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

# Deliverable 1.1.1

## Catalogue of current data handling practices

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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 cities' 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.

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Title: Catalogue of current data handling pratices

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Description: Catalogue of existing practices for data acquisition and management related to groundwater in pilot cities based on city factsheets, including general approach how to assess data situation in cities.

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# 1. Introduction

MARGIN's aim is to enable cities in the Alpine Space to manage groundwater sustainability, addressing the growing impacts of climate change and urbanization to foster city's climate-resilience. Linz, Ljubljana, Milan and Munich serve as pilot cities.

As a first step, the project assesses the data availability and how data is handeled currently in each pilot city. Additionally, the governance workflows related to the groundwater sustainability management were analyzed. This assessment followed a general and transferable approach, that was improved with the experiences made in the pilot cities.

This report describes the developed methodology (Chapter 2) and presents the assessment in the pilot cities (Chapter 3). The results are compared across the pilot cities in Chapter 4. Short versions of the pilot city assessments are described in city-wide fact sheets (see Output O1.1).

To complete the analysis of the current situation of the groundwater management in the pilot cities, the reports D1.2.1 "Catalogue of current strategies and measures "and D1.3.1 "Catalogue of current regulations "describe existing strategies and measures, as well as regulations related to groundwater management. These outcomes are also summarized in the city-wide fact sheets. The Output 1.1 "Catalogue of fact sheets for the current state of groundwater management in Alpine cities" compiles all the fact sheets.

The resulting materials of the assessments in the pilot areas are designed to provide a foundation for follow-up activites in the pilot areas themselves and to support other Alpine Space cities in understanding their current data and governance situation. The follow-up activities in MARGIN include improved potential and 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, which will be described in the final "Gamebook" (report D3.3.1).

Within the overarching theme of "groundwater sustainability management in the light of climate change and urbanization" MARGIN focuses on four key topics including the below indicated subtopics:

**Groundwater extremes**: Includes the subtopic of **risks of flooding cellars and flooding of terrain due to extreme high levels**. Urbanization characterized by extensive impervious surface coverage significantly reduces natural infiltration capacity, potentially resulting in localized groundwater mounding where concentrated recharge occurs. Climate Change influences precipitation intenisty and pattern which changes also the pattern and intensity of groundwater recharge. Regarding **extreme low levels**, **negative influence on existing installations, utilizations and potential land subsidence** is considered. Droughts, higher average temperatures with increased evaporation, and reduced infiltration due to increased runoff at intense precipitation events, can reduce groundwater recharge. Rising urban water demand or implemented infrastructure/construction elements in the groundwater body can locally lower the groundwater levels as well.

**Rainwater infiltration**: Climate change affects rainfall patterns, often resulting in more intense but shorter precipitation events, which are less effective for infiltration. Urbanization increases surface sealing, which prevents natural infiltration and strongly increases surface runoff. As a result groundwater recharge can be reduced, whereas stress on sewage system can be increased.

**Thermal use of groundwater**: Includes the subtopics of assess the potenial for an optimal and sustainable use to integrate it in heat energy planning for contributing to cities heat transition and to cities climate goals. Additionally, the subtopics of **decreasing or increasing groundwater temperatures, and interference with other groundwater uses** are addressed. In the context of climate change, the need for sustainable heating and cooling sources raises rapidly. This is generally the case in dense urban areas, and more so in the Alpine space, with its limited surface and subsurface space in the valleys. Groundwater use for heating and cooling relies on stable groundwater conditions, as well as other uses of groundwater (e.g. for drinking water, industrial purposes or irrigation) do, which puts pressure on the same resource. Predominante cooling with groundwater, as well as the underground urban heat island effect can also increase groundwater temperatures to a point where cooling with groundwater becomes inefficient.

**Ecosystem health including groundwater temperature and quality:** Groundwater chemistry and temperature are critical determinants of ecosystem health, directly influencing biodiversity and ecological functions within aquatic systems. Chemical parameters like dissolved oxygen, pH, and nutrient concentrations create environmental conditions that support diverse microbial communities and specialized groundwater fauna. Changes in groundwater chemistry can significantly reduce biodiversity and alter microbial activity, compromising ecosystem services including water purification and natural contaminant attenuation. Groundwater temperature can act as one of the key regulators of biological processes.

## Motivation

While robust data collection is an essential pillar of groundwater sustainability management, its full value emerges when supported by the governance systems that give it meaning and direction. Effective decision-making - whether for assessing groundwater potentials and risks or for designing targeted mitigation measures - depends on the combination of well-maintained datasets and clear, coordinated institutional processes that ensure this information is gathered, shared, and applied in a timely and impactful way.

From the outset of the MARGIN project, it became clear that technical data issues cannot be separated from governance realities. Experiences in earlier studies and projects showed the following recurring barriers to effective groundwater:

**Incoherent data infrastructure** – Information is scattered across multiple authorities, departments, service organisations, and private companies, with no single point of integration.

**Limited digitalisation** – Important datasets remain undigitised or not machine-readable, restricting their use in modern analytical and management tools.

**Communication gaps** – Municipalities frequently lack comprehensive knowledge regarding the existence and location of relevant data across different internal and external institutional levels, significantly constraining opportunities for collaborative analysis and evidence-based decision-making. This challenge extends beyond the municipal level to encompass state and federal institutions, creating systemic barriers to effective intergovernmental coordination and data utilization

**Data privacy and sharing restrictions** – Private sector organizations may understandably maintain reservations about sharing information due to valid legal, commercial, and institutional considerations, though such constraints may limit the data resources available for effective public groundwater management

These issues are not only technical. They are symptoms of how governance processes operate. The way municipal departments and institutions interact by defining roles, coordinating tasks, sharing data, and making decisions fundamentally determines the accessibility, reliability, and usability of groundwater information. Across the MARGIN cities, several governance challenges were known from the beginning:

**Lack of clear role allocation** – Fragmented or overlapping responsibilities lead to inefficiencies and conflicting approaches.

**Limited interdepartmental cooperation** – Weak or absent mechanisms for structured collaboration, data sharing, and joint decision-making.

**Siloed data management** – Valuable datasets confined within individual departments limit cross-sectoral integration and holistic planning.

**Missing formal procedures** – No standardised process for collecting, updating, sharing, and applying groundwater data across departments.

Recognizing this, the MARGIN project conducted a detailed analysis of governance processes behind groundwater data management. This **governance analysis** includes mapping institutional responsibilities, data flows between the involved parties, interdepartmental interactions, and licensing processes, with the goal to identify opportunities for better coordination and to provide a foundation for transferring good practices across cities.

This dual approach of combining technical data assessment with governance analysis allows for a more comprehensive understanding of how to improve groundwater sustainability through both better data and better collaboration.

# 2. General assessment approach

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.

## 2.1 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.

### 2.1.1 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

### 2.1.2 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: ANNEX I-** Questionnaire

### 2.1.3 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: ANNEX II -** Interview general template

## 2.2 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.

### 2.2.1 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 Table 2, Table 4, Table 9).

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)

### 2.2.2 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.

## 2.3 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

### 2.3.1 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.

### 2.3.2. 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).

### 2.3.3. 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.

## 2.4 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.

### 2.4.1 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.

## 2.4.2 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.

## 2.4.2 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. |

# 3. Pilot city assessment

This chapter describes the data handling and governance workflows of all pilot cities, including a pilot specific description of the methodology used for the assessment. The assessment was done individually in the pilot areas, but followed a joint approach, which is described in chapter 3. The tools used in all pilot cities to address the stakeholders for the assessment were an online questionnaire and expert interviews (see templates in Annex I- Annex III). The fact sheets of Output O1.1 provide an overview of the whole pilot city status, including a summary of this report and additional information on their hydrogeology, strategies and measures, and regulations related to groundwater sustainability management.

## 3.1 Pilot city assessment - Linz

### 3.1.1 Methodology - Linz

The methodology applied in Linz followed the general approach outlined in chapter 3. These methodical steps were designed to capture not only the availability and accessibility of data, but also the governance structures behind how this data is generated, shared, and used in decision-making processes. The approach was applied systematically across all participating cities. The following section presents the relevant stakeholders in Linz, who were invited to complete the questionnaire and with whom meetings were conducted.

