topographic influences. The average annual temperature is currently 10.6 °C (1994-2024) and the annual average rainfall is 845 mm (1994-2024). The city has experienced dramatic warming, with temperatures increasing by 1.4°C between 1961-1990 and 1991-2020 climate periods, totaling 2.1°C above pre-industrial levels[4].

Precipitation patterns show no clear annual trends, though summer remains the wettest season with July recording the highest monthly precipitation. However, heavy rainfall events are increasing in intensity, particularly during July, August, and October.

Future climate projections indicate more frequent heatwaves, prolonged droughts alternating with intense flooding events, and increased extreme weather occurrences [1]. Heat extremes are intensifying markedly, with heat days (≥30°C) having increased to 21 annually in recent decades, while tropical nights (≥20°C) have doubled in the past decade. The urban heat island effect significantly amplifies these temperature increases, as urban areas in Linz experience substantially higher temperatures than surrounding rural environments due to reduced ventilation, heat-absorbing building materials, anthropogenic heat sources, and limited vegetation. Climate-change sensitive residential

[4] Magistrat Linz – Planung, Technik und Umwelt (2023): Zukunft Linz. Der klimagerechte Weg von Linz zur Anpassung an den Klimawandel. Projektleitung: Mag. Johannes Horak, PhD – Stadtklimatologie und Umwelt. Linz, 30.06.2023.

areas with low vegetation cover and high-risk demographics now encompass approximately half of Linz's residential areas, housing nearly two-thirds of the city's population.

Pilot area information	
Pilot Area	Linz
Country	Austria
Area (km^2)	96,05
Elevation	262 m ü.A. (Linz Stadt ID56, GeoSphere)
Inhabitants	213,557 (2025, Statistik Austria)
Inhabitants/km^2	2,223
Level of urbanisation	Urban Centre (Eurostat/OECD Functional Urban Area)
Economy	Largest ecological, cultural and financial hub in the region Upper Austria. Large industry sector, important gateway for international shipping and trade.
Infrastructure	Tram system (partly underground), rail network, 1 airport, central traffic hub on the motorway network

Climatological settings	
Mean air temperature	10.6 °C (1994-2024, Linz Stadt ID56, GeoSphere Austria)
Annual rainfall	845 mm (1994-2024, Linz Stadt ID56, GeoSphere Austria)
Heating Degree Days	2611.09 (Eurostat, Linz-Wels, 2024)
Cooling Degree Days	93.30 (Eurostat, Linz-Wels, 2024)
Length of heating season	The period from October 1st to April 30th is used as a practical guideline, but has no official legal basis.
Length of cooling season	The length of the cooling season is not explicitly defined, but cooling degree days (CDD) are used.

Regional hydrogeological and geological characteristics

The **quaternary groundwater aquifer system of Linz** is structured around two interconnected groundwater bodies: the Welser Heide and the Linzer Feld, which merge in the Linz area to form the Linzer Basin[5]. This aquifer system is predominantly composed of sediments from the lower terrace (Würm glacial terrace) and valley alluvium. It also includes components of the high terrace (Riss glacial terrace), which are primarily located north of the Traun River, showing a more heterogeneous groundwater flow. The quaternary deposits exhibit thickness variations that directly correlate with paleochannel systems[6]. The most significant gravel accumulations up to approximately 30 m occur within Pleistocene Danube erosion channels, which represent ancient river courses that created deep scours in the underlying geology. The Riss glacial terrace (Hochterrasse) contributes approximately 15 m of gravel deposits. The Würm glacial terrace (Niederterrasse) south of the Danube consists of approximately 12 m of gravel, though this can increase to over 20 m in areas where it intersects with Pleistocene erosion channels. The Holocene alluvial deposits generally range from 7 to 11 m in thickness. Hydraulic conductivity values range between approximately 1×10^{-2} m/s for Danube alluvial deposits and 5×10^{-3} m/s for lower terrace areas, reflecting the general pattern of higher permeability in recent alluvial deposits compared to older terrace materials. The high terrace area exhibits considerable heterogeneity in hydraulic properties due to the variable nature of glacial gravel deposits.

The **aquifer system is protected** by a variable covering that significantly influences groundwater recharge rates and vulnerability to contamination [2]. The total coverage includes both natural deposits such as loess, loess loam, alluvial clay, alluvial sand, alluvial fan material, and colluvium, as well as artificial fill materials associated with urban and industrial development. On the high terrace areas, this total coverage reaches maximum thicknesses of 19 m, providing substantial groundwater protection. Within the urban core of Linz, the coverage typically ranges from 2 to 4 m, while in some areas it decreases from 0.5 to 1 m, resulting in varying degrees of aquifer vulnerability. The aquitard system underlying this quaternary aquifer consists extensively of marine fine-sandy clay marls from the Egerian period known as "Alter Schlier" which forms a regional confining layer beneath the productive aquifer zones. The thickness of this confining layer varies significantly across the basin, reaching up to 100 m at the northern basin margin and expanding to as much as 500 m in the central basin area, providing effective hydraulic separation from deeper groundwater systems.

The overall **water balance** for the area north of the Danube river, the area between Danube and Traun river and the small area south of the Traun river reveals a total groundwater resource availability of over 3.7 m^3/s, with the largest single positive component consisting

[5] Vohryzka, K. (1973): Hydrogeologie von Oberösterreich; Amt der oö. Landesregierung, Abteilung Wasser- und Energierecht.

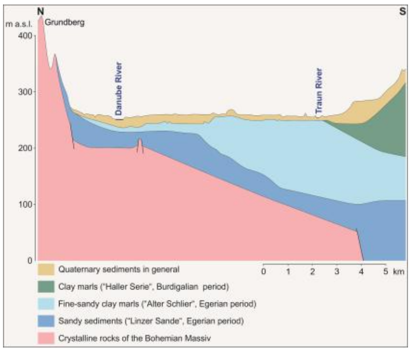
[6] Land Oberösterreich (2004): Grundwasserbewirtschaftung Linz - Hydrologische und thermische Ist-Situation. Amt der Oberösterreichischen Landesregierung, Abteilung Wasserwirtschaft, Grund- und Trinkwasserwirtschaft, Linz.

of lateral inflow of 1.1 m^3/s primarily from the Welser Heide area [2]. It is important to mention, that the area north of the Danube shows a very limited lateral inflow component from the Bohemian Massiv with 0,06 m^3/s compared to 0,65 m^3/s recharge from Danube infiltration. Danube riverbank filtration contributes over 0.9 m^3/s, representing a crucial component of the regional water budget, while additional Danube water infiltration through sealing wall systems contributes nearly 0.7 m^3/s, though this water is immediately captured by drainage systems. Traun riverbank filtration with 0,6 m^3/s is also important. The annual groundwater recharge from precipitation infiltration is estimated at 0,3 m^3/s and represents only about 7% of the total positive water balance components.

The groundwater level dynamics within the quaternary aquifer system are highly controlled by the operational regime of the **Abwinden-Asten Danube power plant**, which has created an artificially regulated hydrological environment that dampens natural groundwater fluctuations [2]. The impoundment created by this facility has necessitated extensive sealing wall systems and drainage infrastructure along the Danube River to prevent groundwater flooding of urban and industrial areas, while simultaneously maintaining stable conditions for water supply operations. Seasonal groundwater level fluctuations are therefore minimal, with ranges typically between 0.1 and 0.5 m. The management of groundwater resources involves multiple stakeholder organizations including Verbund Austrian Hydro Power AG operating wells for dewatering purposes. Approximately 1.9 m^3/s is utilized through direct groundwater extraction for municipal, industrial, and commercial purposes, while the remaining portion is largely captured through drainage systems necessary for flood protection and urban infrastructure maintenance. Only approximately 0.4 m^3/s leaves the study area through natural processes, including exfiltration to the Traun River and associated channels, as well as parallel groundwater flow along the Danube corridor.

A **deeper aquifer system (“Linzer Sande”)** consists of sandy sediments from the Egerian period, characterized by hydraulic conductivities significantly lower than those observed in the overlying Quaternary aquifer. These sedimentary formations are positioned beneath the Schlier formation and above the crystalline basement rock[7]. The aquifer extends to a thickness of up to 100 m and exhibits hydraulic conductivities ranging from 10^{-6} to 10^{-8} m/s. This deeper system remains unexploited and is protected from groundwater extraction activities.

[7] Heiss, G., Jung, M., Metz, A. & Spendlingwimmer, R. (2005): Die Grundwasservorkommen innerhalb der tertiären Sande der oberösterreichischen Molassezone. – Technischer Endbericht, 53 S., Amt der Oberösterreichischen Landesregierung, Abteilung Grund- und Trinkwasserwirtschaft, Linz.



The figure shows a simplified geological cross section from north to south through the area of Linz [modified from 3].

The **average groundwater temperature** is slightly elevated by approximately 1°C above the annual mean air temperature. In certain sub-areas, a significant increase in groundwater temperature has been identified[2]. This is primarily associated with the underground urban heat island effect, including locally concentrated cooling water uses (20% of the total extraction permits are attributed to cooling water applications). Additionally, an influence from waste heat from urban development and industrial facilities is assumed.

Linz – Data Overview

Groundwater responsibilities are not limited to one authority in Linz but rather distributed among multiple stakeholders. This means that data acquisition, storage and usage is scattered across different authorities, companies or institutions, although public databases are available for selected parameters.

Following stakeholders were identified as relevant in the pilot area Linz:

Authorities

- **Magistrat Linz**: The Municipal Authority of Linz oversees groundwater sustainability mainly through two divisions. The department **Planning, Engineering and Environment (PTU)** with the sub-department **Water Management (LINZ-WW)** protects city water bodies, advises on water issues, and conducts limited measurement campaigns.
  The **Construction and District Administration (BBV)** handles urban planning, zoning, and water rights, with responsibilities split across North, Central, and South areas.

- **State Government of Upper Austria (OÖ)**: Groundwater sustainability is managed within the **Directorate for Environment and Water Management (UWD)**. Key roles are held by the Department for Facility-, Environmental- and Water Law (AUWR), which handles permitting and legal enforcement, and the **Department for Water Management (OÖ-WW)**, responsible for protecting water resources, monitoring quality, and planning. Notable OÖ-WW sub-units include Groundwater Protection (OÖ-GWS), Water Information (OÖ-WI), Drinking Water Safety Planning (OÖ-TV), and Hydrography (OÖ-HY).

Companies with full or partial public ownership

- **VERBUND – Austrian Hydro Power AG (VHP)**: Is Austria's top electricity producer, operating two hydropower plants near Linz. The Abwinden-Asten plant directly affects Linz's groundwater, which is also influenced by backwater, sealing, and drainage systems along the Danube. The plant provides flood protection through backwater dams. VHP also monitors groundwater impacts using several monitoring stations.
- **LINZ AG**: Is a city-owned utility company, providing essential public services to the city and surrounding municipalities. Its core business areas include energy supply, municipal services, and public transport. The department **LINZ AG WASSER** is the main water supplier for the City of Linz and 25 surrounding municipalities. It manages three water protection areas within the city and conducts over 2,000 water analyses annually in both groundwater and the water supply system.

National institutions

- **Umweltbundesamt (UBA)**: It serves as the federal authority overseeing groundwater data management and evaluation across Austria, working with national and provincial agencies. The agency manages over 2,000 monitoring sites, ensuring that policy decisions are based on quality data and reviewing compliance with EU groundwater standards.
- **Hydrographisches Zentralbüro (HZB)**: Is Austria's national hydrographic service, coordinating data collection, quality assurance, and publication of water cycle information from federal states. Valid data is reviewed and published in the Hydrographic Yearbook and on the ehyd platform.

Civil engineering bureaus

Several engineering offices are in the greater Linz area, actively contributing to data collection, processing, and analysis through their work. An example is the planning office **G.U.T.-GmbH**, which has built up a substantial database on groundwater resources in the Linz region over its 30 years of operation.

Industry

Linz's identity as an industrial city is strongly shaped by large-scale operations at Chemiepark Linz and Voestalpine. These companies not only drive economic and infrastructural development but also have a significant impact on the local groundwater system (e.g. groundwater usage for cooling and other industrial processes). Due to their scale and environmental responsibilities, these companies also maintain comprehensive hydrological data (e.g. groundwater level data).

While a large part of groundwater mostly remains scarce and in the possession of the responsible stakeholder, several public databases or register containing groundwater data are available:

- **Water Book (WB)**: Public register documenting all licensed water uses. Maintained by the provincial government, it stores facility permits and information, with key details available digitally via WIS and DORIS. The Linz Stadt Water Book is kept at the New Town Hall in physical form.

- **Water Information system (WIS)**: Database managed by Upper Austria's Water Information Department, providing structured access to water rights and data via the DORIS portal, though public access is limited.

- **H2O Database (H2Odb)**: operated by UBA, it publicly provides groundwater quality data from monitoring programs, helping to assess natural conditions and pollution. Users can customize queries for different measuring sites.

- **Electronic Hydrographic Data (eHYD)**: Austria's hydrographic services provide public access to water data through the eHYD platform, as required by law. eHYD offers an interactive map with hydrological information from about 9,600 monitoring stations.

- **Digital Upper Austrian Spatial Information System (DORIS)**: Is Upper Austria's public geographic information system, providing searchable and downloadable data on water topics such as groundwater quality, usage rights, and protection areas. Users can access and visualize maps and expert information on water and geology, making DORIS a valuable resource for anyone interested in regional water data.

The following table summarizes the groundwater-related data availability in the pilot area of Linz for the most relevant categories. For a complete and detailed version see Deliverable D1.1.1.

Parameter	**Short description**	**Data format**	**Responsible organisation**
Location of groundwater measuring points	Collection of the location of all groundwater measuring sites from multiple stakeholders	Point data, Excel files with coordinates	OÖ-WW, BMLUK, VHP, LIZ AG WASSER, HZB, ASFINAG
Groundwater temperature	Collectino of groundwater data at various measuring points from multiple stakeholders	Csv/txt files	OÖ-AA, BMLUK, VHP, ASFINAG
Groundwater chemistry	Physical and chemical groundwater data, pollutant threshhold and regulations	Point data, Excel files	OÖ-WW, ASFINAG
Groundwater level	Continous as well as extreme HGW100 groundwater levels	Shapefile, Excel file	OÖ-WW, LIZ AG WASSER
Groundwater bodies	Groundwater resources, priority areas, shallow and deeper groundwater bodies	Shapefile	OÖ-WW
Confined aquifer	Areas with confined groundwater according to §31c (5) WRG	Shapefile	OÖ-WW
Upper boundary of confining layer	Layer boundaries of the top of the upper groundwater confined layer	Shapefile	OÖ-WW

Borehole heat exchangers	Legaly approved geothermal heat pumps	Shapefile	OÖ-WW
Groundwater usage	Installations approved unter water law	Shapefile	OÖ-WW
Boreholes	Drillings in the pilot area, reasons for the drillings vary	Shapefile	OÖ-WW

Linz – Topics Overview

Topic	Relevance
1. Groundwater extremes	**Average (2,5)**
High GW: Flooding of cellars	Low (2)
High GW: Flooding of terrain	Low (2)
Low GW: Negative influence on utilizations	High (4)
Low GW: Land subsidence	Very Low (1)
2 Rainwater infiltration	**Relevance not evaluated**
3. Thermal groundwater use	**High (4)**
Interference or restriction management	High (4)
Increasing groundwater temperatures through geothermal installations	Very High (5)
Decreasing groundwater temperatures or too low temperatures	Very Low (1)
4. Groundwater quality and ecosystem health	**High (4)**
Groundwater temperature	Very High (5)
Ecosystem analysis	Average (3)
Groundwater quality	Very High (5)

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Linz – Topics in Detail

1. Groundwater extremes

- High GW - Flooding cellars (2,2)
- High GW - Flooding of terrain (2)
- Low GW - Negative influence on utilizations (4)
- Low GW - Land subsidence (1,3)

Relevance

Although the topic of groundwater extremes did not score particularly high in relation to other topics, one concern that most stakeholders issued is the negative influence of low groundwater levels on utilizations. As a result of climate change, groundwater levels are expected to decline in the future, leading to the fact that many utilizations such as wells and heating pumps cannot use the resulting deeper situated groundwater. High groundwater levels on the other hand were of lower concern to the stakeholders questioned.

Governance

The main stakeholders involved in groundwater measurements in Linz are the Hydrographic Central Bureau of Austria (HZB) and the Hydrographic Service Upper Austria (OÖ-HY). They provide publicly available live-data for a limited number of monitoring points as well as annual reviews. Additionally, LINZ AG WASSER and the Verbund – Austrian Hydro Power AG perform regular groundwater monitorings in the water protection areas and near the hydro power plants respectively.

Data-handling

Groundwater level data is collected primarily through construction projects and dedicated monitoring systems. The OÖ-HY oversees the state's groundwater monitoring, with station operations managed by hydrographic units and local staff.
Three main data collection methods are used in Linz:

- Remote transmission from automated stations (including two in Linz), with expansion planned.
- Continuous monitoring via automated loggers, with quarterly maintenance.
- Weekly manual checks by Verbund, with regular quality controls and data transmission.

All data is managed through HyDaMS, the unified hydrographic system. Monthly groundwater overviews are published online, and HyDaMS provides statistical tools for identifying extreme groundwater levels. High groundwater maps are created using these data and shared with stakeholders, with plans to make them publicly accessible through platforms like HORA.

Gaps

Data gaps

While measurements are conducted regularly using various methods, **data updates are infrequent**. Annual publications by the Division I/3 – Water Management (HZB), combined with lengthy quality checks, often delay data release by several years. As a result, **timely access to recent groundwater information is limited** unless raw data is specifically requested.