### 3.1.2 Stakeholders - Linz

The following stakeholder groups were identified as relevant for Linz:

- Authorities
- Companies with full or partial public ownership
- Civil engineering bureaus
- Industry

- National institutions

**Note:** To improve readability, most German stakeholder names have been freely translated into English as official translations are missing.

### *Authorities*

The most relevant authorities for Linz are the Magistrat der Stadt Linz (Municipality Authority of Linz) on municipal level and the Amt der Oberösterreichischen Landesregierung (State Government of Upper Austria) on the state level.

A general overview of the governmental structure of the **Municipal Authority of Linz** can be found at https://www.linz.at/verwaltung/6252.php. Regarding groundwater sustainability management, the following two divisions play a significant role, for their internal structure see Figure 1.

- **Planung, Technik und Umwelt** (Planning, Engineering and Environment - PTU), with the Abteilung Wasserwirtschaft (Water Management department - LINZ-WW) as the key authority in this area. **Linz-WW** sees itself as the "guardian" of the city's water bodies. Its responsibilities include groundwater and surface water protection, and technical consultation for authorities, industry, and the public. Data collection through measurement campaigns plays, however, a minor role.

- **Bau- und Bezirksverwaltung** (Construction and District Administration division) (BBV) is responsible for a wide range of administrative tasks (e.g., urban planning and zoning, trade law, building law, road and forestry law) within the jurisdiction of the City of Linz, including procedures under the Austrian Water Rights Act (WRG). Responsibilities within BBV are geographically divided into three areas: North, Central, and South - with the South area also handling matters related to commercial activities.

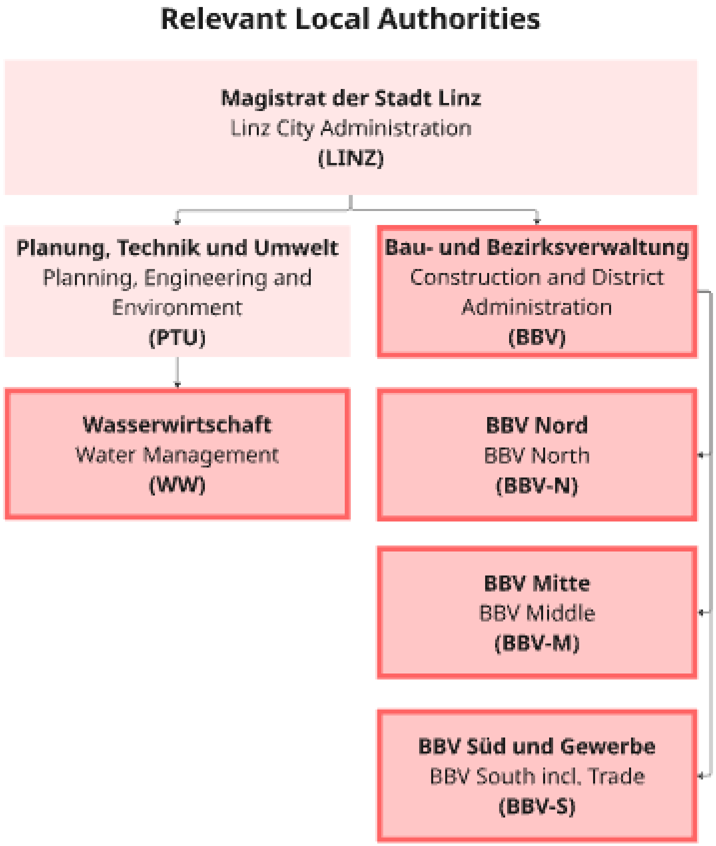


*Figure 1: Relevant departments for groundwater sustainability management of the Municipal Authority of Linz. The whole organization structure is available at https://www.linz.at/verwaltung/6252.php .*

In the **State Government of Upper Austria** (OÖ), all areas relevant for the topic of groundwater sustainability management can be found within the Directorate for Environment and Water Management (UWD). Here, the Department for Facility-, Environmental- and Water Law (AUWR) and the Department for Water Management (OÖ-WW) play the most important roles with their individual working groups. Figure 2 gives an overview of the relevant subunits. The whole governmental structure can be found at the homepage of the State Government (https://www.land-oberoesterreich.gv.at/default.htm).

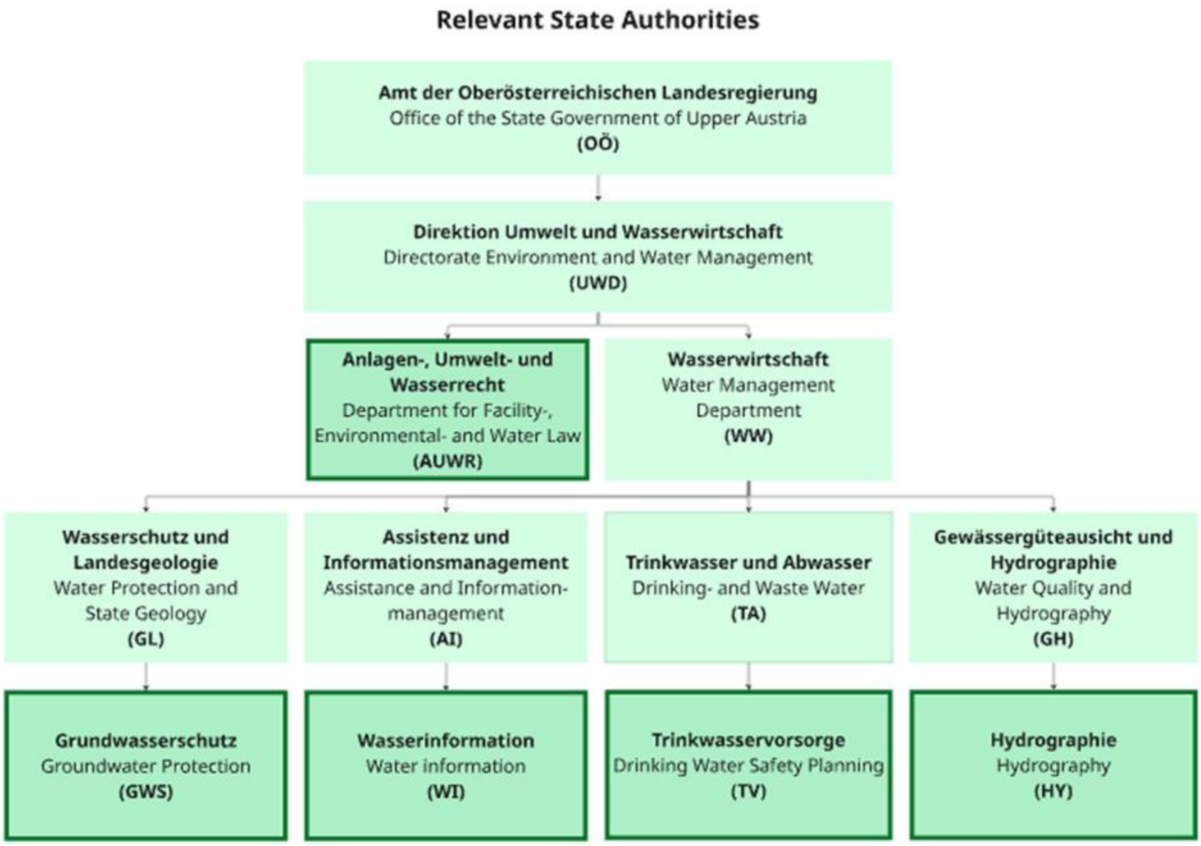


*Figure 2: Departments and subdivisions within the State Government of Upper Austria relevant to groundwater sustainability management. The whole governmental structure is available at https://www.land-oberoesterreich.gv.at/default.htm.*

The **Water Management Department** (OÖ-WW) is responsible for protecting and managing the state's water resources. This includes monitoring and improving the quality of surface and groundwater, ensuring safe and sustainable drinking water supply, and overseeing water-related infrastructure projects. Furthermore, it collects and analyzes hydrological data to support long-term water resource planning and climate adaptation strategies.

Most project-relevant sub-units of OÖ-WW are:

- Groundwater Protection (OÖ-GWS)
- Water Information (responsible for the Wasserinformationsystem (Water Information System) (WIS)) (OÖ-WI)
- Drinking Water Safety Planning (OÖ-TV)

- Hydrography (Measures relevant parameters of the water cycle like precipitation, runoff, groundwater levels) (OÖ-HY)

The **Department for Facility-, Environmental- and Water Law (AUWR)** is responsible for the legal and administrative implementation of environmental, facility, and water-related regulations. Regarding water law, AUWR oversees permitting procedures and coordinates inspections and investigations of water bodies, enforcing legal obligations related to environmental protection.

### *Companies with full or partial public ownership*

**VERBUND – Austrian Hydro Power AG (VHP)** is Austria's leading electricity company, producing electricity from hydropower. In the Linz area it operates two power plants on Danube. One of them - Abwinden-Asten - has a direct influence on the groundwater body in Linz. The groundwater conditions in Linz are determined by the backwater from the Abwinden-Asten Danube power plant as well as by the sealing and drainage systems running alongside the Danube. The powerplant provides also flood protection for Linz through backwater dams along the Danube banks and the Traun River, which flows into the Danube's impoundment area upstream of the plant. To monitor the impact on groundwater, VERBUND AG maintains several monitoring stations along the Danube.

**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. As the water supplier for the City of Linz and 25 surrounding municipalities, the company manages three water protection areas within the city and conducts over 2,000 water analyses annually in both groundwater and the water supply system.

### *Civil engineering bureaus*

Several engineering offices are located 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).

***National institutions***

In addition to public institutions at the municipal and state level, there are stakeholders at the federal level. Primarily, these support the state level in the development of measurement campaigns and compile and provide data at the federal level.

**Umweltbundesamt (Environment Agency Austria) (UBA)** operates as the federal authority responsible for data management, standardization, and evaluation of the national groundwater quality network, working closely with the Federal Ministry of Agriculture and Forestry and nine provincial authorities. The agency manages over 2,000 monitoring sites across Austria, providing quality-assured data for policy decisions and ensuring compliance with EU Water Framework Directive requirements for maintaining good groundwater status.

**Hydrographisches Zentralbüro (Hydrographic Central Bureau of Austria) (HZB)** is the national hydrographic service, operating a nationwide network of observation stations to collect, analyze and publish data on the water circle (e.g. surface- and groundwater). HZB coordinates uniform data collection protocols, quality assurance, data analysis, and the publication of hydrographic information at the federal level. HZB receives the data via HyDaMs (see below) from the federal states and conducts a final review and incorporates the officially valid data into the Hydrographic Yearbook and the publicly available ehyd platform (see below).

### 3.1.3 Data handling and inventory - Linz

***Data availability and handling - Linz***

The following data bases are the most relevant for Linz. Various sources provide groundwater related data. Publicly accessible information, like groundwater chemistry and temperature at specific sites, can be found at H2O Fachdatenbank - Startseite, eHYD – der Zugang zu hydrographischen Daten Österreichs and DORIS (DORIS interMAP - Wasser & Geologie). Other parameters are restricted to the stakeholders responsible for them.

The **Wasserbuch (Water Book) (WB)** is a public register where all licensed water usages are documented (comparable to the land register). Its primary purpose is to record existing and newly granted water rights, and it is maintained by the provincial governor (respectively by the Department Water Information (WI) of the State Government of Upper Austria). For each facility, the Water Book contains relevant documents such as deeds, permits, plans, technical descriptions, etc. The detailed reports and plans are only available in paper and short excerpts with the most important properties of the water rights are stored in a digital database (WIS – see below). The digital information can be retrieved via WIS and the DORIS (official GIS of Upper Austria). The Water Book for the district of Linz Stadt is located at the Magistrate of the City of Linz in the New Town Hall.

The **Wasserinformationssystem (Water Information System) (WIS)** is a database operated by the Department Water Information (WI) of the State Government of Upper Austria. It offers structured access to water usage rights and water-related data (e.g., measurement stations, groundwater- and surface water, protection areas, water facilities). It can be accessed via the publicly available web portal DORIS (geographic information system) (https://www.doris.at/themen/umwelt/wasser.aspx). However, this publicly available information is limited compared to internal use.

The **H2O Fachdatenbank (H2O database) (H2Odb)** is a public database which contains a multitude of groundwater quality parameters. It is operated by UBA and mainly used for groundwater quality monitoring in Austrian groundwater bodies. Most of the data is a product of the GZÜV (Water Quality Monitoring Ordinance) measuring program and the goal of the database is to draw conclusions about the natural state of the groundwater and possible changes caused by nutrient inputs or chemical pollutants. The database allows customized requests with different parameters and measuring sites. It can be found at https://wasser.umweltbundesamt.at/h2odb/index.xhtml .

The UBA also conducts various special monitoring programs as part of the GZÜV to investigate environmental pollutants not covered in standard monitoring, for example pharmaceutical active substances, antibiotics and mercury in groundwater. This information is included in the H2O database and also publicly accessible.

Austria's hydrographic services – one for each federal state, plus viadonau, which is responsible for the Danube River – operate the publicly available database **eHYD (Elektronische Hydrographische Daten) (Electronic Hydrographic Data).** The legal basis for this database is provided by the Austrian Water Rights Act of 1959 and the Environmental Information Act, which mandate that measurement data and evaluations collected by public authorities be made freely available to the public.

This is implemented through the eHYD web platform. eHYD provides an interactive map of Austria, offering online access to hydrologically relevant parameters such as precipitation, groundwater levels, and river discharge. According to the eHYD website (https://ehyd.gv.at/), data from approximately 9,600 monitoring stations are currently available.

All data collected by the state's hydrographic services is managed using the unified **Hydrographic Data Management System (HyDaMS)**. This system encompasses data acquisition, quality control and analytical tools (for example extreme value statistics). It enables data access through a simple user interface, provides many hydrologically relevant functionalities for time series, and allows modular expansion with additional analysis tools. The data model essentially comprises master data and time series, with the master data being stored in a relational database. HyDaMS is not publicly accessible and remains a working tool exclusively for the hydrographic service and the HZB.

The **DORIS** (Digitales Oberösterreichisches Raum-Informations-System) platform serves as the geographic information system of Upper Austria, offering online access to a wide range of geographic base maps and expert thematic data such as water and geology. A wide range of groundwater-related information like groundwater layers and barrier maps, water usage rights (via the Wasserbuch), protection areas and hydro-geological data from the WIS database can be queried and visualized via the integrated WebGIS application. Accompanying data can be downloaded in the form of .zip-files. The DORIS and all of its information is available to the public.