Another gap concerns **high-level groundwater data**: spatial coverage is incomplete, and many records are outdated. More frequent updates and improved mapping would greatly enhance the current system.

Governance gaps
Beyond technical monitoring and data manipulation issues, **institutional arrangements also constrain access** to groundwater level data. The Hydrographic Data Management System (HyDaMS) is currently accessible only to the hydrographic service. Project-related datasets are made available only after completion and transfer to the regional authority, with no mechanisms in place for interim sharing. Raw data can specifically be requested but is time consuming.
For other stakeholders, **acquiring groundwater data remains a time-consuming** process, as access relies on formal requests for raw datasets rather than automated data exchange. Establishing systematic data-sharing procedures, and expanding access to HyDaMS or a similar platform, would enhance collaboration, reduce administrative delays, and support integrated groundwater management.

Measures & strategies
The eHYD groundwater monitoring network, which includes around 250 stations in Linz, supplies real-time groundwater data and supports comprehensive mapping. While not directly tied to climate change or urbanization strategies, this network provides a valuable foundation for related measures.
Key Technical Tools include:

- Numerical Modelling for groundwater impact assessment in accordance with national guidelines (ÖWAV-Regelblatt 222)
- Groundwater Management Linz (2004) study, which documented local hydrogeology and informs future planning. It included groundwater balance calculations, temperature monitorin networks, plausibility analysis of measurements, thematic mapping and hydrogeological cross-sections

Strategic and Policy Frameworks include:

- Upper Austria’s Drinking Water Future (2005): Prioritizes sustainable groundwater use, local water sourcing, and public ownership. It focuses on groundwater protection, maintaining local networks, crisis preparedness, and quality standards for individual water supplies.
- Drinking Water Security Plan (2023): Issued by the BML, aims to ensure long-term, high-quality drinking water, strengthen data and forecasting, and improve resilience to water scarcity through networked infrastructure, expanded protection zones, and enhanced monitoring.
- 1st Linz Climate Strategy (2019): Developed by the city’s planning department, this strategy targets climate resilience with measures such as urban heat mitigation, water retention, and promoting biodiversity—indirectly supporting groundwater management.
- Climate Adaptation Concept Future Linz (2023): Building on the previous climate strategy, this plan addresses risks like water scarcity and flooding through rainwater

harvesting, retention areas, and better water infrastructure, aiming to reduce pressure on groundwater resources.
Regulations • Austrian Water Rights Act • Municipal Water Supply Act • National Water Management Plan Decree • Environmental Information Act • Upper Austrian Building Act • Spatial Planning Act Upper Austria • Environmental Support Act

2. Rainwater infiltration • Sponge City Concept
Relevance Linz applies the Sponge City concept within its 1st Climate Strategy (2019) to ensure sustainable management of rainwater infiltration by integrating infiltration, retention, and evapotranspiration measures into urban planning and construction. This strategic approach enables rainwater to be absorbed, easing pressure on sewer systems, replenishing groundwater, and enhancing the city's resilience to climate impacts such as flooding and drought. However, stakeholders have identified a critical tension between the benefits of groundwater recharge through rainwater infiltration and concerns about potential groundwater quality degradation. Urban stormwater can carry various contaminants including metals, organic compounds, nutrients, pathogens, and road salts that may reach groundwater systems through infiltration processes. This quality-quantity trade-off represents a key challenge in urban water management, where the environmental benefits of increased groundwater recharge must be balanced against potential contamination risks.
Governance Linz's approach to rainwater infiltration represents a multi-layered governance framework that integrates technical standards, environmental protection, and climate adaptation strategies. It confronts the fundamental tension between groundwater recharge benefits and contamination risks.
Data-handling Based on the data inventory assessment, no specific datasets on rainwater infiltration have been identified, revealing a significant data gap that hampers evidence-based urban water management decision-making in Linz.
Gaps • Despite its technical merit and policy integration, this stakeholder-identified tension between rainwater infiltration benefits and groundwater quality concerns has been identified in the stakeholder consultation process, revealing an implementation gap between strategic vision, scientific understanding (quantity/quality concerns), and stakeholder priorities.

- Effective rainwater infiltration governance in Linz requires developing systematic coordination mechanisms that bridge the gap between strategic planning and operational implementation. This includes establishing clear protocols for interdepartmental collaboration, creating shared data platforms for monitoring and evaluation, and developing integrated approval processes that streamline regulatory compliance while maintaining environmental protection standards.
- Current urban planning systems lack proper data integration for stormwater management, which is problematic given cities' sustainability commitments. Better systematic collection and analysis of stormwater data is needed to support effective policy-making and implementation of sustainable drainage solutions.

Measures & strategies
The 1st Linz Climate Strategy (2019) promotes rainwater infiltration through measures like the "sponge city" concept to enhance water retention and support sustainable groundwater management as part of broader climate adaptation efforts.

Regulations

- ÖWAV Rule Sheet 45: Surface Water Drainage through Infiltration into the Subsoil
- ÖWAV Rule Sheet 35: Discharge of stormwater into surface water bodies
- General Wastewater Emissions Decree
- Guideline for the Management of Stormwater from Roofs and Paved Surfaces in Upper Austria
- Ordinance on the Protection of Public Parks, Green Areas and Playgrounds in Linz
- Amendment to the zoning plan, Edictal Ordinance No. 2 and No. 3 in Linz
- Linz Sewer System Ordinance
- Rainwater Infiltration Systems for Runoff from Roof Surfaces and Paved Areas, ÖNORM B 2506

3. Thermal groundwater use – Heat energy planning &interference

- Interference or restriction management (4,2)
- Increasing groundwater temperatures through geothermal installations (5)
- Decreasing groundwater temperatures or too low temperatures (1,3)

Relevance
Linz has set the ambitious goal of becoming a climate-neutral industrial city by 2040. To achieve this, extensive measures are required across various sectors. One particularly important measure is the investigation of geothermal potential in the greater Linz area.

Governance
Depending on the amount of extraction, different authorities are relevant in Linz. For systems with an extraction amount of up to 5 l/s, the examination and approval are carried out by the Linz City Administration. Larger systems, on the other hand, must be approved by the office of the State Government of Upper Austria.

Data-handling
The submission of the documents to both authorities has so far been done analogously. The documents must be submitted analog and in triplicate to the authority. The documents are then reviewed by the authorities. For this purpose, they can refer to the Water Information System (WIS) (contains existing water rights, groundwater-relevant parameters such as flow direction, gradient etc.).

If the installation is approved, it will be entered into the Water Book (public register in which all licensed water usages are documented). Furthermore, all analog documents (certificates, plans, technical reports) will be archived in the new town hall (Linz City Administration).
Responsibility for the archive, however, lies with the office of the State Government of Upper Austria, which also transfers the most relevant water management data into the WIS. The transferred information includes the main properties of the water rights. To implement the data into the WIS, OÖ-WI retrieves the analogue files from Linz-WW on a regular basis.

Gaps

Data gaps
Digital information on thermal groundwater installations is limited. Applications for new geothermal systems, both above and below 5 L/s, are still submitted in analogue form, with records stored only in physical archives at the Municipal Authority of Linz. Digital storage is added later by the regional authority (WIS), but access remains limited, and not all documents are digitized.
The **WIS database contains only basic information**, such as location and licensed abstraction and reinjection rates. Key data—like heat and cold production, monitoring results, well depth, and pumping tests—are missing. The GeoBOOST report D2.2 (2024, Brancher & Steiner) suggests parameters for a more comprehensive database.
Without a full digital overview, existing installations cannot be properly considered in potential calculations, lowering the reliability of potential maps for planning sustainable groundwater use. Although **detailed groundwater temperature maps were produced in the early 2000s, they are outdated**. Updating these maps would be a good foundation for creating accurate potential maps, enabling the city authority to manage groundwater for heating and cooling more sustainably.

Governance gaps
Integrated thermal groundwater management including both heating and cooling is currently missing. Up-to-date groundwater potential maps that consider existing installations would be an important first step.
Currently, collaboration between the Municipal Authority of Linz and the Federal State Government of Upper Austria is hindered by **analogue data transfer**, delaying updates to the digital water rights registry (WIS). Implementing direct digital data transfer and a shared, regularly updated installation database would greatly improve coordination. These measures are essential for establishing a sustainable and efficient groundwater management system.

Measures & strategies Existing measures include Environmental Impact Assessment Procedures: Geothermal installations are evaluated using federal guidelines (ÖWAV Rule Sheet 207), with tools like the SIA 384/6 method for sizing, Ingerle-Rauch for thermal plume prediction, and software such as FEFLOW for advanced modelling. As part of its goal to achieve climate neutrality by 2040, Linz published its Climate Neutrality Concept in March 2024, which identifies geothermal energy - and thus thermal groundwater use - as a key measure for decarbonizing the energy system and integrating heat energy planning into urban development. The city adheres to standardized requirements for geothermal installations, including a maximum allowable temperature spread of 6 K. Installations designed solely for cooling purposes are no longer approved, reflecting a shift toward more sustainable and balanced thermal groundwater use.
Regulations • Austrian Water Rights Act, see registration section • ÖWAV Rule Sheet 207: Thermal Use of Groundwater and Subsurface - Heating and Cooling • ÖWAV Guideline 43: Guidelines for Application of the Thermal Plume Formula of ÖWAV Regulation Sheet 207 • Information Sheet for Heating and Cooling with Groundwater for Upper Austria

4. Groundwater quality and ecosystem health • Groundwater temperature (4,7) • Ecosystem analysis (2,6) • Groundwater quality (5)
Relevance Groundwater quality is an important concern for various stakeholders. Some issues can be traced to human activities, such as the use of pesticides or nitrates, while others, including the rise in groundwater temperature, are more closely associated with climate change. Although ecosystem analysis did not receive high scores in the questionnaire, its significance remains, given that data on groundwater ecosystems is limited and the environmental impact of groundwater ecosystems has not been thoroughly investigated.
Governance The Federal Ministry of Agriculture, Forestry, Climate Action, Environment, Regions and Water Management (BMLUK) administers the national GZÜV program, which entails systematic groundwater quality monitoring at designated measurement stations, including several within the Linz pilot area. The water department of the regional authority (OÖ-WW) is tasked with conducting routine sampling at GZÜV sites in addition to carrying out specialized monitoring activities. The Umweltbundesamt (UBA) provides support in groundwater analysis and oversees the H2O database within the WISA system.

Additionally, LINZ AG WASSER is responsible for monitoring groundwater quality within the water protection areas, while industry sites such as VOEST and the Chemiepark conduct groundwater monitoring in their respective locations.

Data-handling

The Groundwater quality at 38 GZÜV sites in the pilot area is regularly monitored by OÖ-WW and the UBA, with results stored in the WISA and H2O databases. Public access is limited to selected data, though annual national reports are available. LINZ AG WASSER regularly monitors 60 sites inside the water protection areas of Linz, but most data is not shared with outsider stakeholders. Industry sites like VOEST and Chemistry Park also conduct internal monitoring without sharing data.
OÖ-WW performs targeted sampling in specific cases, with the results being entered into the WISA system via the UBA. Special monitoring programs are often run by civil engineering firms when information on new parameters or contamination concerns arise.

Currently, there is **no monitoring of the ecological status of groundwater in Linz**; thus, no data on groundwater fauna exists. Microbiological-ecological variables such as Total Cell Count (TCC), internal ATP, and Dissolved Organic Matter (DOM) were measured at 24 sites in 2019, with data available in the H2O database.

Gaps

Data gaps
Monitoring of groundwater quality in Linz is limited in scope. While chemical and physical parameters are regularly measured, **no systematic monitoring of the ecological status of groundwater** is in place. Currently, only microbiological-ecological variables such as Total Cell Count (TCC), internal ATP, and Dissolved Organic Matter (DOM) are recorded under the GZÜV program. Broader ecological information, particularly regarding groundwater fauna and biodiversity, is largely absent. Given Linz's commitment to the European Green City Accord (2023), which emphasizes biodiversity, the integration of groundwater fauna monitoring would represent a significant step toward assessing ecosystem health more comprehensively.

Governance gaps
Although annual groundwater quality reports are publicly accessible through the H2O database, **access to detailed datasets is restricted to selected authorities**, namely the Umweltbundesamt (UBA) and the regional authority OÖ-GWS. In addition, extensive groundwater quality data are collected by major stakeholders, such as LINZ AG WASSER, VOEST, and Chemistry Park, within water protection zones and industrial sites. However, these records typically remain with the respective owners and are not shared with other organizations or the public.
While site-level data can sometimes be provided upon request, the **lack of a coordinated and integrated database** limits efficient data use and broader groundwater management. Establishing a shared platform, fed by both public authorities and private stakeholders, would greatly improve transparency, comparability, and operational efficiency.

Measures & strategies

European Green City Accord is currently the only strategy which could acknowledge the ecological aspects and thereby the organisms associated to groundwater as a habitat.
Zukunft Trinkwasser (2005): This federal strategy addresses contamination risks by implementing remediation programs in polluted regions and ensuring compliance with technical standards for water infrastructure.
OÖ. Pestizidstrategie 2023: This federal strategy aims to protect groundwater and surface water quality by reducing the use of problematic pesticides and their metabolites.

Regulations

- Austrian Water Rights Act
- Drinking Water Decree
- Food Act
- Quality Objective Decree for Groundwater Chemistry
- Quality Objective Decree for Surface Water Ecology
- ÖVGW Technical guidance W 72: Protection and Conservation Zones
- Groundwater Priority Guideline Upper Austria
- Drinking Water Protection Areas Guideline for Upper Austria
- Technical guidance for Route Selection Procedures of the Upper Austrian Department of Spatial Planning
- Guideline to Establishing a Drinking Water Protection Area
- Gravel Management Plan for the Upper Austrian Central Region
- Water Protection on Roads, RVS 04.04.11
- Groundwater Protection Area Ordinance Scharlinz
- Groundwater Protection Area Ordinance Urfahr
- Groundwater Protection Area Ordinance St. Georgener Bucht
- Ordinance of the Municipal Council of the State Capital Linz on the Use of De-icing and Gritting Materials
- Ordinance on Excavation and Break-up Works on Municipal Traffic and Green Areas of the City of Linz

Linz – Further Information

Contact information

- GeoSphere Austria
- University of Vienna
- LINZ AG WASSER

Acknowledgements

Institutional Websites of Stakeholders

- Geosphere Austria Wetterprognose Österreich
- University of Vienna Universität Wien – Studieren, Forschen, Leben in Wien
- LINZ AG WASSER Wasser der LINZ AG
- Magistrat Linz Stadt Linz - Offizielle Website | Stadt Linz
- Land Oberösterreich Land Oberösterreich - Umwelt und Natur

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3.3 MILAN

Short overview

Hydrogeology

- multilayered alluvial plain type aquifer
- good groundwater conditions

Main usage of groundwater

- drinking water
- irrigation/industrial
- geothermal heating and cooling

Data overview and handling practices

- 90 piezometers for GW level monitoring (two times per year)
- 3000 GWHP wells for ~700 systems

Measures & strategies and regulation & policies

- Environmental assessment procedure
- Groundwater control wells
- Climate and Air Plan
- The water protection and use plan (PTUA)

Topics

- Groundwater extremes (GW flooding)
- Thermal use of groundwater (management, interactions, potential, sustainability)
- Rainwater Infiltration
- Groundwater ecology

Gaps

- Fragmented data collection/digitalization
    - Poor groundwater level
    - No groundwater temperature
- Risk analysis of GW fluctuations
- Database of geothermal systems with detailed information
- Tool to assess the interactions of GWHP

Milan – General Overview

Extended description of the city

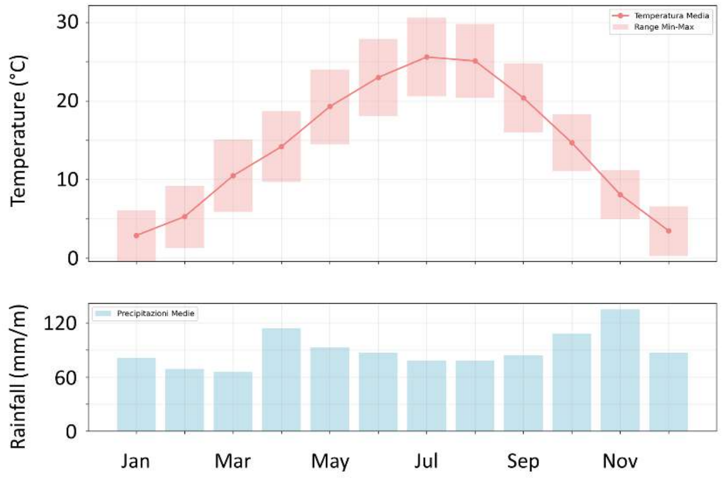
With over 1.37 million inhabitants, Milan is the second most populous city in Italy and a key economic and cultural hub of the country. The population density is approximately 7,700 inhabitants/km², making it one of the most densely populated cities in Europe. The urbanisation rate in the metropolitan area is around 65–70%, reflecting Milan's central role in the highly developed and urbanised Lombardy region. The city continues to grow steadily, especially in its metropolitan area, which includes over 3.2 million people.

Extent and altitude

The municipal area of Milan covers approximately 181 km² and stretches about 15 km east-west and 13 km north-south. The average elevation of the urban area is around 120 metres above sea level. The elevation gently decreases from north to south, moving from the Alps reliefs towards the Po River,15 with an average slope gradient of 2-3‰. The highest point is in the northwestern part of the city, near the Trenno Park and Monte Stella (also known as the "Montagnetta di San Siro"), reaching approximately 145 m a.s.l. The lowest point lies in the southeastern part of the municipality, near the Parco Agricolo Sud, at around 97 m a.s.l.

Climate

Milan has a humid subtropical climate, with hot, humid summers and cool to cold winters, although temperatures rarely drop below -5 to -7 °C. Summer temperatures commonly range between 25 and 35 °C, occasionally exceeding 38 °C during heatwaves. Weather patterns are influenced by the Po Valley basin, the nearby Alps, and the Liguro-Apennine barrier, which can trap humidity and pollutants, especially in winter. The highest temperature ever recorded in Milan was 40.3 °C (Arpa Lombardia, 2022), while the lowest was around -17.6 °C (Milano Brera, 1855). The average annual temperature increased from approximately 15°C, reflecting a general warming trend. Average annual precipitation is about 945 mm, but it varies considerably: from under 600 mm in particularly dry years to over 1,200 mm in wetter ones. Most rainfall occurs in spring and autumn, while summer can bring short but intense thunderstorms. In the following graphs the average monthly temperature and daily precipitation, for the periods 1985-2040, 2041-2070 and 2071-2100 are reported.



Pilot area information	
Pilot Area	Milan
Country	Italy
Area (km^2)	181
Elevation	120 m a.s.l.
Inhabitants	5,351,148 (metropolitan area)
Inhabitants/km^2	1398 (metropolitan area), 6836 (city of Milan) (ISTAT, 2020)
Level of urbanization	41% build-up areas and infrastructures, 50% agricultural areas and 8% woodlands (Città Metropolitana)
Economy	Leading financial, industrial, and innovation hub in Italy. Key sectors: finance, fashion, design, tech, manufacturing, media.
Infrastructure	Extensive metro (6 underground lines) and rail network, 2 airports, high-speed rail hub, major motorway connections.

Climatological settings	
Mean air temperature	Approx. 13.0 °C (1961–1990) Approx. 13.7 °C (1981–2010), with a warming trend in recent decades
Annual rainfall	Around 945 mm (varies from less than 600 mm to over 1,200 mm)
Heating Degree Days	About 3,500–3,800 HDD (setpoint 18 °C) - 283.4 (agri4cast)
Cooling Degree Days	About 300–400 CDD (setpoint 24 °C) - 283.4 (agri4cast)
Length of heating season	Approximately 6 months (mid-October to mid-April)
Length of cooling season	Approximately 2 months (July and August, with peaks in June/September)

Regional hydrogeological and geological characteristics

Hydrogeology

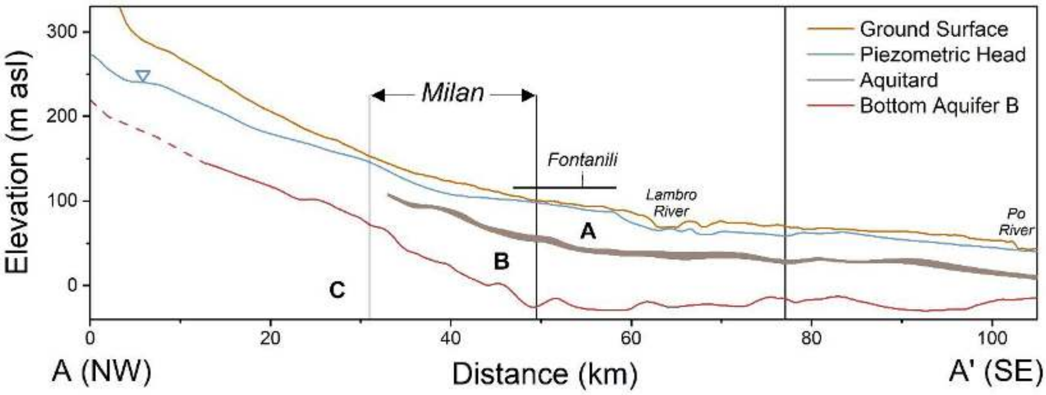


Figure 1 – Schematic hydrogeological section through the Po alluvial plain

Milan is in the central part of the Po Valley (Pianura Padana), a vast sedimentary basin formed by the accumulation of alluvial deposits from the Po River and its tributaries over the last several hundred thousand years. The Quaternary subsoil consists mainly of thick aquifer layers (A, B and C in the figure above) of gravels and sands, interbedded by aquitard layers of clay, and silt. The terrain gently slopes from the Alps in the north towards the Adriatic Sea in the southeast with a slope gradient of 2-3‰. The aquifers underlying Milan are generally composed of coarse-grained alluvial sediments with variable thickness, often exceeding 50 meters in some areas, providing productive groundwater reservoirs. These porous layers exhibit generally good hydraulic permeability, though permeability decreases in zones with higher clay and silt content. The groundwater plays an important role in supplying water for municipal and industrial uses, although it requires careful management due to variable recharge rates and the presence of anthropogenic contamination in some zones.

Groundwater

The groundwater in the alluvial and fluvial sediments of the Po Valley forms the uppermost aquifer layer beneath Milan and generally flows in a southeast direction, following the gentle slope of the terrain towards the Adriatic Sea. Within the urban area, the flow direction is influenced by the main watercourses, including the Lambro River and its tributaries, as well as artificial drainage and canal systems. The hydro chemical characteristics of Milan's shallow groundwater are typically dominated by calcium-magnesium-bicarbonate type waters, reflecting the carbonate-rich sediments of the surrounding Alpine region. Unlike some areas affected by elevated concentrations of iron and manganese, Milan's urban groundwater generally exhibits good quality for potential thermal use.

This makes the shallow quaternary aquifer a suitable target for thermal groundwater utilization, such as groundwater heat pumps. The hydraulic gradient of the groundwater table is relatively low, estimated around 2 to 3 ‰, consistent with the gentle regional slope.

Groundwater flow velocities in the area average between 5 and 10 meters per day, depending on local hydraulic conditions and geological heterogeneity.

Urbanisation and groundwater usage

The metropolitan city of Milan is about 1600 Km^2 distributed over 133 Municipalities, including the city of Milan, and is about 41% formed by build-up areas and infrastructures, 50% formed by agricultural areas and only 8% formed by woodlands. The dense urban fabric, combined with industrial and commercial activities, places significant pressure on local groundwater resources. Groundwater in Milan's quaternary alluvial aquifers plays a crucial role in supplying water for municipal, industrial, and agricultural uses, especially in surrounding peri-urban areas. However, urbanisation has also led to challenges such as groundwater contamination from industrial pollutants, leakage from sewer systems, and changes in natural recharge patterns due to impermeable surfaces. To balance demand and environmental protection, Milan has implemented strict regulations and monitoring programs aimed at protecting groundwater quality and promoting sustainable usage. Moreover, there is growing interest in leveraging groundwater for thermal energy through heat pump systems, capitalizing on the good hydro chemical quality of shallow aquifers. Overall, while urbanisation increases pressure on groundwater, ongoing management efforts aim to ensure its sustainable exploitation alongside urban development.

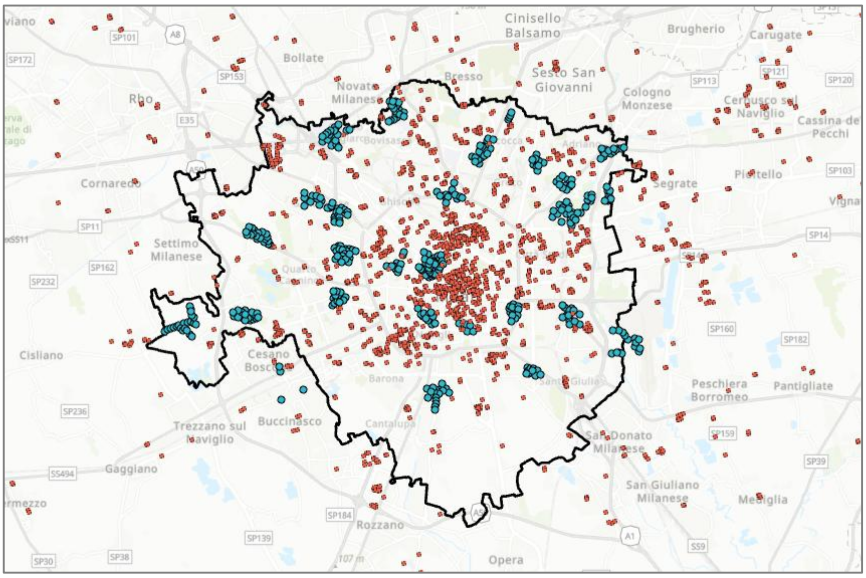


Figure 2 – Map showing the location of drinking wells (blue dots) and GWHP wells 8red dots) in the Milan area

MARGIN is co-financed by the European Regional Development Fund through the Interreg Alpine Space programme. **See more about MARGIN at www.alpine-space.eu/project/margin.**

Milan – Data Overview

Thanks to the jointed networks, the two partners collaborated to engage a wide range of municipal/regional departments and public authorities involved in groundwater-related planning, implementation, and data governance. The following stakeholders were directly or indirectly involved in the processes analysed:

Authorities

- Comune di Milano **– Direzione Verde e Ambiente (PP) (Municipality of Milan)** oversees environmental and urban planning, green infrastructure, and energy–climate strategies, ensuring the sustainable use of groundwater.
- Città Metropolitana di Milano **- Settore Risorse Idriche e Attività Estrattive** (Metropolitan City of Milan), is the competent authority for groundwater abstraction permits, compliance monitoring, and coordination of extraction activities across municipalities.
- Regione Lombardia (Lombardy Region) is the competent regional authority for defining groundwater and geothermal energy policies, strategies, and regulatory frameworks
- ARPA Lombardia (Regional Environmental Protection Agency of Lombardy) is responsible for environmental monitoring and technical control of groundwater quality and quantity.

Universities

- University of Milan-Bicocca - Department of Earth and Environmental Sciences **(PP)** provides scientific and technical expertise in hydrogeology, groundwater quality, and low-enthalpy geothermal systems.

Companies with full or partial public ownership

- MM s.p.a. **– Settore Acquedotto** is the water supply division of MM S.p.A. (water service provider public company). It is responsible for the operation, maintenance, and monitoring of Milan's public water supply, which is primarily sourced from deep aquifers. **Settore Infrastrutture** is the infrastructure division of MM S.p.A.. It manages the planning, construction, and maintenance of public works, including public transports and underground metro lines interacting with groundwater.
- Gruppo CAP is the integrated water service provider for the wider Milan metropolitan area. Its responsibilities include groundwater abstraction, treatment, distribution, and aquifer monitoring.
- A2A Company is a multi-utility company active in the fields of energy, environment, and infrastructure services. In the context of groundwater and geothermal energy, it focuses on the deployment of district heating and cooling networks.

Groundwater and hydrogeological data in the Milan area are elaborated and distributed by different stakeholders. Aquifer characterization is mainly done by the regional authority (Lombardy Region) with the regional plan on water use and protection (PTUA). Groundwater monitoring (levels and quality) is mainly done by the water service providers (MM spa in the municipality and Gruppo-CAP in the metropolitan area). Piezometric maps are elaborated and distributed in a pdf format about two times per year according to the availability of monitoring data from the water company. Additional piezometric contour lines at regional level are distributed by Città Metropolitana di Milano. Data on groundwater usage is managed by the province authority of resource protection (Città Metropolitana di Milano). They have been recently diffused online but the quality is too poor for quantitative analysis.

As a general comment, groundwater quantitative data is scarce in terms of temporal and spatial coverage and update frequency, but also poorly available to the stakeholders (available only upon request or archived in formats that are not suitable for direct use).

The following table summarizes the data availability in the city of Milan for the most relevant categories. For a complete and detailed version see the Deliverable D1.1.1

Parameter	**Short description**	**Data format**	**Responsible organisation**
Elevation	Digital elevation model	Raster image	Regione Lombardia
Aquifer surfaces	Elevation contour lines of dividing surfaces between aquifer bodies (Piano di Tutela delle Acque)	Shapefile	Regione Lombardia
Groundwater levels	2 records per year from 2022 (older archived). Interpolated from point data.	Pdf/image	MM s.p.a.
	2 records per year from 2013 (discontinuous). Interpolated from point data.	Available as vector isolines (≥ 2.5m). Shapefile	Città Metropolitana di Milano
Groundwater depth to surface	Phreatic shallow aquifer (derived from the ground elevation and the groundwater height)	Pdf/image	MM s.p.a.
Groundwater level time series	Data available only at some sporadic locations with very poor frequency (mainly outside the Milan municipality)	Available only as online charts	MM s.p.a. - Gruppo CAP
Groundwater quality data	Available only as aggregated data for subdomains of the city (no single values at sampling locations are available)	Tables	MM s.p.a.
Amount of water used /groundwater	Location of authorized groundwater extraction wells with information on the type of use, well depth and (not	Shapefile	Città Metropolitana di Milano

discharge / water demand	for all) the average or maximum discharge. Poor data quality, update frequency unknown. 1) webgis of wells (retrieved from the declaration to regional office, annual extracted amount for tributary value) 2) offline database (retrieved from the declaration to regional office annual extracted amount for tributary value and other sources)		
Water protection area	Polygons that identify zones with specific restrictions. Identified in the municipal territory government plan (PGT)	Shapefile	Municipality of Milan
Climate data	Weather monitoring stations: daily rainfall; daily air temperature Data has been available for the last 10-30 years. Older data available at the National climate observatory for some points (in the center of Milan, the oldest station records from 1700)	CSV (Comma Separated Values)	ARPA Lombardia
Surface Waters	Hydrographic network, basins, minor rivers, open hydrography datasets (available online)	Shapefile	Regione Lombardia

Milan – Topics Overview

The table below synthesise the relevance for each topic analysed by the MRGIN project. Ranks are based integrating the findings from the stakeholder questionnaires and the insights derived from expert interviews.

Topic	**Relevance**
1 Groundwater extremes	Average (3)
1.1 High GW: Flooding cellars & Flooding of terrain	**Very high (5)**
1.2 Low GW: Negative influence[1] on utilizations	Average (3)
1.3 Low GW: Land subsidence	Low (2)
2 Rainwater infiltration	**High (4)**
3 Thermal groundwater use	**High (4)**
3.1 Heat energy planning & Interference (Negative influence) management[2]	**Very High (5)**
3.2 Increasing groundwater temperatures through geothermal utilisations & Decreasing groundwater temperatures or too low temperatures	**High (4)**
4 Groundwater quality and ecosystem health	Average (3)
4.1 Groundwater temperature	Average (3)
4.2 Ecosystem analysis	Average (3)
4.3 Groundwater quality	Average (3)

Milan – Topics in Detail

1 Groundwater extremes
1.1 High GW: Flooding cellars & Flooding of terrain
1.2 Low GW: Negative influence[1] on utilizations
1.3 Low GW: Land subsidence
Relevance Concerns over groundwater extremes were mostly raised by the city departments and the public service provider (drinking water and infrastructures). Their concerns are related to the impacts on infrastructures such as basements, underground tunnels and stations. Groundwater levels in the Milan area have experienced significant fluctuations over recent decades, driven by both human activities and climate variability. A notable rebound in groundwater levels has been observed following the decommissioning of numerous industrial facilities (starting from 1970) that had previously extracted large volumes of groundwater (around 1950). The most critical issues have occurred during periods of intense precipitation (e.g., in 2014 and 2024), when rising groundwater levels flooded underground structures such as building basements, metro stations, and tunnels. A city-wide strategy that integrates continuous monitoring of groundwater levels, identification of at-risk structures, assessment of future flood risks, and evaluation of the effectiveness of current mitigation strategies, including adjustments to groundwater level control wells, is seen especially necessary.
Governance The main stakeholders involved are the Municipality of Milan (PP) and the public construction company (MM spa). Although some sporadic actions have been undertaken in the past (see D1.2.1), there is currently no clear governance framework addressing this issue, nor a well-defined long-term vision. A **city-wide strategy regarding high groundwater level and the associated risk of flooding** is still lacking. A strategy that integrates continuous monitoring of groundwater levels, identification of at-risk structures, assessment of future flood risks, and evaluation of the effectiveness of current mitigation strategies, including adjustments to groundwater level control wells, would be beneficial.

Data-handling

Knowledge is missing about where and which underground structures might be at **risk of flooding** due to groundwater rising in the present or in the future. A monitoring strategy for the topic of extreme high groundwater levels is still missing. Essential data are:

- Groundwater level historical time series (statistically significant, at least 10 years)
  - These data are not available and information on which location have been monitored and for how long are missing, owned by the integrated water service but not digitally available to the public
- Database of underground structures with their depth and level of waterproofing
  - A dataset doesn't exist. The public construction company has the information on underground tunnels and metro station's location and depth

Gaps

The following relevant aspects, which are currently lacking and need to be further developed, have been identified:

- A **survey about the elements at risk of groundwater flooding (risk analysis)** to gain information on where and how many underground structures might be at risk in the present or in the future.
- A **monitoring strategy of groundwater levels including data collection**, as data collection remains highly fragmented among stakeholders, and extreme-level analysis is not yet standardized for operational planning.
- A **coordinated mitigation approach**, that includes the quantification and evaluation of the effectiveness of existing measures (groundwater level control wells).

Measures & strategies

Since the early 2000s, mitigation efforts have included:

- local remediation by the public construction agency, primarily through waterproofing public infrastructure;
- the installation of groundwater level control wells to extract groundwater.

However, unresolved issues persist in various areas, and a comprehensive/coordinated approach of the mitigation measures that have been implemented (groundwater level control wells) is lacking, particularly as the severity of the problem has increased over the past ten years.