### *Data inventory - Linz*

*Table 2. Available data sets – Linz*

| Parameter | Data set/data base, online-link | Short description | Status | Time | Data format | Publicly available | Responsible Organisation |
|---|---|---|---|---|---|---|---|
| General parameter | Name of the dataset or database and online-link (if applicable) | Short description about content of the data set | Is data updated regularly or not | Time period covered or date of creation | Point, polygon, raster, PDF, analog | | Organization/Department responsible for the data |
| **Location of groundwater monitoring points** | BAA_VHP_Beo_Stammdaten_mit_Zugangsinfo.xlsx<br>BAA_Linz_AG_Stammdaten.xlsx | List of measuring points observed by VHP & Linz AG | static | Transmitted January 2025 | Excel file with coordinates | No | VHP |
| | Mest_Quant_aktiv.shp<br>Mest_Quant_inaktiv.shp | List of active and inactive measuring points in Upper Austria | static | Transmitted November 2024 | Point data | No | OÖ-WW |
| | Messstellen_fuer_LinzAG.gpkg | List of measuring points from the company G.U.T. | static | Transmitted March 2025 | Point data | No | GUT Gruppe Umwelt + Technik GmbH |
| | LAGSonden.shp | List of the measuring points of LINZ AG | updated | Transmitted March 2025 | Point data | No | LINZ AG WASSER |
| | LINZ AG-WASSERMST-Stammdaten_2003 bis 02-2023_MAL_20231004.xlsx | List of measuring points from ASFINAG | static | 2003 - 2023 | Excel file with coordinates | No | Blp GeoServices GmbH & Forstinger, ASFINAG |
| | GZÜV_MSt_Linz.xlsx<br>GZÜV Messnetz Grundwasser - Datensatz - Open Government Data Austria | GZÜV measurement points | static | Created March 2025 | Excel file with coordinates | Yes | BMLUK |
| | HZB_Stammdaten.shp | Measuring points from HZB | static | Transmitted March 2025 | Point data | No | HZB |
| **Groundwater temperature** | GWT-Daten.csv | Groundwater temperature data, 14 measuring points | static | 1992 – 2024 (varies inside dataset) | Csv files | No | OÖ-AA |
| | BAA_VHP_Temp_Daten.txt | Groundwater temperature data, 12 measuring points | static | 2001 – 2025 (2 points)<br>2023 – 2025 (10 points) | Txt files | No | VHP |
| | VerbundLeymüller_ASFINAG A26.csv | Groundwater temperature data, 242 measuring points | static | 2003 – 2023 (varies inside dataset) | Csv files | No | Blp GeoServices GmbH & Forstinger, ASFINAG |
| | ehyd_Messstellen_einzeln<br>eHYD – der Zugang zu hydrographischen Daten Österreichs | Groundwater temperature data, 12 measuring points | Updated (ehyd) | 1992 – 2022 (varies inside dataset) | Csv files | Yes | BMLUK |
| **Groundwater chemistry** | GZUEV_MST_GW-Chem_MARGIN.shp<br>H2O_Qualitätsdatenabfrage_GW-Chem.xlsx<br>H2O Fachdatenbank - Qualitätsdatenabfrage Öffentlich | Groundwater depth, conductivity, oxygen, Cl2 | Updated (H2O-db) | 1992 - 2024 | Point data Excel file | Yes | OÖ-WW |
| | Anlage 5.3_A26_GW_Chemie_tabellarisch_1_2023.xlsx | Groundwater chemistry data, 65 measuring points | static | 2009 - 2013 | Excel file | No | Blp GeoServices GmbH & Forstinger, ASFINAG |
| | GW_BEOBACHTUNGSGEBIET.shp<br>https://e- | GW chemical status criteria, pollutant threshold and regulations | updated | 2007, updated 2025 | Shapefile | Yes (DORIS) | OÖ-WW |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | gov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/GW_BEOBACHTUNGSGEBIET.zip | | | | | | |
| **Groundwater level** | 202x_Abstichmessungen, Quartalssonden_Heilham/Plesching/Scharlinz_20xx | Groundwater levels in the water protection areas | updated | Since 2018 | Excel files | No | LINZ AG WASSER |
| | LINZ AGGW_SCHICHTENLINIEN.shp | contour lines of equal groundwater elevation from various projects | updated annually | Since 2008 | Shapefile | No | OÖ-WW |
| | GW_HOECHSTSTAENDE_HGW_100_5M.shp https://e-gov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/GW_HOECHSTSTAENDE_HGW_100_5M.zip | extreme HGW100 groundwater levels | static, updated if needed | 2025 | Shapefile | Yes (DORIS) | OÖ-WW |
| **Groundwater bodies** | GRUNDWASSERVORRANGFLAECHEN.shp https://e-gov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/GRUNDWASSERVORRANGFLAECHEN.zip | priority groundwater areas for securing drinking water supply | updated | Since 2022 | Shapefile | Yes (DORIS) | OÖ-WW |
| | GW_VORKOMMEN.shp https://egov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/GW_VORKOMMEN.zip | grundwater resources (first horizon) | static | 2004 | Shapefile | Yes (DORIS) | OÖ-WW |
| | OBFL_GWKOERPER_WRRL.shp https://egov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/OBFL_GWKOERPER_WRRL.zip | delineation of shallow groundwater bodies | unknown | 2007, updated 2021 | Shapefile | Yes (DORIS) | OÖ-WW |
| | TIEF_KOERPER.shp https://e-gov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/GW_HOECHSTSTAENDE_HGW_100_5M.zip | Deeper GW bodies in Upper Austria, especially horizons in tertiary sands | static | 2013, updated 2017 | Shapefile | Yes (DORIS) | OÖ-WW |
| **Confined aquifer** | GW_GESPANNT_GEM_WRG.shp https://egov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/GW_GESPANNT_GEM_WRG.zip | areas with confined groundwater according to §31c (5) WRG | updated annually | Since 2011 | Shapefile | Yes (DORIS) | OÖ-WW |
| **Upper boundary of confining layer** | SCHLIERRELIEFPLAN.shp https://e-gov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/SCHLIERRELIEFPLAN.zip | Layer boundaries of the top of the upper groundwater confined layer | static | Since 2009, updated 2016 | Shapefile | Yes (DORIS) | OÖ-WW |
| **Borehole heat exchangers** | ERDWAERMESONDEN.shp https://egov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/ERDWAERMESONDEN.zip | legally approved geothermal heat pumps | static | 2011, updated 2024 | Shapefile | Yes (DORIS) | OÖ-WW |
| **Groundwater usage** | WISMAP_WASSERBUCH.shp https://e-gov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/WISMAP_WASSERBUCH.zip | installations approved under water law | Updated continously | Since 2009 | Shapefile | Yes (DORIS) | OÖ-WW |
| **Boreholes** | WISMAP_GEOLOGIS_BOHRPUNKTE.shp https://egov.ooe.gv.at/at.gv.ooe.dorisdaten/DORIS_U/WISMAP_GEOLOGIS_BOHRPUNKTE.zip | drillings from various sources; reasons for drilling vary | unknown | 2001, updated 2018 | Shapefile | Yes (DORIS) | OÖ-WW |

## 3.1.4 Governance analysis - Linz

This section describes the currently in place governance workflows of the topics thermal use of groundwater, groundwater levels, and groundwater quality and ecosystem management. For the other topics, no such governance workflows could be identified.

### *Thermal use of groundwater*

The approval of a new groundwater heat pump in Linz is either granted by LINV_BBV or by OÖ-AUWR. The responsibility depends on the planned water extraction rate, with systems up to 5 l/s to be approved by the Municipal Authority of Linz and above 5 l/s to be approved by the State Government of Upper Austria. The approval process is very similar at both authorities. Regarding acquisition, availability and storage of data, however, differences were detected between both authorities.

If a new groundwater heat pump is to be installed and therefore also granted a water right, a civil engineering bureau prepares the necessary submission documents. The basis for this is often data from the WIS (existing water rights, groundwater-relevant parameters such as flow direction, gradient, etc.).

The State Government of Upper Austria issued the information sheet "Grundwasser-Wärmepumpen bis 5 l/s" in 2006, which indicates the required content of the submission documents. It can be downloaded at the following link: https://www.land-oberoesterreich.gv.at/Mediendateien/Formulare/Dokumente_BH_VB/GWP_bis5l.pdf

This document also includes potential reasons for rejecting new systems.

These include:

- Thermal impacts of the planned system on a water protection area (Zone I or II)
- Thermal impacts on drinking water wells or springs that do not require approval
- The use of confined groundwater
- Negative impacts on existing water rights

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. Then the competent authority (OÖ-AUWR or LINZ-BBV) reviews the documents for jurisdiction and completeness, and subsequently forwards it to the responsible experts (OÖ-GWS respectively LINZ-WW).

For this purpose, they can refer to the WIS. Experts from OÖ-GWS have access to the full content of the WIS, while experts from LINZ-WW only have standard access to it.

Furthermore, to analyze whether third-party rights are affected, the experts use the OWAV Rule Sheet 207: Thermal Use of Groundwater and Subsurface – Heating and Cooling (Link: https://www.oewav.at/Page.aspx?target=196960&mode=form&app=134598&edit=0&current=293648&view=205658&predefQuery=-1). The thermal plume expansion (width, length, direction) calculated using this guideline can then be used to assess whether third-party rights are being impacted. However, there is no continuously updated thermal plume map available that could be used to check when new installations are planned. A comprehensive overview of the existing approved thermal fronts is lacking.

If the installation is approved (regardless of whether by LINZ or OÖ) a permit is issued to grant the water right and after the procedure is completed, ÖÖ-WI enters the new installation into the Water Book by. Furthermore, all analog documents (certificates, plans, technical reports) are archived in the new town hall. Since the archive is located right next to the offices of LINZ-WW, they have the advantage of gaining quick and unbureaucratic access to detailed analog information.

Responsibility for the archive, however, lies with OÖ-WI, which also transfers the most relevant water management data into the WIS, where Linz-WW only has standard access. 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.

### *Groundwater level*

Concerning groundwater levels, data generally comes from mostly two sources, either **construction projects** or **monitoring systems**.

During **construction projects**, or other projects that require a groundwater level monitoring, civil engineering bureaus collect the groundwater level data. If relevant, this data is incorporated later into the publicly available WIS dataset (see GW_SCHICHTENLINIEN.shp in Table 2).