Regulations

No specific regulation addresses issues related to groundwater extremes. The general regulations on groundwater protection and extraction procedures are listed (See details in D1.3.1):

National Legislation (Italy)

Legislative Decree No. 152 of April 3, 2006 – "Environmental Regulations":
This decree regulates water resources (both surface and groundwater), sets quality objectives, and outlines protection criteria.
Legislative Decree No. 152 of September 30, 2009 – Implementation of Directive 2006/118/EC:
Defines measures to prevent and control groundwater pollution and establishes criteria for the classification and chemical/quantitative assessment of groundwater bodies.

Regional Legislation (Lombardy)

Regional Law No. 26 of December 12, 2003
"Regulation of Local Public Services of Economic Interest":
Governs the use of surface and groundwater, water-saving measures, and water reuse.
Regional Regulation No. 2 of March 24, 2006
"Regulation of the Use of Surface and Groundwater":
Establishes procedures for using water resources, including for domestic, agricultural, and industrial purposes.

2 Rainwater infiltration

Relevance

Although this topic was not included in the questionnaire, it was raised as relevant by the Municipality of Milan (PP) due to the strict relationship with groundwater recharge, integrated management of surface waters and groundwater. Rainwater infiltration is highly relevant in Milan due to the city's urban development, hydrogeological context, and increasing climate-related stresses. Milan is a densely urbanized city with extensive impermeable surfaces (asphalt, concrete), which severely limit natural infiltration. As a result, most rainwater runs off into the combined sewage system, heightening the risks of urban flooding, overloading wastewater treatment plants, and pollution entering water bodies. Moreover, Milan sits above a highly productive aquifer system, which is a key source of drinking water, industrial use, and irrigation. Reduced rainwater infiltration means less groundwater recharge, contributing to the lowering of water tables in certain areas and creating imbalances in the aquifer system. Additionally, Milan is increasingly affected by extreme precipitation events, with sudden, intense rainfall followed by long dry spells. This exacerbates surface runoff and reduces the effectiveness of natural infiltration processes.

Thus, groundwater recharge from infiltration is of high interest considering the city of Milan's heavy dependence on groundwater for water and energy supply.

Governance

The main actors in the field of rainwater management are: i) The Lombardy Region, acting as regulator, planner, and controller. It issues the regulatory framework, promotes the monitoring and inspection of implemented works; and may co-finance interventions through regional or European funds; ii) The Municipality of Milan, acting as regulator, supervisor, and promoter; integrates regional criteria into the Territorial Government Plan (PGT), the Building Regulations, and municipal technical guidelines; ensures construction projects comply with regulations on hydraulic invariance; issues permits only if projects respect the permitted flow rates; collaborates with Metropolitana Milanese (MM S.p.A.), the water and sewage system operator, for the technical evaluation of complex projects; publishes guidelines and manuals for professionals; and promotes awareness campaigns and pilot projects in collaboration with universities and private companies; iii) MM S.p.A., acting as technical evaluator, network manager, controller, planning support, and innovation promoter. It reviews and approves hydraulic projects for compliance with hydraulic invariance; maintains the sewer network, retention basins, and drainage systems; verifies technical compliance during both design and construction phases; collaborates with the Municipality on urban water planning; and experiments with sustainable solutions and manages pilot projects. iv) ARPA Lombardia (the Regional Environmental Protection Agency), which provides technical support, environmental monitoring, and oversight. It quantitatively and qualitatively monitors surface waters and discharges; manages the SIRE Acque Information System—a regional platform for managing data on discharges and piezometric levels, with both manual and automatic inputs from monitoring stations;

supports Civil Protection in hydrogeological risk management; and offers scientific and technical expertise, as well as public information services.

Data-handling

The main data relevant to the management and control of rainwater infiltration include hydrological data, sewer network data, and discharge flow data. Hydrological data are collected by ARPA Lombardia, processed by MM S.p.A. and the Municipality of Milan, and then shared by ARPA Lombardia, MM S.p.A., the Municipality of Milan, and the Lombardy Region. Sewer network data are collected by MM S.p.A. and the Municipality of Milan, which also collaborate in processing and sharing the data, in coordination with ARPA Lombardia. Discharge flow data are collected, processed, and shared by ARPA Lombardia and MM S.p.A., while data on discharge permits are collected, processed, and shared by the Municipality of Milan and the Metropolitan City of Milan (Città Metropolitana di Milano).

Gaps

The main challenges the city administration faces regarding rainwater infiltration are high urbanization and the impacts of climate change, particularly the increase in intense rainfall events. Extensive soil sealing across the urban area prevents natural rainwater infiltration, while heavy storms overload the sewer network, reduce the efficiency of wastewater treatment plants, and lead to surface water pollution. Data related to these issues—such as hydrological data, sewer network information, and discharge flow measurements—are well collected and shared with designers and planners at both regional and local levels. These datasets are available in digital format through dedicated platforms.

However, quantification of groundwater recharge from infiltration in the urban area is a complex challenge due to the absence of quantitative data. In this perspective, the Milan city lacks a dataset of locations where infiltration from collected rainwater occurs. In particular, given the regulatory framework (See Deliverable D1.3.1), all projects that modify soil permeability, both in urban redevelopment and new land transformation, must prefer infiltration into the soil, provided the water does not come from potentially polluted surfaces. These amounts are collected but not available to all stakeholders dealing with quantitative analysis of groundwater.

Measures & strategies

To address these challenges, several initiatives for sustainable rainwater management are underway. The Sponge City project, funded by the Italian PNRR (Recovery and Resilience Plan), aims to increase urban permeability through green infrastructure, such as permeable pavements, rain gardens, and green roofs. Furthermore, regulatory updates to Milan's building code now require developers to integrate on-site rainwater management, promoting infiltration and reducing runoff into the sewer system.

Regulations
Regional Regulation 7/2017 – Hydraulic and Hydrological Invariance: it outlines the criteria and methods for ensuring hydraulic and hydrological invariance, promoting the adoption of Sustainable Urban Drainage Systems with a preference for stormwater infiltration into the soil. **Regional Regulation 6/2019:** it regulates the discharge of stormwater runoff throughout the Lombardy Region, especially for industrial or potentially polluted areas. **Regional Regulation 3/2025**: application of the principles of hydraulic and hydrological invariance in urban and peri-urban contexts, updating the criteria and methods established by Regional Regulation no. 7/2017

3 Thermal groundwater use
3.1 Heat energy planning
3.2 Increasing groundwater temperatures through geothermal utilisations
3.3 Decreasing groundwater temperatures or too low temperatures
3.4 Interference (Negative influence) management

Relevance

The use of groundwater for heating and cooling systems is a growing focus in Milan's transition towards climate neutrality. Recent EU directives and national regulations have encouraged the development of shallow geothermal energy as a renewable, low-emission source. Milan is in a very prone area with a high potential for thermal use of shallow groundwater. Therefore, it is experiencing a strong growth in the application of this technology for heating and cooling. On the other hand, the high built-up density and associated energy demand is fostering a rapid development of shallow geothermal applications which require appropriate tools to monitor and model the associated effects on both the quality and quantity of the available resource.

In the city of Milan, the total number of geothermal wells (GWHP) has increased significantly in the last 5 years, with an actual rate of about + 300/400 new GWHP systems per year, covering a total thermal energy demand (including heating and cooling) from about 40 to 400 GWh/a. Due to this very rapid growth and the resulting criticalities such as increased groundwater temperatures and interferences between systems, the technical agencies and the stakeholders see the management of the shallow geothermal resource a priority task for the sustainable use of this resource.

Governance

The primary stakeholder involved is the provincial environmental authority (Città Metropolitana di Milano), which oversees the authorization process for groundwater extraction wells, including those intended for thermal use. The Municipality of Milan, the integrated water service provider, and other relevant stakeholders may be consulted on a case-by-case basis for strategic or significant projects.

Large-scale projects (with an average total discharge exceeding 50 l/s) are reviewed by the regional authority (Regione Lombardia). Additionally, if the peak discharge exceeds 50 l/s or 100 l/s, further environmental assessment procedures must be evaluated by Regione Lombardia.

Project proponents are required to demonstrate the sustainability of the proposed system and assess potential interferences with other users. However, no comprehensive city-scale evaluation procedure is currently in place.

Data-handling

Essential data to deal with this issue are:

- **Information on the existing shallow geothermal systems** such as location and characteristics of extraction/injection wells but also the amount of extracted groundwater and the exchanged energy per season (heating and cooling) is scarce.
    - The collection and availability of such information is essential to develop quantitative analysis. However, these data are not properly collected and stored. Only the location of wells and their mean/peak discharge are known. No information exists on the amount of energy produced with groundwater. The provincial authority on groundwater resources (Città Metropolitana di Milano) manages the authorization process, but a database is still lacking and few information are available to the public.
- **Groundwater temperature** monitoring data
    - Besides the working loads of the existing systems, the information of the current thermal regime of the groundwater is crucial to determine the thermal exchange potential for heating and cooling and to optimize the energy extraction on a city-scale level. However, no official strategy for groundwater temperature monitoring exist. The only dataset available is provided by PP UniMIB but it was developed for research activities and the maintenance is not guaranteed. The development of a groundwater monitoring strategy of the groundwater bodies relevant for thermal use should be prioritized by the competent authority.

Gaps

At present day, there is a poor management of the thermal use of the groundwater resource, from missing groundwater geothermal well database, to quantitative tools to support the authorization process that preserve the resource, but also city-wide studies to showcase the available thermal potential and energy extraction optimization strategies.

The following relevant aspects, which are currently lacking and need to be further developed, have been identified:

- **Proper regulation** to deal with data collection and management of the groundwater resource for thermal use. A better cooperation among the authorities would help to define throughout the regulation the essential needs for a better management.
- **A database and a regular data collection process** to gather useful information on shallow geothermal installations to develop quantitative analysis. The provincial authority on groundwater resources (Città Metropolitana di Milano) manages the authorization process but a database is still lacking, and few information are available to the public.
- **Planning and management instruments** that could help to optimize groundwater thermal exploitation as well as to evaluate possible interference and sustainability issues of existing and new installations. For example: evaluation of the thermal potential of groundwater, risk management tools to coordinate multiple groundwater uses and interference geothermal systems.

The above proposed tools should be integrated in a GIS to improve the visualization and decision-making about shallow geothermal resource in the urban area. This would be beneficial for urban planners to optimize the extraction of groundwater-based thermal energy but also for proposer to better design the systems in a sustainable way.

Measures & strategies

The Milan Municipality (PP-CMil) and the Province of Milan (Città Metropolitana di Milano) have commissioned the University of Milan-Bicocca (PP-Unimib) to identify strategies to improve the management of geothermal installations, with particular focus on the highly urbanized area of Milan. Unimib has conducted a first spatial screening of the existing systems and proposes a series of actions to promote the development of this technology. No actions have been yet implemented but awareness was raised among the stakeholders on:

- The need to develop a database of geothermal installations by digitizing relevant data from existing systems and automatically collecting them for new geothermal systems requests;
- Adopt quantitative tools to streamline the management of new requests by maximizing the extractable thermal potential and minimizing issues related to mutual interference between systems.

Regulations

National Legislation

Legislative Decree No. 22 of February 22, 2010 – Implements Directive 2006/118/EC:
While focused on groundwater protection, it impacts geothermal plant installation and operation as well.
Legislative Decree No. 28 of 2011 – "Implementation of Directive 2009/28/EC":
Promotes the use of renewable energy sources, including geothermal. Provides simplified administrative procedures (PAS) for small-scale geothermal installations.

Regional Legislation (Lombardy)

Regional Regulation No. 7 of February 15, 2010 – "Regulation on Groundwater Use":
Includes specific rules for the use of groundwater in geothermal systems and for the installation of geothermal probes (i.e., closed-loop systems).
Regional regulation No. 38 of November 10, 2015, Art. 13 - "Legge di semplificazione 2015":
Regulation for the use and reinjection into aquifers of groundwater used for thermal exchange in heat pump systems (i.e., open-loop systems).
Regional Council Resolution No. X/6203 – 08/02/2017:
Approval of implementation methods and content of preliminary investigations required by regional law 38/2015 for the purpose of granting authorization for the discharge into aquifers of groundwater extracted for thermal exchange using heat pumps (i.e., open-loop systems).

Although technical guidelines exist, there are no specific binding rules governing the spatial arrangement of geothermal wells and their interaction with other existing wells. For example, there is no clear definition of the required separation between plants, between extraction and injection wells, or of the maximum allowable discharge/thermal potential. In addition, coordination between subsurface and surface water priorities is weak, and there is no specific regulation indicating where reinjection should occur, whether back into aquifers or into surface water systems. Such regulatory instruments are essential to prevent poor design practices and disputes between designers and permitting authorities, and to ensure a sustainable use of the resource in the future.

Current regulations only require designers to demonstrate, through numerical modelling, that no negative impacts occur beyond the system. However, this requirement needs to be standardized through regulations that specify the sources of input parameters, the types of analyses to be carried out, and the distances at which impacts must be assessed.

Data collection is not mandatory such as the extracted volumes and energy, and the temperature difference between intake and discharge is essential to evaluate the status of the resource and the cumulative impacts of multiple systems. Moreover, no monitoring of actual extraction volumes or thermal energy is in place for these systems. This limits the ability to assess the status of the resource, reducing the sustainability of existing systems and constraining the optimal development of new installations by preventing full use of the resource potential.

4 Groundwater quality and ecosystem health
4.1 Groundwater temperature
4.2 Ecosystem analysis
4.3 Groundwater quality including temperature
4.3 Groundwater quality
Relevance Groundwater quality in urban areas is a critical issue, given the dual importance of clean groundwater as a source of drinking water and its potential for heat and cold production. However, in the City of Milan, limited information is available on the effects of urbanization on groundwater temperature and ecosystem health. While the hydrochemical status of groundwater is not the focus of this project, it remains highly relevant in urban contexts due to the numerous potential pollution sources linked to human activities. Groundwater temperature measurements data are essential to monitor the impact of urbanization on the groundwater thermal regime. **Groundwater ecosystem analyses are completely lacking** in the city of Milan.

Governance Groundwater ecosystems are not systematically assessed, as no protocols or legally mandated monitoring programs are in place. As a result, potential changes in ecological status remain unobserved. Groundwater quality monitoring is carried out by different agencies at selected sites, but the information is generally published only in the form of annual reports. More detailed and integrated datasets, as well as inclusion of ecological parameters, are currently lacking.
Data-handling Groundwater quality is regularly measured at drinking wells but information is poorly available (both for shallow and deep aquifers). Groundwater temperature is not monitored by authorities. Increase of the subsurface urban heat island effect needs to be monitored (see also Topic 3 Thermal groundwater use) No groundwater biodiversity assessment exists.
Gaps Policy fragmentation: groundwater quality responsibilities are split among municipal, regional, and utility agencies, limiting coordinated action. Limited public reporting: Groundwater quality data is often not fully transparent or accessible to citizens or civil society. No specific strategies in place that deal with groundwater ecosystem management. Often groundwater ecosystems are included in topics of groundwater quality or biodiversity in water in general.
Measures & strategies Milan follows the European Union's Water Framework Directive (WFD) and the Groundwater Directive (2006/118/EC), which provide a legal framework to monitor and protect groundwater from pollution. Technical tools like numerical models and statistical analyses have successfully identified contamination hotspots, supporting targeted mitigation and resource planning. However, there has been limited assessment of chemical and microbiological impacts. Considering the changes in the groundwater thermal regime driven by urbanization and climate change, it is necessary to evaluate whether thermal changes influence groundwater chemistry or microbiota.
Regulations **Legislative Decree No. 152 of April 3, 2006 – Environmental Regulations** regulates water resources (both surface and groundwater), sets quality objectives, and outlines protection criteria. Includes Water Framework obligations (monitor groundwater

status, pressures and measures) and requires authorities to set monitoring programs used for status assessment and reporting. **Legislative Decree No. 152 of September 30, 2009 – Implementation of Directive 2006/118/EC** measures to prevent and control groundwater pollution and establishes criteria for the classification and chemical/quantitative assessment of groundwater bodies. No regulation is in place for groundwater ecology.

Milan – Further Information

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Acknowledgements

- **Comune di Milano** – Direzione Verde e Ambiente
- **Città Metropolitana di Milano** - Settore Risorse idriche e attività estrattive

Institutional Websites of Stakeholders

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- Città Metropolitana di Milano https://www.cittametropolitana.mi.it/
- Comune di Milano https://www.comune.milano.it/
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- Servizio Meteorologico dell'Aeronautica Militare www.meteoam.it

3.4 MUNICH

Short overview

Hydrogeology

- thick alluvial unconsolidated sediment deposits
- unconfined, highly productive intergranular aquifer

Main usage of groundwater

- drinking water
- industrial
- geothermal heating and cooling

Data overview and handling practices

- The monitoring networks provide systematically collected data (GW level and chemical parameters)
- Groundwater and geothermal data are partly accessible through web portals
- ~150 GW geothermal systems

Measures & strategies and regulation & policies

- Sustainable Urban Strategy
- Local energy plan
- Drinking water protection zones
- Municipal Spatial Plan

Topics

- Thermal use of groundwater (management, interactions, sustainability)
- Groundwater quality and ecosystem health
- Rainwater Infiltration

Gaps

- The monitoring networks are not integrated into a single system
- Limited monitoring of groundwater temperature and thermal use
- Lack of tools to assess interactions of thermal groundwater uses
- No established methodology for groundwater ecosystem assessment

Munich – General Overview

Description of the city

Municipality of the City of Munich (Landeshauptstadt München), located ~80 km north of the Alps on the Munich Gravel Plain (Münchner Schotterebene). The city is crossed by the River Isar and, east to west, by smaller watercourses such as the Würm and Hachinger Bach (all with delineated floodplains). Forests dominate to the south (e.g., Perlacher Forst), while to the north and northeast groundwater conditions and post-glacial deposits give rise to wetlands and peatlands such as Dachauer Moos and Erdinger Moos.

Munich is among the EU's strongest metropolitan economies, anchored by advanced manufacturing and mobility, electronics/engineering, and insurance/reinsurance, with a growing ICT/start-up ecosystem. In 2024, the unemployment rate averaged 4.5%. The most recent city GDP published by the state statistics office is ~€128.8 bn (2021). The concentration of DAX companies has attracted additional international investment-bank offices to serve local DAX clients.

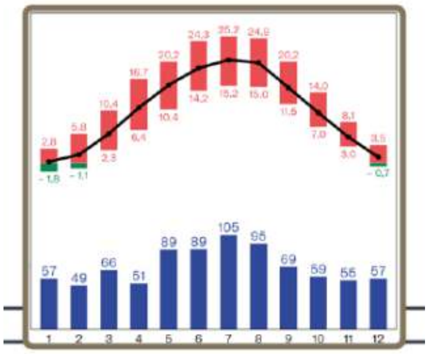
Extent and altitude

With over 1.6 million inhabitants, Munich is the most densely populated city and one of the fastest-growing municipalities in Germany. The populations density is 5,162 inhabitants/km^2. The urbanisation rate is 61%.

The city area covers 310.73 km^2 and extends over 27 km in a west-east direction and over 20 km in a north-south direction. The average altitude of Munich's urban area is 519 m a.s.l. The highest point is approx. 580 m a.s.l. south of the Warnberg/Solln, while the lowest point is located on the northern edge of Feldmoching at approx. 480 m a.s.l.

Climate

Greater Munich has a cool, temperate climate with comparatively cold winters, but rarely with temperatures below -20 °C, and also comparatively warm summers with temperatures of 20 to 35 °C. Weather-determining factors are the Alps and the Danube as a regional weather divide. The highest temperature measured to date was 37.5 °C, the lowest temperature was -31.6 °C. The mean annual temperature rose from 9.1 °C in the reference period 1961-1990 to 9.7 °C for the climate period 1981-2010. The mean annual precipitation is 954 mm in the reference period 1971-2000, varying between 657 mm in 2003 and 1,298 mm in 1966.



Pilot area information	
Pilot Area	Munich
Country	Germany
Area (km²)	31o.73 km²
Elevation	519 m a.s.l.
Inhabitants	1,603,776 (31.12.2024)
Inhabitants/km²	5,161
Level of urbanisation	61% : City / densely populated area (Level 1)
Economy	In 2024, the unemployment rate averaged 4.5% (lowest among Germany's major cities per the city administration). Per-capita purchasing power in 2024 was €36,461, ~35% above the national average. The most recent city GDP published by the state statistics office is ~€128.8 bn (2021).
Infrastructure	

Climatological settings	
Mean air temperature	10.1°C
Annual rainfall	940 mm
Heating Degree Days	≈ 2,600 degree-days/year Definition per Eurostat: base 15 °C, HDD sums daily (15 °C – Tmean) when Tmean < 15 °C; NUTS-3 region DE212 (Munich, Kreisfreie Stadt). (Annual index values vary by year; order of magnitude ~2.6k for the 1991–2020 climate.)
Cooling Degree Days	≈ 140 degree-days/year Definition per Eurostat: base 24 °C, CDD sums daily (Tmean – 24 °C) when Tmean > 24 °C; NUTS-3 region DE212. (Annual index values vary by year; climate-normal magnitude ~100–150.)
Length of heating season	October to May
Length of cooling season	June to September

Regional hydrogeological and geological characteristics

The Bavarian capital is located between the Northern Limestone Alps in the south and the Danube in the north on the so-called Munich Gravel Plain. The extensive gravel body was formed by sand and debris loads of the large glacial and meltwater streams of the Würm Ice Age, which ended around 10,000 years ago. The surface of the plain slopes approx. 0.5 % to the north. The underlying Tertiary base does not have this inclination, which is why the thickness of the gravel decreases from south to north. The gravel generally has a low proportion of cohesive material, clay or silt, and has a good to very good hydraulic permeability of usually over 1 * 10-3 m/s. The coarse-grained carbonate gravels have attained a maximum thickness of 30 m, and constitute a very productive

Geological setting

Munich sits ~80 km north of the Alps on the Munich Gravel Plain (Münchner Schotterebene), a fluvioglacial body of Würm- and Riss-age gravels/sands over Tertiary strata (Upper Freshwater Molasse, OSM). Within the city the quaternary gravel aquifer reaches up to ~30 m thickness (and up to ~60 m south of the city), providing a large, highly permeable porous aquifer; fine-grained Tertiary layers below act as aquitards separating multi-storey groundwater horizons.

Hydraulic properties

Hydraulic conductivities in the quaternary gravels commonly fall in the 10^{-3}–10^{-2} m/s range (numerous pumping-test syntheses across the plain), with local variability tied to grain-size contrasts. Depth to groundwater (Flurabstand) typically ranges ~5–10 m in central Munich, shallowing northward (<5 m in places) and deepening toward the southern city edge (locally ~30 m).

Groundwater dynamics

Regional flow in the quaternary aquifer trends from SW toward N/NE; major surface waters—Isar (citywide), Amper/Würm (west)—locally steer gradients and produce high velocities near valley flanks. Computed groundwater velocities are typically 5–10 m/day, often 10–20 m/day in larger zones, and can exceed 30 m/day adjacent to the Isar slope.

Hydrochemistry and quality

The quaternary "Kalkschotter" aquifer is characteristically Ca–Mg–HCO_3 type, weakly alkaline and well oxygenated—typical for carbonate-rich foreland gravels. These conditions underpin the city's high-quality raw water. (SWM's published analyses also note no treatment chemicals added to supply water.)

Main groundwater uses

Public drinking-water supply (SWM): Production comes primarily from Mangfall Valley and Loisach Valley, with the Munich Gravel Plain used as a reserve/for peak demand. SWM states roughly ~75 % of supply originates in the Mangfalltal, with the balance from Loisach and the Schotterebene.

Thermal use (heating/cooling): The gravel aquifer's high K and stable temperatures make it well-suited for groundwater-source heat pumps and cooling; such installations are generally permissible citywide (exceptions in designated protection zones; permits required under water law).

Construction dewatering and temporary uses: Conducted under water-law permits via the city's RKU/WWA procedures.

Munich – Data Overview

Data-catalogue audit -> In the framework of MARGIN, a catalogue of groundwater-relevant datasets has been created. For each of the datasets, the following information were recorded: data set/database (name), short description, access link, status (public/internal; active/discontinued), time (period covered and refresh rate), data format (vector, raster, CSV, API, PDF), literature (documentation/references), and responsible organisation. In plain terms: what the dataset is, where to find it, how current it is, in what format it comes, and who documents and owns it. This structure made it easy to spot real gaps, missing datasets, unclear status, outdated or incomplete time ranges, non-machine-readable formats, and datasets with no clear owner. In short, the exercise delivered an evidence-based baseline for improving data handling and governance across Munich's groundwater workflows. A complete data inventory catalogue can be founded in **D.1.1.1.**

Analysis of metadata collection catalogue

Data Risk Overview

high data status

medium data status

low data status

High: data are measured, available as machine-readable digital file and accessible openly online. **Medium**: data are measured and digitally available, but access/use is constrained (portal-restricted, PDFs-only, view-only tiles) or stewardship is unclear.
Low: data are not measured, not digitally available, not online available, or there is no clear owner/awareness.

Dataset	**Principal deficiency**	**Data status**
Groundwater level time series	Although groundwater levels are continuously measured by GKD Bayern and technically accessible, the city lacks a long-term, unified, and open archive. The GKD system provides only a rolling 12-month window, while WWA and RKU maintain fragmented and partly static datasets (PDF or request-only). There is no consistent integration between the LfU state-level feed and the municipal databases, making historical analysis and cross-departmental use difficult	Medium – High
Groundwater temperature time series	Groundwater temperature measurements exist in multiple institutional and academic datasets, but none offer a continuous, interoperable time series. All sources are static (PDFs or isolated studies), lacking open, standardized, and regularly updated data suitable for long-term monitoring or modeling.	Medium

	Measured and digitally available at source level (RKU, TUM), but not maintained as a dynamic, machine-readable dataset; access remains restricted and fragmented across institutions.	
Vertical temperature profiles	Despite the long-term and high-quality monitoring by LfU, the vertical temperature profile data are not openly accessible or integrated with municipal or research databases. The City of Munich lacks its own vertical temperature monitoring, and academic datasets (TUM) are static and isolated, preventing the creation of an interoperable, regularly updated temperature-depth dataset.	Medium
Contour maps (average / high / low levels)	The groundwater contour maps exist only as static or request-based layers (PDF, CAD, or internal GIS) produced at different times without version control or linkage to live monitoring data. There is no unified, continuously updated, or openly accessible geospatial archive of groundwater-level contours for Munich.	Medium
Groundwater bodies	The 3D hydrogeological model and derived maps are static research products (2016) not integrated into an open or regularly updated municipal data framework. Data are available only upon request, without version control or systematic updates linking new borehole data or monitoring results.	Medium
Hydraulic conductivity	Hydraulic conductivity data for Munich are derived from multiple reliable but static sources (TUM, LfU, WWA, RKU) without a unified or updatable spatial database. Access is restricted to institutional requests, and there is no integration or version control linking ongoing pumping tests with the official hydrogeological model.	Medium
Depth to groundwater	The spatial groundwater depth map (Flurabstand) is static and outdated, while live depth data (GKD) exist only at discrete stations. There is no integrated, up-to-date geospatial dataset combining continuous monitoring data with full spatial coverage for the city.	Medium-High

Aquifer thickness / saturated zone	The aquifer thickness map is scientifically robust and digitally available in GIS format but static (2014) and not openly accessible. It is not updated or integrated with newer borehole or monitoring data, limiting its applicability for current hydrogeological assessments.	Medium
Basis of aquifer	The aquifer basis isoline map is static (2016), not openly accessible, and lacks version control or integration with updated borehole data.	Medium
Sewer network	Although the sewer and stormwater infrastructure data are regularly measured and maintained by MSE, they are not openly accessible. The datasets are distributed between internal operational systems and annual summary reports, with no unified, open, or machine-readable geospatial database.	Medium
District heating network	The district heating system dataset is regularly maintained in GIS format by SWM but is not publicly accessible. It contains only internal geospatial data, with publicly available information limited to general statistics.	Medium
Construction sites	The dataset on construction sites with temporary groundwater use is incomplete, not regularly updated, and only available internally. It lacks integration with the official groundwater use databases and is not accessible for external or research purposes	Low
Culvert wells	The dataset is digitally maintained and regularly updated but remains internal. It is not openly accessible or shared beyond BAU and SWM, limiting its integration into broader groundwater and infrastructure planning frameworks.	Medium-High

Buildings basement reaching groundwater levels	The dataset is incomplete, static, and only available internally. It is not regularly updated or integrated into broader groundwater management databases, limiting its usefulness for systematic groundwater–building interaction analysis.	Low
Climate observations / rainfall	Although rainfall data are continuously measured and available through DWD, local MSE precipitation datasets are not open or integrated. Public datasets differ in format (CSV, HTML, PDF), and there is no unified, citywide rainfall database combining national and municipal sources	Medium-High
Digital Elevation Model 1 m	The high-resolution 1 m Digital Elevation Model for Munich is highly accurate and updated regularly, but it is not openly accessible. In contrast, the publicly available DEMs for Bavaria and Germany have lower spatial resolution, which limits the integration between the precise municipal data and the lower reaolution open datasets.	Medium High-
Surface sealing	The surface sealing data are spatially detailed and irregularly updated but remain view-only and not openly downloadable. Statistical reports are static PDFs, and there is no integrated, machine-readable database combining both spatial and quantitative sealing information	Medium-High
Amount of water used / groundwater discharge / water demand	Although groundwater use and thermal energy datasets are regularly measured and digitally maintained, they are not publicly available. Data are stored in internal databases (Wasserbuch, LfU, WWA) without open access or integration into a unified municipal framework combining abstraction volumes and thermal use.	Medium
Temperature maps	Groundwater temperature maps exist as static or view-only layers without regular updates or open accessibility. The 2014 dataset is outdated, and newer academic studies are not	Medium

	integrated into the municipal Geoportal, preventing the creation of a unified, up-to-date thermal monitoring layer.	
Chemistry and Groundwater quality	Groundwater quality and water consumption data are available only as static PDF reports from different institutions. They are not standardized, machine-readable, or integrated into a unified citywide groundwater quality and use database.	Medium
Microbiology (observation wells)	Microbiological groundwater data are not collected regularly and exist only as isolated case studies or research projects. There is no continuous monitoring program, open database, or standardized data structure for microbiological observation wells in Munich.	Low
Groundwater fauna	Groundwater fauna data exist only from a single academic sampling campaign. There is no ongoing monitoring, municipal dataset, or open database documenting groundwater fauna in observation wells	Low

Groundwater-data handling according to Questionnaire

Section A. Data availability and accessibility

Key insights

1. **Measuring responsibilities**

- Environmental and construction departments are consistently identified as the city's core monitoring capability.
- The drainage department appears less frequently in measurement roles; its long-term monitoring remit remains unclear.
- Across cases, regional authorities, the city utility and private operators also contribute data—confirming a hybrid network of municipal and external producersproducers.

2. **Leadership clarity**

- There is no broadly accepted coordination mandate at city scale. Stakeholders align with three different models—single coordinating department, joint leadership, and absence of a designated lead—indicating unclear ownership of cross-department data and decisions.

3. **Dataset coverage**

- Fundamental series—ground-water level, temperature and chemistry—are consistenly captured.
- Vertical temperature profiles and water-use/abstraction data show incomplete or irregular coverage.
- Ecosystem monitoring is absent from current practice, creating a critical blind spot for environmental assessment and long-term performance tracking. This is the most significant thematic gap.

4. **Accessibility**

- While all stakeholders confirm digital holdings, online publication is inconsistent.
- Closed portals and disperse links impede uniform data sharing.

5. **Operational implications**

- Even city departments depend on external data streams.
- Ambiguous leadership and uneven online visibility hinder data integration and reduce public transparency.
- The absence of ecosystem monitoring leaves a critical component of groundwater management unaddressed.

A strategic overview of these insights and a complete analysis is provided in Deliverable **D1.1.1**

Section B: Groundwater maps availability.

Risk Summary

high data status
medium data status
low data status

high: data are measured, available as machine-readable digital file and accessible openly online.
medium: data are measured and digitally available, but access/use is constrained (portal-restricted, PDFs-only, view-only tiles) or stewardship is unclear.
low: data are not measured, not digitally available, not online available, or there is no clear owner/awareness.

Data / map	measured	digitally available	online available	data status
Groundwater level series	yes	yes	only WWA portal	Medium

Groundwater temperature series	yes	yes	partial[8]	Medium
Vertical temperature profiles	yes	yes	no	Medium
Ecosystem data	once	no	no	Low
Chemical data	yes	yes	WWA / SWM partial	Medium
Water use / abstraction	yes	yes	no	Low
Climate / rainfall	yes	yes	DWD open data	High
Contourline spatial data sets	yes	yes	Digital available at LfU	High
Permeability & thickness spatial data sets	yes	yes	Digital available at LfU	High
Temperature spatial data set	yes	yes	Digital available at LfU	High
Groundwater recharge map	calculated	yes	no	Medium

[8] some data can be founded in the portal

Key insights

Map code	Map title
1	Contour – Average level
2	Contour – High level
3	Contour – Low level
4	Hydrogeo – Ground-water bodies
5	Hydrogeo – Hydraulic conductivity / permeability coefficient
6	Hydrogeo – Permeability coefficient (separate)
7	Hydrogeo – Ground-water depth to surface
8	Hydrogeo – Aquifer thickness
9	Hydrogeo – Thickness of saturated zone
10	Hydrogeo – Basis of aquifer
11	Hydrogeo – Ground-water discharge
12	Ground-water temperature maps

- There is a solid common base: maps 1, 4, and 10 are used by everyone, so the baseline for planning is reliable.
- Use drops to almost universal for maps 2, 3, 7, 9, and 12, showing broad but not complete alignment.
- Awareness is uneven for maps 5 and 8, and map 6 is barely used (only once), which weakens detailed feasibility checks.
- The biggest gap is map 11 (groundwater-discharge), no one has it, leaving a clear blind spot in assessments.

Conclusion: strong baseline, but advanced screening and prioritisation are constrained by patchy use of permeability/thickness layers and the absence of a discharge map.

Response profiles

- One department reports the full suite except for the missing discharge layer.
- A second lists a mid-range subset (1-4, 7, 9-10, 12).
- The water-supply utility cites only the three baseline layers (1, 4, 10) and does not enumerate temperature maps.
- The regional authority covers most hydro-layers but omits the separate permeability coefficient (6) and the discharge map (11).

Implications

- Core contour information (codes 1, 4, 10) is widely known and can be used confidently for city-scale planning.
- Permeability and thickness maps (5, 6, 8) suffer from inconsistent visibility, suggesting uneven internal dissemination or non-standardised availability.
- The absence of a discharge map (11) constitutes a clear data gap that should be addressed.
- The utility's narrower map set indicates a preference for operationally relevant products, highlighting the need to align technical layers with practical decision-making requirements across all stakeholders.