The OÖ-HY is responsible for the **groundwater monitoring system** on state level. Operational activities at the measuring stations are performed by the state-level hydrographic units, which also supervise and coordinate the work of local observers and field staff.

The regular data collection of groundwater level in Linz can be divided into three technical categories:

- **Measurement Stations with Remote Transmission:**
  Data from several monitoring stations of Upper Austria (2 in Linz) are transmitted remotely via General Packet Radio Service (GPRS) and published at the homepage of hydrographic services (https://hydro.ooe.gv.at/#/overview/Grundwasserstand?filter=%7B%7D). It is planned to install more stations.
- **Automated groundwater monitoring with data loggers** using continuous pressure probes with temperature sensors or float-encoder systems, employing data collectors with modems for direct transmission to hydrographic services with quarterly maintenance checks and comparison against manual measurement control values. The hydrographic service is responsible.
- **Weekly manual groundwater monitoring is** mainly organized by Verbund (hydro power company) with bi-annual quality checks by hydrographic service staff and monthly data transmission for digital recording and error verification.

All data is managed using the unified Hydrographic Data Management System (HyDaMS). A monthly characterization of groundwater is published on the website of the OÖ-HY (https://hydro.ooe.gv.at/#/Startseite). This provides a current overview of the general groundwater situation.

HyDaMS provides embedded extreme statistical tools to derive **extreme values** (e.g. extreme – high – groundwater levels) for each monitoring point with at least 10 years of groundwater monitoring. The GeoSphere Austria is currently involved in producing high groundwater level maps based on extreme values derived from HyDaMS. Outcomes are made available to other stakeholders like OÖ-WW, using for example the HGW100 dataset for its WIS, furtermore it is also planned to publish HGW100 maps in HORA (HORA - Natural Hazard Overview & Risk Assessment Austria).

### *Rainwater Infiltration*

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. Upper Austria's management guideline addresses this through requiring pre-treatment measures including soil filters for contaminated surface types. The governance system establishes clear hierarchies: technical filters for highly contaminated areas, soil filters for moderate contamination, and direct infiltration only for clean surface waters. The governance structure operates through hierarchical regulatory layers, beginning with federal standards and cascading to municipal implementation. ÖWAV Rule Sheets 45 and 35 establish the technical foundation by defining state-of-the-art infiltration practices and surface water discharge protocols. These regulations prioritize infiltration over discharge, mandating that surface water discharge only occurs when infiltration is "not possible or not permissible".

## *Ground water quality and ecosystem*

Several organisations monitor the groundwater quality in Linz. For all organisations and their responsibilities, see Figure 3. The monitoring frequency, the area covered, and the parameters examined vary according to the organization. A differentiation must be made between **regular groundwater quality monitoring** and **special parameter- or event-related monitoring**.

### Groundwater quality

The groundwater quality **at 38 GZÜV sites** across the pilot area is regularly monitored. The BMLUK oversees the GZÜV-program while sampling is carried out by the state authority (OÖ-WW), with analyses done either in laboratories of OÖ-WW or at the UBA. Results are archived in the WISA database and the H2O Fachdatenbank (https://wasser.umweltbundesamt.at/h2odb/). Only selected data is public. Additionally, UBA publishes comprehensive annual groundwater quality reports for Austria that are fully accessible.

Within the **three water protection areas** of Scharlinz, Heilham, and Plesching, LINZ AG conducts regular monitoring at 60 measuring sites. The collected data is stored by LINZ AG and is generally not distributed to other parties. Of these sites, 24 are monitored as required by an administrative order from the regional authority, with analysis results provided to Verbund – Hydro Power AG.

Measuring sites on **industry company sites** are regularly monitored by the respective stakeholders (VOEST and chemistry park). However, the frequency and scope of this monitoring is not known. Data is likely stored internally and not shared with other organisations.

In addition to regular monitoring, **OÖ-WW** (department Grundwasserschutz) conducts samplings at selected areas and analysis is performed only for specific parameters. Those specific monitoring programs are arranged either when information about a new parameter relevant to groundwater quality emerges and/or might become relevant for certain regulations, when one or several parameters are suspected of causing potential harm to the groundwater quality or when it is required in the restoration of contaminated sites. OÖ-WW often commissions civil engineering bureaus (e.g. G.U.T. GmbH) to assist in these special monitoring programs. The resulting data is stored in the responsible departments (mostly OÖ-WW, department Gewässerschutz) and shared with UBA, who registers the data onto the WISA platform in the H2O database.

### Groundwater ecosystem health

Currently, there is no monitoring to assess the ecological status of groundwater in the pilot area of Linz, meaning that no data for groundwater fauna is available.

Microbiological-ecological variables, including Total Cell Count (TCC), internal ATP, and Dissolved Organic Matter (DOM), were measured during the GZÜV monitoring campaign 2019. Sampling was conducted by OÖ-WW at 24 sites located within the pilot area. Analysis of microbiological variables was carried out by the University of Vienna. The data for TCC and internal ATP is accessible via the H2O database.

| Governance analysis - Linz | Data Collection | Data analysis & storage | Data publication / sharing |
|---|---|---|---|
| Heating pumps | Civil engin. bureaus | OÖ-UWD, Civil engin. bureaus, LINZ-WW, (reduced) open access | digital: OÖ-UWD; hard copy: LINZ-WW |
| Groundwater level Monitoring | OÖ-HY | OÖ-HY, HZB | OÖ-HY, HZB |
| Published Groundwater level datasets | Civil engin. bureaus, Industry | WIS | WIS |
| Groundwater level datasets at institution level | LINZ-WW, LINZ AG WASSER, VHP | LINZ AG WASSER, VHP | None |
| Special data sets (extreme levels) | OÖ-HY | GeoSphere Austria, HZB | OÖ-GL, LINZ-WW |
| Ground water quality - regular monitoring | OÖ-WW, LINZ AG WASSER, Industry | OÖ-WW, UBA, LINZ AG WASSER, Industry | OÖ-WW, UBA → H2Odb, Industry, LINZ AG WASSER, VHP |
| Ground water quality - Special parameters | OÖ-WW, Civil engin. bureaus, LINZ AG WASSER | OÖ-WW, LINZ-WW, Civil engin. bureaus, LINZ AG WASSER | OÖ-WW, UBA → H2Odb, Civil engin. bureaus, LINZ AG WASSER |
| Ground water ecology | None | None | None |
| | TCC, DOM, ATP Analysis: OÖ-WW | OÖ-WW | UBA → H2Odb |

*Figure 3: All stakeholders involved in data collection, analysis/storage and publication of groundwater quality and ecology in Linz.*

## 3.1.5 Challenges and gaps - Linz

### *Thermal use of groundwater*

#### Data gaps

Digital information on **existing thermal groundwater installations** is scarce. Applications for new geothermal systems, both above and below 5 L/s, are still submitted in analogue form. Consequently, the Municipal Authority of Linz stores these records only in physical archives, making retrieval difficult. Digital storage is done later by the regional authority (WIS), but access is limited to the city authority and other stakeholders, and not all documents are digitally available.

The **installation data stored at the WIS is limited** to the location and licensed abstraction and reinjection rates. Essential parameters, such as the heat and cold production, monitoring data, well depth, and pumping test results, are missing. The GeoBOOST report D2.2 (2024, Brancher & Steiner) provides a useful template of parameters that could be included in a standardized installation database.

The absence of a comprehensive digital overview means existing installations cannot be incorporated into potential calculations. This reduces the accuracy of potential maps, which are fundamental for planning sustainable groundwater use. Although **high resolution groundwater temperatures maps** were produced in the early 2000s, they are now outdated. Updating these maps would be a good starting point for the calculation of **potential maps for the thermal use of groundwater**, which are currently lacking. Such tools, including existing installations, would provide the city authority with a good basis for sustainable and efficient groundwater use for heating and cooling.

#### Governance gaps

An **integrated thermal management of the groundwater**, aimed at efficient and sustainable use including heating and cooling, is currently lacking. Up-to-date groundwater potential maps that account for existing installations would represent the first step toward such a framework.