A strategic overview of these insights and a complete analysis is provided in Deliverable **D1.1.1**

Insights summary Q1: Munich possesses a rich but highly fragmented groundwater information. Core hydro-parameters, water levels, temperatures, and basic chemistry, are measured by multiple actors; however, consistent leadership, unified access, and ecological coverage are lacking.

1. **Governance**

- The Department of Climate and Environment (RKU) and the Construction Department (Baureferat) are the only city units cited by every respondent as active measurers.
- Stakeholders diverge on who coordinates the network: one votes for a single lead (RKU), two for joint leadership, and one for none. This ambiguity hinders coherent policy delivery.

2. **Data availability**

- All respondents hold digital files, yet online publication is uneven—fully absent for one stakeholder and only partial for the others.
- Ecosystem indicators (microbiology, fauna) and a groundwater-discharge map do not exist in institutional form, leaving critical blind spots in environmental assessment.

3. **Map coverage**

- Baseline layers—average contour, groundwater bodies, and aquifer base—are universally recognised, ensuring a good foundation for spatial planning.
- The absence of a discharge map constitutes a clear data gap that should be addressed.

Integrated Overview – Questionnaire and Dataset-Catalogue Audit

Munich possesses a wealth of groundwater information, yet the portfolio is fragmented and digitally immature. Two-thirds of key datasets are divided among three or more custodians and are issued mainly as static PDFs. Only seven of 23 layers—principally water-level, rainfall and topography—are available in open, machine-readable form. Internal surveys reveal that half of the city's own departments are unsure where critical files, such as permeability, microbiology or fauna data, are stored. True legal barriers are confined to four security-sensitive layers (sewer, district-heat networks, precise well coordinates and private pump-test logs); most other restrictions stem from outdated workflows rather than regulation.

Gap	Observed evidence	Operational impact	Effects	Risk

1	**Incoherent data infrastructure**	• ≈ 65 % of datasets are spread over 3+ owners • Many files live only as annexes to single projects.	• Duplicate field campaigns. • Conflicting figures in permit files. • Extra weeks on modelling jobs.	
2	**Limited digitalisation**	Only 7 / 23 layers come as CSV / GeoTIFF / API (levels, DEM, rainfall, …). All others are PDFs or view-only maps.	• Dashboards can't auto-update. • Staff spend hours re-typing tables , it creates risk of errors.	
3	**Communication gaps**	Questionnaire: on average 2 of 4 key departments didn't know where a dataset sits (fauna, microbiology).	• Decisions based on out-of-date info. • Same consultant hired twice for identical analysis.	
4	**Data-privacy / KRITIS limits**	Only 4 datasets (sewer, district heat, exact well coords, private pump tests) are truly security- or business-restricted.	·The legal block is real but small; most data are held back for procedural reasons, not law.	

Still the city's ability to convert that knowledge into agile, climate-resilient decision-making is constrained by three systemic weaknesses:

1. **Fragmented governance**

   - Groundwater monitoring is conducted by various municipal departments, as well as regional authorities, utilities, and private operators.
   - There is no universally recognised lead organisation for data coordination, resulting in duplicated fieldwork, inconsistent permit records, and delays in policy implementation. The RKU holds partial responsibility for groundwater data but is not formally recognised as its official custodian.

2. **Low digital maturity**

   - Only 7 of 23 catalogue layers—principally water levels, rainfall and the digital elevation model—are released in open, machine-readable formats.
   - The remaining datasets are confined to static PDFs or view-only web maps, which hinders integration into automated dashboards and necessitates manual data entry

3. **Uneven thematic coverage**
   - Core hydro-chemistry is well represented, but vertical temperature profiles, permeability/thickness layers and, above all, ecological indicators (microbiology and fauna) are patchy or absent.

Only a narrow subset of layers is legitimately restricted under critical-infrastructure (KRITIS) rules or contractual confidentiality like; detailed sewer network maps, district-heating pipe routes, exact well coordinates, mapped rainwater infiltration areas and parcels assessed for the stormwater fee, and proprietary pump-test results. For most other groundwater-related datasets, there is no statutory barrier to open release; non-publication primarily reflects internal process issues rather than legal prohibitions.

Without a clearly mandated data lead and an integrated portal, the city risks continued duplication of monitoring campaigns, slower permit reviews, and sub-optimal adaptation strategies. Conversely, most data reside outside strict security or privacy constraints, so improvement hinges on governance and workflow—not legislation.

Munich – Topic Overview

The table below synthesise the relevance for each topic analysed by the MRGIN project. Ranks are based integrating the findings from the stakeholder questionnaires and the insights derived from expert interviews.

Topic	**Relevance**
1. Groundwater extremes	Average (3)
1.1 High GW: Flooding cellars & Flooding of terrain	Average (2.5)
1.2 Low GW: Negative influence[9] on utilisations	Average (3.5)
1.3 Low GW: Land subsidence	Very Low (0.5)
2. Rainwater infiltration	High (4)
3. Thermal groundwater use	High (4)
3.1 Heat energy planning & Interference (Negative influence) management[10]	Very high (4.5)
3.2 Increasing groundwater temperatures through geothermal utilisations & Decreasing groundwater temperatures or too low temperatures	Low (2)
4 Groundwater quality and ecosystem health	Average (3)
4.1 Ecosystem analysis	Low (2)
4.2 Groundwater quality and temperature	Very high (4.5)

[9] Negative influences on utilisations may include impacts on pumping wells used for drinking water supply, industrial processes, or heat pump operations.
[10] Interference or restriction management

MARGIN is co-financed by the European Regional Development Fund through the Interreg Alpine Space programme. See more about MARGIN at www.alpine-space.eu/project/margin.

Munich – Topics in Detail

1 Rainwater Infiltration

1.1 Sponge city concept

Relevance -> Munich applies the Sponge City concept to ensure the sustainable management of rainwater infiltration by integrating infiltration, retention, and evapotranspiration measures into urban planning and construction. This approach enables rainwater to be absorbed, easing pressure on sewer systems, replenishing groundwater, and enhancing the city's resilience to climate impacts such as flooding and drought. Yet infiltration is not only a technical measure but also a governance challenge, requiring close coordination among planning, environmental, hydraulic, and construction departments. Because the process spans regulatory frameworks, technical approvals, construction, and long-term operation, it serves as a valuable lens to examine how institutional structures, interdepartmental cooperation, and data practices shape the effectiveness of urban adaptation strategies. Studying this process is therefore essential to identify the enabling conditions and challenges of Sponge City implementation and to generate lessons transferable to other cities.

Governance -> Rainwater infiltration management through the Sponge City concept is organized into two phases. In the Planning Phase (B-Plan), the planning office (PLAN) leads the process, supported by the climate and environment department (RKU) for climate assessments and adaptation criteria. The hydraulic authority (MSE) contributes technical requirements for drainage and infiltration, the construction department (BAU) checks space allocation for infiltration in public areas, and the regional water authority (WWA) provides expert opinions during the zoning process. In the Implementation Phase, responsibilities split between public spaces—where BAU leads construction, MSE defines and supervises hydraulic performance, and RKU issues water-law permits if required—and private parcels, where MSE approves and tests drainage systems, LBK grants building permits, and RKU provides additional water-law authorizations. Each track advances through defined steps such as technical review, construction, functional testing, and acceptance, ensuring that infiltration is embedded in both city-scale projects and parcel-level developments.

For a complete overview of governance workflows, please refer to **Deliverable D1.1.1**, which provides detailed governance workflows and full process descriptions with defined interdepartmental interactions.

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Main Actors

- PLAN (Referat für Stadtplanung und Bauordnung – Stadtplanung): Leads urban planning and coordinates the B-Plan process, ensuring land-use frameworks integrate infiltration and climate-adaptation measures.
- RKU (Referat für Klima- und Umweltschutz): Responsible for climate and environmental assessments, water-law permits, and integrating adaptation requirements into planning and implementation.
- MSE (Münchner Stadtentwässerung): Acts as hydraulic authority, approves and supervises property drainage systems, defines technical criteria for infiltration, and manages storm-water fees.
- BAU (Baureferat – Hochbau/Tiefbau): Executes civil works in public spaces (streets, schools, municipal buildings) and oversees construction quality, safety, and maintenance.
- WWA (Wasserwirtschaftsamt München): Regional water authority providing expert opinions, technical advice, and regulatory guidance on groundwater protection and infiltration feasibility.

Governance insights

Planning Phase

1. Groundwater monitoring wells are operated by RKU, MSE, SWM and BAU within a common database.
2. RKU holds primary access, updates the shared database, and (in practice) handles most groundwater-data requests.

Implementation Phase / City Scale

1. **Ownership and Access**
   Groundwater wells are shared across departments, but the public-facing roles (who maintains the database, update cycles, and how internal/external requests are routed) are not codified.
2. **Internal routing for municipal fee-reduction dossiers**
   The precise responsibilities and evidence requirements between BAU, MSE (technical) and MSE (fees) are not standardised city-wide.
3. **Post-implementation monitoring gap**
   No city-wide asset registry, inspection cadence or KPIs (Key Performance Indicators) exist for installed infiltration measures.

Implementation Phase – Private Buildings.

1. Official city departments websites describe each process separately, MSE (property drainage approval), LBK (building permit), and RKU (water-law permit), but there is no official, integrated end-to-end workflow showing who triggers what, in what

sequence, required hand-offs, and minimum deliverables. Based on interviews and the absence of a published guide, this is a governance gap that should be formalised as a SOP.

2. Post-installation monitoring not standardised: The MSE Leitfaden covers construction and leak testing, but there is no city-wide regime for annual monitoring or owner self-reporting on the long-term performance of infiltration systems.
3. Storm-water fee reduction sits outside the permit flow: The fee webpage explains the principle (less connected area, lower fee), but there is no automatic link from “leak test passed / as-built submitted” to “fee adjusted.” Applicants typically make a separate request to the fees unit and in an optional suggestion.

Insights from the all procces

Emerging vs. Consolidated urban areas – Sponge City approach

The Sponge City approach works best in emerging districts, where infiltration-first measures can be built into plans and designs from the inception. In consolidated (built-up/historic) areas, retrofits face hard limits, sealed surfaces, dense utilities, heritage rules, many owners, and higher costs to rehabilitate. There, an evapotranspiration-led mix (green roofs/facades, street trees, permeable surfaces, capture-and-reuse) is usually more realistic, with targeted infiltration only where ground conditions allow it. Stormwater fee incentives help in emerging context but rarely shift decisions in consolidated areas on their own; change at scale needs block-level programs, coordinated public-realm works, faster permits, and additional funding. Policy should match the context: mandate infiltration-first in emerging areas, and support coordinated, incentive-backed retrofits in consolidated districts, with monitoring to demonstrate performance and guide improvement.

Data-handling -> Data for Munich’s Sponge-City work is produced and shared across departments along the planning–installation chain. Groundwater monitoring wells are operated jointly by RKU, MSE, SWM and BAU within a common database; RKU has primary access, updates this shared store, and in practice handles most groundwater-data requests. During planning, PLAN prepares the B-Plan and expert commissions, RKU reviews and issues assessments, MSE provides technical feedback, and WWA contributes an expert opinion; because RKU, WWA and MSE may generate overlapping inputs at this stage, aligning content and data sources is explicitly required. During installation, decisions and test results are recorded in real time on site to ensure traceability; at functional testing, MSE issues the hydraulic test protocol, BAU confirms structural integrity, and RKU verifies compliance with permit conditions before acceptance. Where applicable, BAU and MSE compile a short dossier for MSE Fees to adjust the storm-water charge.

Good Practices Identified in the governance process

Although the previous chapter identified several governance and data-handling gaps in Munich's Sponge City process, certain elements of the current implementation stand out as consistent strengths:

1. **Strategic Leadership in Climate Adaptation**: PLAN and RKU jointly lead climate adaptation planning, embedding environmental considerations at the earliest stage of city-scale strategies. This ensures climate objectives are not treated as an afterthought but as a guiding principle in urban planning.
2. **Clear technical and regulatory sequencing for specific technical objective:** Each department is clearly defined and technically specialised in the activities under its mandate. MSE focuses on drainage and hydraulic approvals, BAU on street and public-space works, RKU on environmental and climate assessments. This clarity ensures that for any given technical objective, the responsible department acts as the competent authority, providing expertise and regulatory certainty for a specific objective.
3. **Joint supervision and performance-based acceptance:** Coordinated technical inspections (BAU and MSE), documented functional testing, and performance-based acceptance criteria ensure that implemented measures operate as intended before final handover.
4. The use of storm-water fee reductions as an incentive to promote nature-based solutions in support of the Sponge City concept.
5. **Emerging Data Governance Initiatives:** RKU's IT department is developing a megadata catalogue that integrates principles of data quality and sustainability. While still in progress, it shows the city's awareness of governance challenges in data handling and creates an opportunity to align with the GeoKW App for systematic groundwater data management.

Tree-Planting Programme (planning stage): Munich is preparing a tree-planting program to boost evapotranspiration, infiltration, and water retention. It has the potential to complements the Sponge City concept strategies.

Strategies and Measures

The Sponge City concept and its application is part of several federal, state and municipal climate adaptation strategies (e.g., "German Climate Change Adaptation Strategy", "Climate-resilient Munich 2050"). In Munich there is a catalogue of measures that should be implemented where it is feasible. Regarding infiltration solutions there is a preference to use surface infiltration > infiltration basins > basin-trench elements > infiltration trenches > infiltration shafts. Furthermore, roof greening, façade greening, tree pits with 36 m^3 substrate volume in public spaces and a decentralised rainwater management should be implemented. Refer to D1.2.1 for more details on existing measures and strategies regarding groundwater quantity management.

Rules and Regulations

In Munich there are several federal, state and municipal rules that deal with the Sponge City concept. The federal Water Resources Act and Groundwater Protection Decree as well as the Bavarian Water Act by the state incentivise groundwater management that prevents the deterioration of groundwater quantity and prioritise infiltration of rainwater. Also, there is a set of rules by the German Association for Water, Wastewater and Waste e. V. (DWA) and standards by the German Institute for Standardisation (DIN) on the implementation of sustainable urban water management, enhancing infiltration, retention and groundwater recharge.

More specifically in Munich, there is the "Decision bill – Implementing the principles of the sponge city in public spaces", the "Policy decision I – Implementation of the climate goals of Munich" among other climate adaptation regulations that set the rules for the implementation of Sponge City concepts.

2 Thermal groundwater use

2.1 Heat energy planning

2.2 Quartier Strategy

Relevance -> The use of groundwater for geothermal energy is highly relevant in Munich, as it directly supports the city's heat-transition goals and contributes to reducing carbon emissions. With rising energy demand, dense urbanisation, and climate-change pressures, groundwater-fed heat pumps and near-surface geothermal systems offer a sustainable alternative to fossil-based heating. The topic is not yet fully solved, but is being systematically addressed through the Heating Plan and Quartier Strategy, which translate city-wide targets into spatially specific actions. Given Munich's favourable hydrogeological conditions, the integration of geothermal use into urban planning is expected to play an increasingly central role in securing affordable, resilient, and low-carbon heating in the future.

Governance -> The governance of geothermal groundwater use in Munich is embedded in the city's Heating Plan and the Quartier Strategy, both of which translate heat-transition goals into spatially targeted actions. RKU acts as the central coordinator and data steward, integrating inputs from PLAN (urban planning and spatial data), SWM (energy-consumption and network datasets), BAU (underground building data and public assets), MSE (sewer constraints), WWA (groundwater risk zones and permit requirements), and LfU (state-level borehole and groundwater data). Within the Quartier Strategy, a Steering Committee chaired by the Second Mayor involves PLAN, RKU, MOR, and BAU, while the external contractor MGS develops the Integrated Neighbourhood Concepts (IQKs). Responsibilities are clearly defined in the planning phase, with RKU ensuring interdepartmental cooperation and data integration through the *Wärmebedarfsmodell* and the municipal GeoPortal. However, overlaps and dependencies emerge in the Quartier process—particularly due to unclear roles for BAU, reliance on MGS, and fragmented data-sharing rules under DSGVO. The governance workflow therefore reflects both strengths in coordination at the city-wide planning level and gaps in responsibilities, monitoring, and data feedback loops at the neighbourhood scale.

Data-handling -> Data for geothermal heat planning in Munich is collected from multiple departments: PLAN provides the digital city model and zoning data, SWM delivers energy demand and network datasets, BAU contributes underground building data, MSE adds sewer network information, WWA shares groundwater-use records and risk zones, and LfU supplies state-level borehole and groundwater datasets. RKU acts as the central coordinator: it standardises formats, integrates all inputs into the *Wärmebedarfsmodell*, and validates the consolidated baseline. The official outputs—such as suitability maps (*Eignungsgebiete*)—are then published via the municipal GeoPortal to guide planning and neighbourhood concepts. While this workflow ensures a structured integration, data is still exchanged in heterogeneous formats (often PDFs or static tiles), with limited metadata and access restrictions due to privacy (DSGVO) and critical infrastructure rules (KRITIS). In the Quartier Strategy, however, data handling is more fragmented: relevant datasets on energy infrastructure, demand, and potentials are transferred to the external contractor MGS to develop Integrated Neighbourhood Concepts (IQKs). While the GeoPortal supports internal exchange, strict data-protection rules (DSGVO, KRITIS) restrict sharing, and the one-way flow to MGS means that enriched results are not systematically reintegrated into municipal systems. This creates risks of data loss, weak institutional learning, and limits long-term monitoring and iteration.