It is also important to know about **existing installations of thermal groundwater use**. Currently, collaboration between the two main authorities (Municipal Authority of Linz and the Federal State Government of Upper Austria) is hindered by analogue data transfer. This slows down updates to the digital registry of water rights (WIS), which remains incomplete until the next update. Establishing a direct digital transfer of application data, together with a shared and regularly updated installation database, would significantly improve data exchange between authorities. Such measures are essential for setting up an integrated groundwater management system, that supports sustainable and efficient use of groundwater resources.

## *Groundwater level*

### Data gaps

Although measurements are carried out regularly, using different methods, the **frequency of data update is low.** Publications by the Division I/3 – Water Management (HZB) are released only once per year. Because all data series undergo quality testing prior to publication, additional delays of up to several years are common. As a result, timely access to recent groundwater level information is limited, unless raw data are specifically requested.

Another gap concerns groundwater **high-level data. Spatial coverage is incomplete, and available records are outdated** in several areas. A detailed and regularly updated map of groundwater levels, including revised contour lines from new measurement campaigns would significantly improve the current situation.

### 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.

## *Rainwater Infiltration*

### Data gaps

In principle, the Water Quality Monitoring Ordinance (GZÜV) establishes the legal foundation for data collection, requiring standardized monitoring programs for both surface and groundwater. Furthermore, ÖNORM B 2506-3 establishes specific data requirements for infiltration system performance evaluation. The standard mandates comprehensive testing protocols including infiltration rate measurements, particle retention assessments, heavy metal removal efficiency for copper, lead, and zinc, and permeability monitoring under various loading conditions.

Based on the data inventory assessment, no specific datasets on rainwater infiltration have been identified, indicating a gap in data availability that undermines evidence-based decision-making for sustainable urban water management. This absence highlights the need to enhance data handling practices within a holistic urban planning approach, ensuring that stormwater infiltration monitoring, performance evaluation, and environmental impact assessments are systematically integrated into data management systems to support informed policy development and climate adaptation strategies.

### Governance gaps

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.

## *Groundwater quality and ecosystem health*

### 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.

### 3.1.6 Relevance - Linz

The results of the questionnaire conducted with 7 stakeholders (see chapter 2.1.1.) are shown as radar chart, indicating increasing relevance from 1 to 5 (Figure 4).

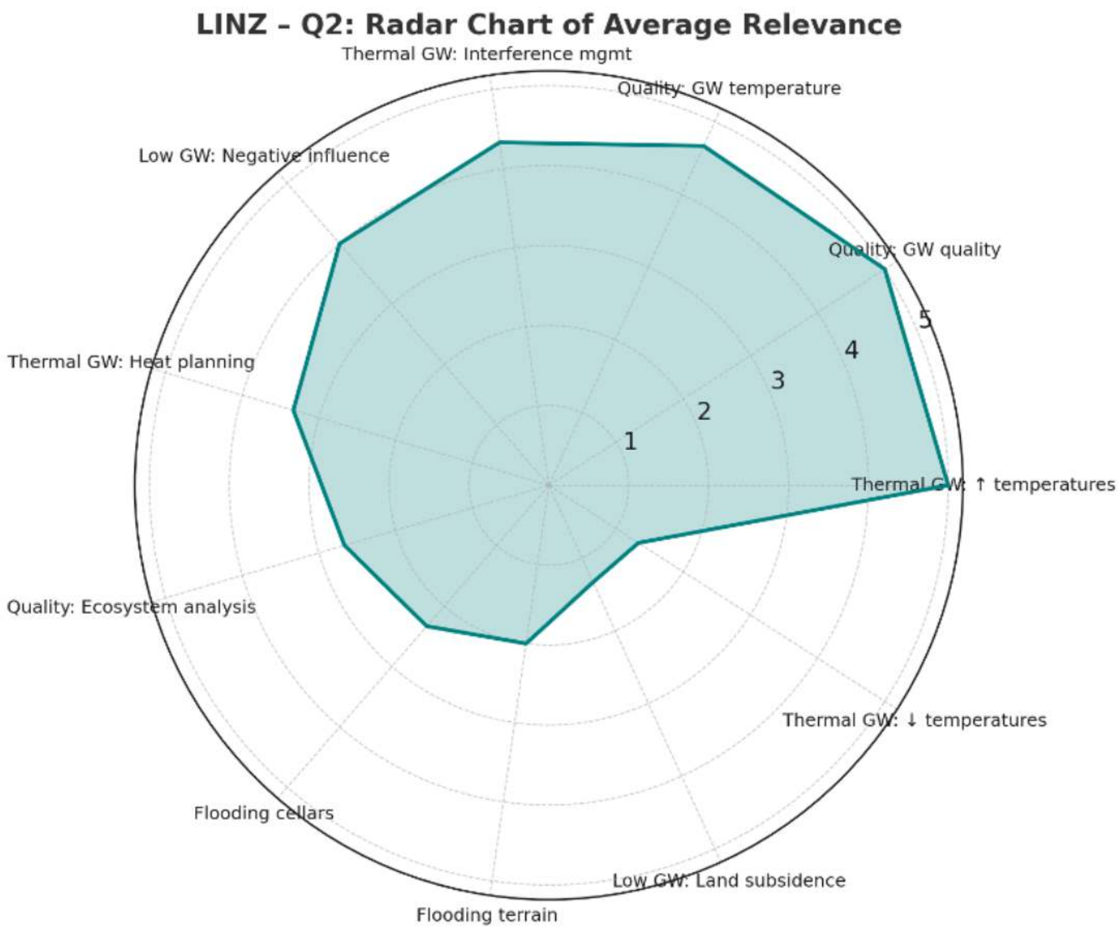


*Figure 4: Increasing relevance from 1 to 5 of groundwater topics in Linz according to the stakeholder questionnaire*

In Linz, the most critical groundwater topics identified within the questionnaire are **groundwater quality**, groundwater temperature and the subsequent **increase of groundwater temperature**, all scoring near the maximum relevance (average score: 4.7 - 5.0). This indicated a strong concern for groundwater quality monitoring and the thermal impacts due to geothermal usage.

**Thermal groundwater interference management** and the influence of **low groundwater level** also scored high (average = 4.0 - 4.3), reflecting attention to conflicts in thermal uses and challenges from declining groundwater levels.

Conversely, **flooding of cellars/terrain**, **land subsidence** and a **decrease of groundwater temperatures** were rated with lower relevance (average = 2.0 - 2.7), suggesting these issues are less prevalent or less prioritized in the city's groundwater management agenda.

The stakeholder discussion, which followed the questionnaire, and the questionnaire outcomes combined, resulted in the evaluation of topic relevance for Linz. Table 3. shows the most important topics including their relevance score (1-high and 2-middle) and a description of the relevant aspects.

The relevance score primarily reflects the outcomes of the questionnaire. However, the stakeholder discussion has revealed additional insights including the identification of additional topics. Based on this discussion, the topic of influence of low groundwater level was downgraded to low relevance and is therefore not included in Table 3.

*Table 3. Relevant topics for Linz. R - Relevance score: 1 – high, 2 – medium, 3 – low (not disclosed here). GW – groundwater.*

| Topic | R | Description |
|---|---|---|
| GW level | 1 | Groundwater levels are monitored already. To close few data gaps and to understand spatial patterns, the creation of **groundwater contour maps** based on monitoring campaigns is essential. |
| GW level | 2 | A **trend analysis of groundwater time series** would be useful as well as modelling extreme groundwater levels, but both are of lower urgency. |
| GW temperature | 1 | Groundwater temperatures are monitored in selected locations and their relevance for thermal groundwater use is known. However, **high-resolution GW temperature maps** including hotspots are needed to detect potential conflicts of use early and to derive targeted management measures. |
| Thermal use of GW | 1 | For permitting procedures, the **calculation and GIS-based visualisation of thermal plumes** is crucial. This allows verification of the applicability of ÖWAV Guideline 207 to Linz and identification of potential adjustments in the licensing phase. Since numbers of groundwater heat pumps are increasing, this topic becomes increasingly relevant. Including existing installations in potential maps would therefore provide a sound decision basis for a sustainable utilization of groundwater for heating and cooling. |
| GW quality | 2 | Infiltration can lead to contamination by chloride and other substances. While chloride is easy to measure, additional parameters (orthophosphate, conductivity, oxygen) are important for ecological assessment. Maintaining high GW quality is critical for Linz, given its protection zones and drinking water supply. |
| GW ecology | 1 | **Biological analyses** provide insights into the ecological functioning of the GW system and are central for programs such as the Green City Accord. The city of Linz is aware of this topic and supports first analysis as currently no data is available. The results of this analysis will support measures for biodiversity conservation. |
| Second GW aquifer | 2 | A second aquifer exists in the deeper Linz sands but is currently only described by a few boreholes. As it is protected, **more accurate information on its extent and thickness** would be valuable. |
| Metadata catalogue | 1 | Knowledge about the availability of groundwater related data sets is relevant for a groundwater sustainability management. A **structured metadata catalogue** would provide this by improving the accessibility and usability of existing groundwater-related data and form the basis for efficient cooperation between the city, the State and other stakeholders. |
| Digital database | 1 | Operational data from installations and hydraulic parameters (kf values) are often stored in analogue formats. A **central digital database** would facilitate consistent collection, long-term maintenance and easy integration into GIS and administrative processes. This is relevant to significantly improve the planning reliability and decision-making basis for the city. |

| | | |
|---|---|---|
| Deep geothermal energy | 1 | Deep geothermal energy is a strategic future topic for sustainable energy supply. Since no potential analyses currently exist, **general recommendations on utilization and methodologies** would be helpful for Linz. |

# 3.2 Pilot city assessment - Ljubljana

## 3.2.1 Methodology - Ljubljana

The methodology applied in Ljubljana followed the general approach outlined in chapter 3. The following section presents the relevant stakeholders in Ljubljana.

## 3.2.2 Stakeholders Ljubljana

The following stakeholder groups were identified as relevant for Ljubljana:

- Authorities
- Companies with full or partial public ownership
- National institutions

### *Authorities*

The most relevant authority for Ljubljana is the **Municipal Authority of Ljubljana (MOL)**. The **Department of Environmental Protection (OVO)** conducts detailed and specialized monitoring of the state of the environment and nature and manages the information system for environmental and nature protection. It prepares vulnerability studies and threat assessments, as well as reports on the state of the environment and nature. The department also evaluates the impacts of planned interventions on the environment, monitors the implementation of spatial planning and related implementing acts. It establishes and maintains a spatial information system, collecting, recording, and analyzing data on intended land use and spatial interventions, while keeping records and documentation of regulations and other municipal acts that govern the use of space.

The **Energy Management Service** ensures the implementation of the local energy concept of the City of Ljubljana, including the tasks of the municipal energy manager. It leads, organizes and coordinates projects to increase the share of renewable energy sources.

### *Companies with full or partial public ownership*

The public company **JP VOKA SNAGA** offers water supply, wastewater treatment and waste management services in Ljubljana. They are in charge of groundwater monitoring for quality and quantity for the purpose of drinking water supply.

### *National institutions*

In addition to public institutions at the municipal level, there are stakeholders at the federal level. Primarily, they conduct measurement campaigns, and compile and provide data at the federal level. The **Slovenian Water Agency (DRSV)** is associated to the Ministry of Natural Resources and Spatial planning and performs administrative and development tasks in the field of water management.

The **Slovenian Environment Agency (ARSO)** is an agency under the Ministry for the Environment, Climate and Energy. It serves as Slovenia's central institution for monitoring, collecting, analysing 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. Data is made available through the online GIS platform Atlas okolja.

The **National Insitute 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.

### 3.2.3 Data handling and inventory - Ljubljana

***Data handling - Ljubljana***

Groundwater related data is mainly available at two web portals ARSO (Slovenian Environmental Agency) and Atlas voda (Slovenian Water Agency). There is mainly data of groundwater monitoring, water permits and water protection areas available. Monitoring data from Slovenian Environmental Agency are available at their website. Other data is available as annual reports or it is necessary to request the data directly from the source. A collection of water permits (including the ones for the thermal use of groundwater) is available at https://ekosklad.si/uploads/1ae84163-8f16-4d31-88b7-da58ffe8110c/Seznam-toplotne-%C4%8Drpalke-2024_12_05.xlsx .

## *Data inventory - Ljubljana*

*Table 4. Available data sets - Ljubljana*

| Parameter | Data set/data base | Short description | Status | Time | Data format | Responsible Organisation |
|---|---|---|---|---|---|---|
| General parameter | Name of the dataset or database and online-link | Short description about content of the data set | Is data updated regularly or not | Time period covered or date of creation | Point, polygon, raster, PDF, analog | Organisation/Department responsible for the data |
| **Climate data** | https://meteo.arso.gov.si/met/sl/app/webmet/ | ARSO provides climate data such as air temperature, precipitation, snow coverage, weather phenomena, air pressure | Regularly updated | Variable | txt | ARSO |
| **Location of groundwater monitoring points** | https://gis.arso.gov.si/atlasokolja/profile.aspx?id=Atlas_Okolja_AXL@Arso | Location of groundwater monitoring points and description, since when the station is operational and which data is measuring | Regularly updated | Variable | Webgis (not available for download) + PDF with stations description | ARSO |
| | https://geohub.gov.si/portal/apps/webappviewer/ | Location of groundwater monitoring points, some are the same as at Atlas okolja | Regularly updated | Variable | Webgis (not available for download) | DRSV |
| **Groundwater level** | https://vode.arso.gov.si/hidarhiv/pod_arhiv_tab.php | Daily data for measuring stations which locations are shown on Atlas okolja | Regularly updated | Variable, (available for 2024 and older) | csv | ARSO |
| **Groundwater temperature** | https://vode.arso.gov.si/hidarhiv/pod_arhiv_tab.php | Daily data for measuring stations which locations are shown on Atlas okolja. Temperature data missing for some stations, depends of measuring sonds in wells | Regularly updated | Variable, (available for 2024 and older) | csv | ARSO |
| **Groundwater protection** | https://podatki.gov.si/dataset/vodovarstvena-obmocja | Polygons of water protection zones for Slovenia | Regularly updated | Variable | Polygon data | DRSV |
| **Groundwater chemistry** | https://www.vokasnaga.si/informacije/kaksno-vodo-pijemo/centralni-vodovodni-sistem-laboratorijska-porocila | Water supply monitoring. Available PDF reports of chemical and microbiological analysis for water-plants | Regularly updated | Variable | PDF | JP VOKA SNAGA |
| **Sewage and water supply network data** | Urbinfo | Map of main sewage system and central water supply system | updated | | Webgis | MOL |
| **Digital Elevation Model** | https://gis.arso.gov.si/evode/profile.aspx?id=atlas_voda_Lidar@Arso | Slovenia is covered with squares 1km$^2$. Each square is possible to download | Not updated, New scanning in process | 2011, 2014, 2015 | txt | ARSO |
| **Sustainable energy atlas** | https://borzen.maps.arcgis.com/apps/webappviewer/ | Map of Geothermal heat pump potential | No data | | Webgis (not available for download) | Borzen published under the authority of Ministry of Infrastructure |
| **Registered geothermal systems** | https://www.ekosklad.si/upload/s/ee57c3c3-f68c-48bc-bb11-c6a2e292ba26/Seznam_toplotne_crpalke-25.2.2025.xlsx | List of registered heat pumps with energy efficiency | Regularly updated | 2025 | csv | EcoFund under the authority of Ministry of the Environment, Climate and Energy |

## 3.2.4 Governance Analysis - Ljubljana

This section provides a detailed description of the currently in place governance workflow of the topic **thermal use of groundwater**. All governance workflows, including those addressing **rainwater infiltration, flooding** and **groundwater quality** are presented in Figure 5. The figure illustrates the relationships between the different stakeholders, their links to the respective topics and their access to data.

### *Thermal groundwater use*

The process begins in the **city-scale planning phase**, including the strategic resolution and key data collection. The MOL – Spatial Planning Department starts the process and coordinates the collection of spatial and geological data. The MOL-Department of Environmental Protection (OVO) carries out preliminary environmental impact assessments, which consider already climate change adaption. During this process, the Slovenian Water Agency (DRSV) provides guidance on given groundwater conditions and restrictions for thermal groundwater use. The baseline data collection includes hydrogeological studies, energy demand, existing infrastructure. Technical support and coordination with external experts take place, as well as an initial evaluation.