Gaps ->

Governance Gaps

1. for Heating Plan – Planning Phase

Data quality before integration: RKU acts as the official coordinator for data management and integration. The main vulnerability lies not in RKU's leadership, but in the quality, coherence, and coordination of datasets provided by external institutions before ingestion. As long as cooperation among the organisations responsible for data measurement remains effective and consistent, the integration process at RKU is reliable and represents a good practice in data governance.

RKU coordinates, and roles for PLAN, SWM, BAU, LfU, MSE, WWA are clear in first instance, however, the real gaps are upstream, including origin, format, metadata, coverage and access for the specific datasets that feed Baseline → Potential → Scenarios.

2. for Quartier Strategy

Unclear Responsibilities: RKU and PLAN are both involved in the development and implementation of IQKs, but in the absence of clear SOPs the division of tasks is not always fully transparent

Unclear Role of BAU: BAU is part of the Steering Committee but its role in later stages is not defined. This limits effective coordination when public space or construction aspects become relevant.

Dependence on External Contractor (MGS): IQKs are developed and implemented by MGS. The city risks losing knowledge and relying too heavily on an external actor instead of strengthening internal capacity.

Monitoring Gap: Although updates are shared and the digital Heat Plan is regularly revised, there is no formal monitoring system to assess the impact of implemented neighbourhood measures. Follow-up focuses on documenting milestones rather than evaluating effectiveness, leaving the city without a feedback loop to guide future strategies.

Publication and Iteration Gap: Although Munich's Integrated Neighbourhood Concepts (IQKs) are publicly available, there is no structured process for updating or revising them after publication. Tools like the ENP and QET assist in their development but lack mechanisms for ongoing feedback or revision. As a result, IQKs risk becoming static, reducing adaptability, stakeholder involvement, and long-term impact.

Data Gaps

a) for Heating Plan – Planning Phase

Fragmented and outdated groundwater temperature datasets: No continuous, up-to-date groundwater temperature time series. Data are static from different years and sources.

Restricted access to KRITIS datasets (district heating, sewer network): Data relevant to thermal balance (e.g. heating, cooling, wastewater temperature) are internal and security-restricted, preventing cross-departmental thermal analysis or simulation.

Incomplete linkage between thermal use and hydrogeological capacity data: Hydraulic and geological parameters needed for sustainable thermal extraction and re-injection are available but static, old (2014–2016), and not open for reuse.

No city-wide thermal monitoring network: There is no coordinated system measuring temperature **fluctuations from thermal groundwater use, so cumulative impacts on aquifers cannot be tracked.**

b) for Quartier Strategy

Restrictions from Data Protection Rules (DSGVO): Data sharing between departments and with MGS is often blocked or slowed by privacy and infrastructure protection regulations.

One-Way Data Flow: Data is transferred to MGS, but there is no clear mechanism to bring enriched results back into the city's systems. This creates a risk of data loss and weak institutional learning.

For a strategic overview, please refer to **Deliverable D1.1.1.**

Good Practices Identified -> Munich's municipal heating plan and Quartier strategy, several strengths stand out as consistent best practices.

Planning Phase

Centralised coordination in the planning phase
RKU acts as the single coordination point for data and processes in the Heating Plan's Concept Phase, integrating inputs from PLAN, SWM, BAU, LfU, MSE, and WWA in a clear sequence (Baseline → Potential Analysis → Scenarios → Political Approval).

Robust methodological sequence
The stepwise structure, baseline assessment, data integration, potential analysis, scenario modelling, and political approval, ensures an orderly and documented progression towards the 2045 target scenario, aligned with the city's Wärmewendestrategie.

Public decision-support instruments
The publication of Eignungsgebiete (suitability maps) on the GeoPortal and the ongoing Quartier updates via the "Wärmewende mit der Nachbarschaft" portal provide transparency and a common reference for technical teams, policymakers, and the public.

Tools: GEO.KW proofed to be a useful tool for the realisation of the geothermal potential in Munich and is currently expanded for the city of Augsburg and Nürnberg.

Quartier strategy

High-Level Political Backing: The Steering Committee, chaired by the Second Mayor, ensures strong political legitimacy, visibility, and cross-departmental engagement from the outset.

Dedicated Coordination Unit: The Geschäftsstelle Quartier within RKU provides central coordination, continuity, and an institutional anchor for the process, reducing fragmentation.

Structured Pipeline for Neighborhoods: The step-by-step process of screening, approval, concept development, and implementation creates transparency and predictability, making the strategy replicable across neighborhoods.

Stakeholder Involvement (District Councils and Residents): The active participation of district councils, stakeholders, and residents strengthens local legitimacy, improves acceptance, and ensures that concepts reflect neighborhood-specific needs.

Strategies and Measures -> The thermal groundwater use in Munich is promoted by the "Munich Heat Plan" and the "Roadmap climate – Climate neutral Munich 2035". Within this framework there are several technical measures in place e.g., GEO.KW, a thermal use database and groundwater temperature monitoring programme.

Rules and Regulations -> Geothermal use of groundwater requires a water law authorisation according to the Water Resources Act and the Bavarian Water Act. In Munich the requirements for obtaining a permit depend on the maximum heating capacity of the planned geothermal installation. The relevant threshold is 50 kW of heating capacity. Technical conditions, e.g., design or maximum temperature spread are set in the Guideline 4640 – Thermal utilisation of the subsurface by the Association of German Engineers, the "Collection of documents" from the Bavarian Water Management Authority and the "Protection of Groundwater and Soil" guidelines by the Bavarian State Office for the Environment

1 Groundwater extremes

Relevance -> Groundwater extremes are a critical issue for Munich, as unusually high or low water tables directly affect urban development, infrastructure, and climate resilience. Elevated groundwater levels increase the risk of basement flooding, damage to sewer systems, and constraints on construction, while unusually low levels can undermine shallow geothermal potential and green infrastructure. Munich already operates a dense monitoring network and publishes official groundwater maps and statements, but the

management of extremes remains fragmented and not yet codified into a citywide process. With climate change and continued urbanisation expected to intensify fluctuations, the relevance of this topic will only grow, making coherent governance and integrated data handling essential to safeguard infrastructure, guide adaptive planning, and reduce risks for residents.
Governance -> The governance of groundwater extremes in Munich is not yet formalised into a single, codified process, but relies on a mix of municipal and state-level responsibilities. The municipal departments (RKU, BAU, MSE) monitor the groundwater situation within their area of responsibility and provide expert opinions on the situation. Statistical evaluations of long-term groundwater level developments are carried out by the RKU. The GeodatenService Munich publishes information on the highest GW level. The RKU as the Lower Water Rights Authority is responsible for permits and the processing of drilling applications and provide statements for planning. The Munich Water Management Authority plays a special role in this process. They provide the technical expert for the city of Munich, analyze the groundwater situation, and contributes regional expertise and assessments. They are also involved in the water law proceedings. LfU and the Groundwater Data Portal of Bavaria (GKD) supply long-term time series and analytical tools from a few observation wells. Despite this institutional landscape, responsibilities remain blurred: it is unclear which department leads the extremes process, roles in planning and permit reviews are not consistently defined, and incident response (e.g., cellar flooding after high groundwater) lacks formal assignment. As a result, governance of extremes shows strengths in monitoring capacity but gaps in ownership, coordination, and integration with planning and infrastructure programs. The process is made more difficult by the fact that, according to legislation, building owners are responsible for waterproofing buildings and therefore much information is not available.
Data-handling -> Data handling for groundwater extremes in Munich builds on a strong monitoring base but remains fragmented in practice. The city operates more than 2,000 observation points for shallow and deep groundwater, complemented by long-term time series from LfU and the Bavarian Groundwater Data Portal (GKD). These datasets are essential for tracking fluctuations, identifying high- and low-water tables, and deriving seasonal patterns. Official cartographic products, such as the average highest groundwater and depth-to-groundwater maps, are digitilized and available through the GeoPortal and the GeodatenService, which also issues official statements (HW 1940) for planning and permits. However, stewardship and update cycles are not consistently defined, and data is published through different channels without a consolidated "single source of truth." While the information exists, limited integration, unclear ownership, and missing feedback loops from incident data (e.g., basement flooding events) constrain its systematic use in planning, permitting, and risk management. **Gaps ->**

Governance gaps

No codified SOP: There's no single, written procedure from concept to analysis to publication to use in permits to response.

Unclear process owner: It's not explicit who leads the groundwater extremes process (policy, updates, escalation).

Roles not formalised: Immediate vs. long-term responsibilities for cellar/groundwater flooding aren't clearly assigned and documented.

Phasing misalignment with other programmes: Groundwater extreme measures are not scheduled in coordination with sewer rehabilitation, geothermal projects, rainwater infiltration or street-tree planning. This lack of alignment means that when these works take place, potential synergies are missed, and opportunities to integrate groundwater measures efficiently are lost.

Data Gaps

Lack of continuous, high-resolution groundwater level datasets across all monitoring wells: There is no full historical time series accessible city-wide; continuity and long-term trend analysis (e.g., drought or flooding cycles) are limited.

No integrated database linking groundwater levels with rainfall and surface conditions: Without linking precipitation and infiltration data, it is difficult to detect cause–effect relationships during extreme events.

Absence of open-access early-warning: There is no public or interdepartmental alert tool for rising groundwater or extreme low levels, limiting response preparedness.

Outdated groundwater contour and depth maps: Outdated maps do not reflect current hydrological conditions, especially under climate change, reducing accuracy for risk zoning and construction permits.

Incomplete monitoring in areas affected by urban development and sealed surfaces: Groundwater fluctuations near heavily sealed or redeveloped areas are poorly captured, reducing understanding of local extremes.

From Gaps to Opportunities

Munich does not yet operate under a clear, end-to-end process for managing groundwater extremes. Current practices are valuable but function in isolation, without being systematically embedded into related municipal strategies. Nevertheless, there are solid strengths that, if integrated, could significantly improve climate-resilient planning across sectors.

Extending the impact beyond Groundwater Extremes

One of the biggest recurring gaps identified in other processes, such as Sponge City and geothermal use of groundwater process, is the absence of post-implementation monitoring. In Sponge City projects, there is no systematic check on whether natural infiltration measures are actually recharging aquifers where intended, or whether they might be causing unintended side effects.

Similarly, in geothermal projects and other underground works, there is no standard follow-up to assess how construction or extraction has impacted groundwater levels over time.

This is precisely where the Groundwater Extremes process could play a cross-cutting role. If its scope formally included a monitoring function for human interventions, tracking both high and low groundwater trends before and after projects, it could:

- Provide direct feedback to Sponge City planning on the real hydrological performance of infiltration measures.
- Detect and address impacts from geothermal use, deep construction, or drainage works on aquifer levels.
- Support proactive risk management for both flooding and over-extraction.

Strengths of the city actual groundwater extreme management:

1. Extensive monitoring infrastructure – Over 2,000 municipal measurement points, complemented by Bavarian Environment Agency (LfU) and GKD time series, give the city strong baseline capacity to detect changes in groundwater levels.
2. The "Update of the maximum groundwater level map" and the "Investigation/Modelling of Changes in Groundwater Levels due to Anthropogenic and Natural Factors" are part of the climate adaptation strategy and are currently being developed.
3. Recognised official mapping products – Layers such as Mittlerer höchster Grundwasserstand (average highest groundwater) and Mittlerer Grundwasserflurabstand (average depth to groundwater), plus further hydrogeological maps, are already available in the GeoPortal and used in planning and permitting.
4. Existing sectoral applications – High groundwater products and HW 1940 statements are applied in urban planning (B-Plans, basement design), sewer/drainage engineering, shallow geothermal feasibility checks, and high-GW incident prevention.

5. Established technical contributors – RKU, BAU, MSE, GeodatenService, LfU/GKD, and WWA already provide official data and expertise, which could serve as the backbone for an integrated monitoring and feedback system.

The opportunity

By formalising Groundwater Extremes as a process with a monitoring and feedback loop, linked into groundwater strategies, Munich could close a major governance/data gap. This would align with international best practice for adaptive groundwater management, ensuring that infrastructure and nature-based solutions are evaluated not only at the design stage but throughout their operational life.

Strategies and Measures

The City of Munich's climate resilience concept aims to prepare the city for the consequences of climate change by implementing adaptation and climate protection measures to achieve climate neutrality by 2035 and make the city resilient to rising temperatures, droughts, and heavy rainfall. Key areas include strengthening green and blue infrastructure, promoting sustainable mobility and urban development, improving public spaces through desealing and planting, and engaging citizens.

Within the “Climate Adaptation Concept Munich” two measures, “M3-3: Concepts/Guidelines for the early identification of land requirements for water-sensitive measures (sponge city) in planning processes” and “M3-5: Early and ongoing integration of decentralised precipitation management and dealing with heavy rainfall into urban planning” are currently developed.

All strategies and measures promoting the implementation of Sponge City concepts help mitigating the effects of extreme weather events and as a result the occurrence of Groundwater Extremes.

Rules and Regulations

In Munich the DIN 1986-100: Überflutungsnachweis (Flooding certificate) is mandatory for plots with > 800 m^2 drainage area, demonstrating the proof of ‘safety against flooding or controlled, damage-free flooding’. The reference rainfall event is depending on surface sealing of the plot; < 70 %, based on 30-year rainfall event; > 70 %, based on 100-year rainfall event.

For low groundwater events there are no dedicated regulations. However, the guiding principle is that “Groundwater management should prevent deterioration of groundwater quantity and quality and reverse man-made trends of increasing pollutants” as stipulated by the “Water resources act” and the “Groundwater protection decree”.

Good practices

1) Strategic Leadership in Climate Adaptation

PLAN and RKU jointly lead climate adaptation planning, embedding environmental considerations at the earliest stage of city-scale strategies.

This ensures climate objectives are not treated as an afterthought but as a guiding principle in urban planning.

2) Emerging Data Governance Initiatives

RKU's IT department is developing a megadata catalogue that integrates principles of data quality and sustainability.

While still in progress, it shows the city's awareness of governance challenges in data handling and creates an opportunity to align with the GeoKW App for systematic groundwater data management.

3) Groundwater Monitoring Infrastructure

Munich operates an extensive network of **over 2,000 measurement points**, supported by authoritative groundwater maps and technical expertise.

These assets provide a strong foundation for establishing systematic, city-wide monitoring across strategies such as Sponge City and geothermal use.

4) Tree-Planting Programme (in planning stage)

The city is preparing a **tree-planting initiative** designed to enhance evapotranspiration, infiltration, and water retention.

This programme complements the Sponge City concept and illustrates how green infrastructure can be tailored to different urban contexts (emerging vs. consolidated districts).

It also offers a chance to design new incentive schemes (e.g. property fee reductions for planting specific trees in priority locations), once supported by spatial analysis of high-value sites.

1. **Context-Sensitive Strategy Awareness**

Recognition that policy design must match context:

- In emerging districts, infiltration-first measures can be embedded from the outset. In consolidated districts, evapotranspiration-led measures (green roofs, facades, trees, water reuse, permeable pavements) are more feasible.

This nuanced understanding is already influencing planning discussions and pilot initiatives.

Reflections

From Gaps to Opportunities: Connecting Gaps with Good Practices

1. Closing the Monitoring Gap

Current weakness: Munich has no city-wide, systematic pre- and post-implementation monitoring for infiltration, geothermal, or deep construction works. As a result, impacts remain uncertain and unverified. More importantly, without clear final indicators, it is impossible to know whether these strategies are truly working or delivering the intended outcomes.

Opportunity: Introduce a shared monitoring phase across all strategies, coordinated by *Groundwater Extremes*. Munich already has over 2,000 measurement points, authoritative maps, and strong technical expertise. If these assets were connected, they could:

- Provide real-time feedback to Sponge City and geothermal measures.
- Detect early warnings (e.g. excessive water table rise or temperature shifts).
- Generate consistent performance indicators that prove effectiveness and guide improvements.
- Link incentives (stormwater fee reductions, subsidies) directly to verified safe outcomes.

With this, monitoring would become a core governance tool, ensuring that strategies are not only implemented but also measured, validated, and continuously improved.

2. Matching Policy Design to Context

Current weakness: Incentives are still one-size-fits-all. Stormwater fee reductions may work in some cases, but they rarely drive change in consolidated, historic districts, where space is limited and ownership is fragmented.

Opportunity: Develop context-sensitive policies that reflect the reality of different urban areas.

- In emerging districts, infiltration-first measures can be embedded from the start. Here, early-stage incentives make them technically and economically viable.
- In consolidated districts, where sealed surfaces, heritage restrictions, and dense utilities constrain infiltration, a more realistic option is an evapotranspiration-led mix: green roofs, facades, street trees, permeable surfaces, and water reuse, with infiltration only where conditions allow.

To scale impact in these harder contexts, additional tools are needed: block-level programmes, coordinated public works, faster permits, and targeted subsidies.

The planned tree-planting programme in Munich, although not yet implemented, offers a unique opportunity to rethink incentives for consolidated areas. Trees can serve as anchors for evapotranspiration, infiltration, and water retention. Incentives could be designed so that property owners receive fee reductions for planting specific tree species in strategic locations, directly contributing to Sponge City objectives. To make this work, a spatial analysis study would be required to identify priority locations and link them to targeted incentive schemes.

Framed this way, the tree programme is not only ecological—it becomes a strategic governance instrument for consolidated areas, bridging the incentive gap and aligning urban greening with groundwater resilience.

3. Strengthening Data Governance

Current weaknesses

- There are no clear end-to-end procedures (SOPs), and most workflows still rely on email or PDFs instead of a Common Data Environment (CDE).
- Maps and datasets are often published without refresh dates or version tags, making it hard to know if the information is current.
- Valuable datasets exist but are not systematically published or regularly updated.
- Departments are not always aware of what data is available elsewhere, creating duplication and inefficiency.
- Privacy restrictions limit academia's ability to act as a full knowledge-support partner for the city.

Opportunity: Build a digital governance backbone that makes data reliable, accessible, and useful:

- Introduce formal SOPs and codify roles clearly.
- Standardise metadata and versioning, so all datasets carry timestamps and source details.
- Establish regular publication and update cycles for key data.
- Improve internal awareness through dashboards and interdepartmental training.

- Create controlled-access frameworks that allow universities and research institutes to securely work with sensitive data, turning it into applied knowledge products that directly support the city.

A promising step in this direction, confirmed through the interview with the IT department of RKU—is the megadata catalogue currently under development. While still unnamed and in progress, it explicitly integrates principles of data quality and sustainability. This creates an opportunity to coordinate with the GeoKW App, ensuring that groundwater datasets are not only catalogued but also managed within a centralised, authoritative system. If these initiatives are aligned, Munich could establish a data governance model that meets modern standards of quality, transparency, and sustainability, while also strengthening groundwater management in practice.

4. Building a Unified Strategic Vision

Current weakness: At the strategic level, climate adaptation planning is well guided by PLAN and RKU. However, once strategies move to implementation, departments tend to operate in silos, focusing on protecting their own mandates. This is understandable and can be beneficial in ensuring that each unit fulfils its core responsibility. But without a shared sub-strategic vision, valuable opportunities for collaboration and innovation are often lost.

The Sponge City strategy shows this clearly:

- **MSE** concentrates on drainage load and system safety.
- **BAU** prioritises street and public-space projects. In practice, this means BAU might only check that infiltration measures do not interfere with roadworks or underground infrastructure.
- Other actors provide inputs, but without working towards a collective, higher-level goal.

As a result, implementation risks being reduced to “damage control” within silos, instead of departments actively contributing to a broader strategy. For example, if BAU worked under a shared vision, it could move beyond simply protecting its infrastructure to actively collaborating on sealing reductions in certain streets, thereby contributing directly to city-wide infiltration targets.

Opportunity: Establish sub-strategic groups where all departments align around one measurable vision, with shared objectives, values, and success indicators. For Sponge City, this would ensure infiltration, evapotranspiration, and retention measures are implemented not just as technical add-ons, but as part of a joint, city-wide strategy.

It is important to note that Sponge City is only one example where this fragmentation is most visible, because of the number of overlapping mandates. Other strategies (e.g. geothermal or groundwater-based heating) involve fewer actors and clearer responsibilities. Still, addressing the alignment gap in Sponge City could create a model of interdepartmental cooperation that benefits all adaptation strategies in Munich.

Munich – Further Information

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References

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Eurostat nrg_chddr2 (NUTS-3) supplies HDD (base 15 °C) and CDD (base 24 °C) for DE212 Munich with transparent methodology. European Commission

DWD page on Gradtage/Gradtagzahlen explains the German engineering conventions used for heating season calculations. Deutscher Wetterdienst

4 Transferable approach

The catalogue of fact sheets describes current data handling, on-site management and adaption strategies, as well as country-specific/regional regulations and policies regarding present groundwater risks and adaptation measures in the pilot cities. The fact sheets outline lacks, barriers and requirements for a groundwater sustainability management, identified via stakeholder interaction. **A general approach for this assessment is deviated from outcomes and lessons learned in the pilot cities**.

The analyses in the pilot areas were conducted using a common methodology. Based on the experiences gained during its application, the approach was subsequently refined into a general and transferable methodology for assessing data availability, data management practices, and governance processes related to groundwater sustainability. Its implementation across different Alpine cities illustrates its replicability and supports systematic assessment. In this way, the methodology identifies the most relevant topics for a city and outlines areas that require further investigation to advance sustainable groundwater management.

4.1 Step 1 – Stakeholder engagement

Engaging stakeholders is a central step in the methodology, as they hold essential knowledge on data availability, governance practices, and current challenges of groundwater management. The process begins with the **identification of relevant stakeholders**, which ensures that all actors producing, using, or governing groundwater-related data and processes are included from the start.

Stakeholder questionnaires and **stakeholder interviews** have proven to be effective instruments for engaging the stakeholders. The following sections described them in more detail. They can be complemented by formats such as **workshops**, where multiple actors meet to discuss challenges and solutions collectively, or **structured focus groups**, where smaller groups are guided through targeted discussions on specific topics.

Effective engagement should **include feedback loops** to validate preliminary findings and prioritization exercises to jointly assess the relevance of identified issues. Iterative interactions further allow adaptation as new insights emerge.

Equally important is the **systematic documentation of all inputs** from the stakeholders to ensure transparency and reproducibility. Together, these methods provide a solid basis for evaluating the relevance of groundwater-related topics within a city.

4.1.1 Stakeholder identification

First step is the identification of relevant stakeholders, who are later included in the analysis. This involves mapping all actors linked to the cities that produce or use groundwater-related data, as well as organiations engaged in governance processes, e.g. authorities responsible for licensing, environmental regulation or resource management.

The MARGIN activities in the pilot cities identified the following relevant organisations and departments:

- **City departments**, that are responsible for groundwater related data (e.g. groundwater usage data, measurements, infrastructure), licensing or management in general on municipal level. In general, depending on the size of the city, there are several departments involved in the responsabilites.
- **State departments**, that are responsible for groundwater related data (e.g. groundwater usage data, borehole data, groundwater level, bottom of confining layer), licensing of water rights and groundwater management on state level.
- **National organizations**, that are responsible e.g. for the collection and supply of groundwater levels or groundwater chemistry at observation wells, on federal level.
- **Utilities**
  - **Responsible for hydropower stations** in rivers flowing through the cities (which often monitor the groundwater at observation wells)
  - **Drinking water supply** (monitoring of observation wells, abstraction data)
  - **Sewage system providers** (sewage pipe network)
  - **District heating providers** (district heating pipe network)

- **Universities or other research facilities**: Research facilities focusing on geology/hydrogeology or spatial energy planning can have valuable data and knowledge.
- **Geological Survey Organisations**: Experts on geology and hydrogeology that have valuable data and knowledge on state and/or federal level. These organisations sometimes host valuable data bases.
- **Other companies**: Planning or drilling companies conducting e.g. pumping tests, monitoring at wells or hydraulic modelling usually have a large amount of data. Downside is here, that the accessibility of the data is often difficult due to privacy issues.
- **National Meteorological Survey:** Important data providers for e.g. climate scenarios, air and soil temperatures, precipitation

4.1.2 Stakeholder questionnaire

Stakeholders are essential contact points for information on available data and the relevance of citywide groundwater topics. To capture this systematically, a multilingual questionnaire was developed and deployed via KoboToolbox in English, German, Italian, and Slovenian. It includes four thematic sections:

- Groundwater data availability and types
- Institutional responsibilities and coordination
- Existing measures and strategies
- Challenges in governance and implementation

The questionnaire has proven to be a valuable tool for obtaining harmonized responses across multiple stakeholders and serves as useful starting point for subsequent stakeholder interviews.

Access link: KoboToolbox Survey
Reference: D1.1.1 - ANNEX I- Questionnaire

4.1.3 Stakeholder interviews

Questionnaire responses alone were not sufficient to capture all relevant information from the stakeholders. To validate and enrich the questionnaire analysis, semi-structured interviews were conducted with key actors in each city. The interviews explored:

- Role clarity and departmental mandates
- Interdepartmental coordination mechanisms
- Data management and exchange practices
- Regulatory and procedural challenges
- Perceptions of governance effectiveness and bottlenecks
- Available data sets

Side-note to MARGIN specific activities: Within the MARGIN project, the outcomes of these early stakeholder communication activities were shared across participating cities to foster knowledge transfer and transnational cooperation.

A dedicated workshop session was held during the PSG1 meeting in Vienna using the World Cafe methodology, enabling open, rotating group discussions around three key questions:

1. Which groundwater issues are most pressing locally?
2. Which city departments or main stakeholders are involved?
3. Who is responsible for generating or managing groundwater-related data?

This participatory format allowed cross-city validation of selected issues, promoted mutual learning, and laid the foundation for stakeholder mapping.

This step was followed by a stakeholder mapping exercise, which clarified the operational, regulatory, and data-related responsibilities of each department. The resulting overview served as a foundation for conducting targeted interviews, developing governance flow charts, and generating comparative institutional insights across the Alpine region.

Reference: D1.1.1 - ANNEX II - Interview general template

4.2 Step 2 – Data Analysis

The data analysis step **focuses specifically on porous aquifer systems**, which constitute the primary groundwater resource in Alpine valley cities. While the Alpine region also contains fractured bedrock and karst aquifers, the methodology targets porous valley-fill aquifers due to their prevalence in major Alpine settlements, their role as the backbone of urban water supply systems, and their high susceptibility to overexploitation pressure from intensive urban development. The following data requirements and assessment criteria are therefore tailored to the characteristics and management needs of porous aquifer systems.

4.2.1 Analysis of data availability

Next step is to analyse the data availability. Data sources that have proven to provide relevant data sets were municipal portals, state portals, internal data from authorities, academic publications, and industry reports.

In MARGIN the datasets were identified from previous internal knowledge and after specific interviews with the stakeholders involved. The stakeholder questionnaire already indicates some information about available data sets. However, a more detailed metadata list is recommended to be set-up, following the example of the first table included in the pilot city chapters (see **Fehler! Verweisquelle konnte nicht gefunden werden.**, **Fehler! Verweisquelle konnte nicht gefunden werden.**, **Fehler! Verweisquelle konnte nicht gefunden werden.**).

For each dataset, it is recommended to record the following attributes:

- Name and access link (if available)
- Short content description of dataset
- Responsible institution or department
- Data format and structure (digital, analog, raster, point, etc.)
- Update frequency and temporal coverage
- Accessibility (public, internal, restricted)
- Existing documentation or references

This step allows the identification of gaps in data availability, quality, format and ownership.

The following datasets have been identified as essential:

Hydrogeology

- Groundwater level time series (observation wells)
- Groundwater level (contours or raster)
- Base of the aquifer (raster)
- Borehole profiles
- Groundwater recharge (raster)
- Hydraulic conductivity (observation wells or raster)

Infrastructure

- Sewage system
- District heating system

Urban underground infrastructure such as tunnels, garages, metro lines and building basements (etc).

Climatology

- Climate change scenarios
- Climate data as precipitation, data needed to assess evapotranspiration, and groundwater recharge

Surface Information

- Surface sealing
- Digital elevation model

Groundwater Use

- Existing groundwater abstractions
- Existing groundwater use for heating and cooling
- Existing groundwater infiltration locations

Groundwater Quality and Ecosystems

- Groundwater temperature time series (observation wells)
- Groundwater chemistry samples (observation wells)
- Groundwater microbiology samples (observation wells)
- Groundwater fauna samples (observation wells)

4.2.2 Identification of data gaps

After all data has been described, their availability and quality can be assessed. **Data availability** focuses on whether data can be obtained and accessed, while **data quality** evaluates whether the available data are fit for use.

Data availability can be evaluated against the following criteria:

- **Ownership** - whether the responsibility for the dataset is clearly defined or fragmented across institutions
- **Digital availability** - whether the data is accessible in usable digital formats)
- **General accessibility** - whether data can be obtained when needed, recognizing that restrictions may arise not only from legal or security concerns but also from institutional policies or companies withholding information

Data quality aspects to be considered are:

- **Completeness** - whether the records are full or partial
- **Accuracy** – whether the measurement precision, calibration, errors ensure sufficient accuracy

- **Consistency** – whether the same methods over time and across institutions are used
- **Temporal resolution** - how often the data is updated and whether this is timely enough
- **Spatial resolution and coverage** – whether there are enough observation points or is it too patchy
- **Standardization** – whether formats, units and metadata are harmonized

The results of this assessment go into the final relevance ranking of the different topics.

4.3 Step 3 – Governance workflow analysis

The governance workflow analysis examines **how city departments/main stakeholders manage groundwater-related topics** focusing on specific planning and installing processes related to groundwater management (e.g. rainwater infiltration measures, groundwater-based heating systems, groundwater extremes). Both data governance and institutional coordination should be looked at. The aim is to identify strengths, gaps, and overlaps in governance systems, enabling cities to move towards more integrated and climate-resilient groundwater management.

This step investigates:

- How departments cooperate (or fail to cooperate) on groundwater-relevant topics
- What data is generated, shared, or siloed between institutions
- Where responsibilities overlap or remain unclear
- Which governance gaps limit effective action

4.3.1 Governance process mapping

Governance process mapping is the **analytical reconstruction of how specific groundwater-related procedures are carried out** in practice. For each city, selected workflows can be mapped step-by-step to document:

- Tasks and responsibilities at each stage of the process
- Involved departments, authorities, or private stakeholders
- Required data and information inputs
- Legal or procedural references
- Interactions and handovers between actors

This makes it possible to identify departmental isolation, missing links, unclear mandates, and coordination challenges that hinder effective groundwater management.

4.3.2 Visual representation of governance processes

The visual representation translates the reconstructed workflows into interdepartmental flow charts. These diagrams are designed to:

- Show the chronological sequence of planning and implementation steps
- Clarify departmental responsibilities at each stage
- Highlight points of interaction and data exchange between actors

Visualizations serve both as an **analytical tool** (to spot bottlenecks and redundancies) and as a **communication tool** (to present complex governance arrangements in a clear and accessible format).

4.3.3 Identification of governance gaps

In addition to data-related gaps, weaknesses in governance structures can also hinder effective groundwater suitability management. The assessment considers several aspects:

- **Clarity of mandates and responsibilities** – whether roles are clearly defined or overlapping, creating inefficiencies or unclear leadership
- **Legal and procedural alignment** – whether regulations and permitting procedures are consistent or contradictory
- **Inter-departmental cooperation and visibility** – whether departments coordinate effectively, share information, and hand over responsibilities smoothly, or work in isolation
- **Stakeholder participation and transparency** – whether external stakeholders (e.g. utilities, industry, NGOs, citizens) are systematically involved and whether decision-making processes are open and comprehensible
- **Institutional capacity and resources** – whether authorities have sufficient staff, expertise, and financial means to carry out their responsibilities
- **Integration into broader planning** – whether groundwater management is embedded in related areas such as spatial planning, climate adaptation, and infrastructure development

This helps to reveal missing links, weak cooperation, or redundant functions that undermine integrated groundwater governance. The results are integrated into the final relevance ranking of the different topics.

4.4 Step 4 – Identification of relevant topics

The final step of the methodology is to determine which groundwater-related topics deserve deeper investigation within each city. It **integrates the results from the previous steps** - stakeholder engagement, data availability and quality analysis, and governance workflow analysis - into one single evaluation.

4.4.1 Relevance scoring approach

Each topic is assigned a **relevance score of high (1), medium (2), or low (3).** The chosen three-level relevance scoring system represents a deliberately pragmatic approach that prioritizes applicability and transparency. While more sophisticated quantitative assessment methods would be theoretically desirable, a balanced compromise between methodological rigor and practical feasibility is required. Nevertheless, the triangulation of structured stakeholder surveys, expert interviews, and data analysis, combined with transparent documentation of the assessment rationale, ensures a comprehensible and valid evaluation. Future applications of this methodology can build upon this foundation to develop more refined assessment systems.

The scoring is guided by three considerations:

- **Stakeholder perspectives** – topics identified as urgent or important by local actors are weighted higher.
- **Data gaps** – topics with significant shortcomings in availability, accessibility, or quality of datasets receive higher relevance.
- **Governance gaps** – topics where unclear mandates, weak cooperation, or insufficient capacity limit effective management are prioritized.

4.4.2 Documentation and validation

The assessment process ensures transparency and validity through:

- **Multiple information sources** - The evaluation considers evidence from stakeholder questionnaires (quantified relevance assessments), expert interviews (qualitative validation), and objective data gap analysis.
- **Expert judgment validation** - Final assessments are conducted by local experts with extensive practical experience in groundwater management.
- **Transparent documentation** - Each relevance score is accompanied by a detailed justification that summarizes the key evidence and rationale.
- **Cross-city validation** – The assessments are compared between cities to identify systematic patterns and potential inconsistencies.

4.4.3 Relevance Matrix

The outcome is summarized in a relevance matrix, where **each topic is listed alongside its score and a short justification or description**. This explanation can highlight the most pressing evidence (e.g. critical data or governance gaps) or provide a broader description of why the topic is relevant for groundwater sustainability in the city.

For the cities, this matrix provides a clear priority list for where limited resources should be directed first. It also enables comparisons between cities, as shown in the MARGIN project, highlighting which challenges are common to multiple Alpine cities and which are site-specific. In this way, the final assessment guides local follow-up activities and contributes directly to the development of overall guidelines and transferable recommendations that form the core output of MARGIN.

Table 1. Relevance matrix for groundwater sustainability related topics in Alpine cities

Topic	Relevance in the city	Remarks/known issues
Extreme high groundwater level	1, 2 or 3	e.g. frequent basement flooding in district x.
Extreme low groundwater level	1, 2 or 3	e.g. land subsidence occurred. Problems with operating wells due to low water level
Rainwater infiltration	1, 2 or 3	e.g. issues with rainwater infiltration
Thermal groundwater use – heat energy planning/interference with other systems	1, 2 or 3	e.g. increasing number of installations. No monitoring.
Groundwater temperature	1, 2 or 3	e.g. missing temperature data. Known groundwater hot-spots
Groundwater quality/ecology	1, 2 or 3	e.g. declining biodiversity. Lack of data for assessment.