The next phase establishes the **planning framework**. This includes an announcement of the Urban Planning Design. The departments Environmental Protection and Spatial Planning of MOL work closely together on the announcement. The Department of Environmental Protection prepares and issues the formal framework for the competition briefing and the Spatial Planning department integrates findings into planning schemes. Additionally, the Water and Sewage Utility (JP VOKA SNAGA) verifies possibilities for infiltration measures, ensures protection of water resources, and sets conditions for stormwater drainage. The DRSV sets binding conditions for groundwater protection and potential use of aquifers (e.g., max. extraction/injection rates, zones where geothermal boreholes are restricted) and provides a binding expert opinion on the draft of the Detailed Municipal Spatial Plan (OPPN), regarding groundwater protection.

The MOL - Spatial Planning Department **drafts the OPPN (or framework spatial plan), commissions expert studies and the environmental report.** The MOL - Department of Environmental Protection review and evaluates drafts, conducts in-depth assessments for the zoning plan and issues planning recommendations. ARSO provides opinions on environmental and water-related impacts.

The public authorities participate in the **urban development contract**. The MOL - Spatial Planning Department coordinates the contract process, whereas MOL - Department of Environmental Protection issues the final expert statement forming the basis for statutory procedures. DRSV issues final water-related requirements and authorisations (e.g., location of boreholes, conditions for use of groundwater heat pumps, monitoring obligations). ARSO again provides additional technical conditions.

After the **resolution of approval** is granted, the Detailed Municipal Spatial Plan (OPPN) is adopted and included in the local energy concept of the City of Ljubljana (LEK). The implementation part of OPPN is updated every three to four years. As a long-term plan, the strategic part usually does not change.

In the **implementation phase** on city-scale, where new geothermal systems are installed, these individual projects start with a technical kick-off and coordination, led by MOL in cooperation with DRSV and ARSO. In the kick-off, borehole locations, construction logistics and groundwater protection measures are defined. In the final technical review phase, the DRSV issues go/no-go decision on boreholes, confirms technical feasibility and sets hydraulic/thermal criteria. OL/JP VOKA SNAGA reviews the technical execution drawings and site logistics and ARSO issues necessary environmental permits (if Natura 2000 or similar).

Work in the **construction phase** is executed by contractors under supervision of MOL and DRSV. JP VOKA SNAGA ensures compliance with water protection standards. Deviations are resolved in real time. Supervision ensures high quality, with DRSV inspecting borehole depth, casing and groundwater protection and ARSO validating the environmental measures.

After completion, the **system is tested and officially approved.** DRSV verifies the hydraulic and thermal performance, MOL confirms the integration into the city energy planning and ARSO validates its compliance with permits.

The responsibilities for **operation and monitoring** are shared between utility operators and private investors, depending on the ownership. Mandatory long-term monitoring includes documentation of groundwater levels and temperatures.

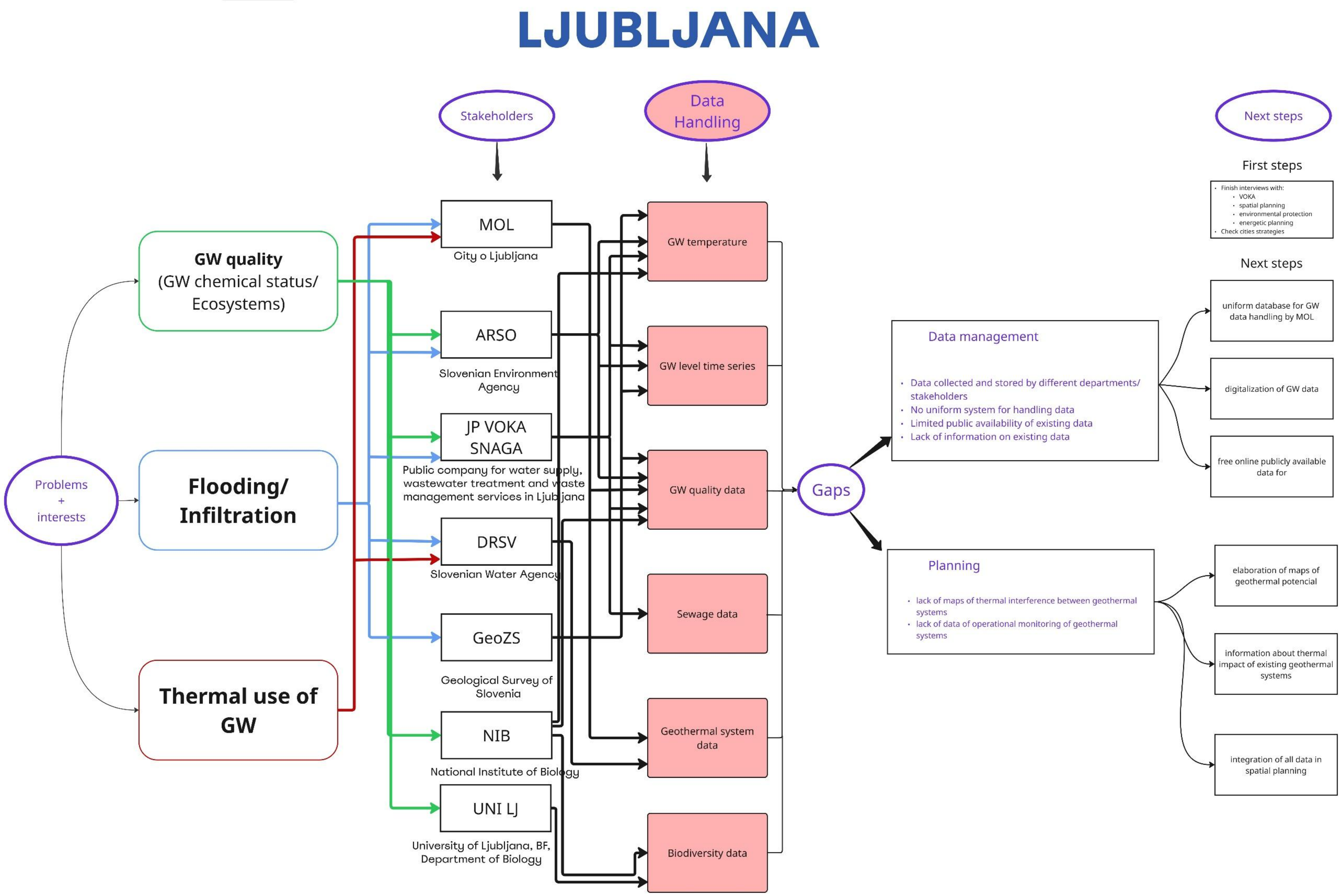


*Figure 5: Governance processes - Ljubljana.*

## 3.2.5 Challenges and gaps - Ljubljana

### *Groundwater quality and ecosystem*

#### Data Gaps

Groundwater ecosystems in Ljubljana 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 testing 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.

#### Governance Gaps

Groundwater ecosystems are not explicitly considered in Slovenian regulations and directives, and thus remain largely overlooked in monitoring and management practices. Current groundwater quality assessments focus almost exclusively on chemical parameters, while **ecological aspects receive little to no attention**.

Public discussion and stakeholder engagement in decisions related to facilities and infrastructure with potential impacts on groundwater are limited.

Furthermore, **existing datasets are not well known among stakeholders**, reducing their ability to fully understand groundwater-related problems and to identify appropriate solutions. Establishing mechanisms for data transparency and structured stakeholder involvement would therefore be an important step toward more inclusive and sustainable groundwater governance.

### *Groundwater flooding*

#### Data Gaps

In Ljubljana, there is a **lack of detailed mapping of shallow, low-permeability layers** that could inform spatial planning and building construction. Such information would be critical for evaluating risks related to groundwater flooding.

Furthermore, **areas suitable for stormwater and rainwater infiltration have only been partially identified**, and the **implementation of rainwater retention solutions remains limited**. These gaps reduce the ability to design effective measures that mitigate groundwater flooding risks.

### Governance Gaps

Available information and potential solutions are not sufficiently integrated into spatial planning processes. Stronger coordination between data collection, planning practices, and implementation measures would be necessary to reduce groundwater flooding risks and improve resilience in urban development.

## *Thermal use of groundwater*

### Data Gaps

**Operational monitoring data for thermal groundwater use** systems in Ljubljana are **only available to a limited extent**, making it difficult to evaluate system performance over time. Spatial information on the thermal impact of operating systems is also missing, yet such data would be essential for planning future installations and avoiding potential interferences.

Furthermore, there is **no central registry of thermal groundwater use systems**, which restricts the ability to maintain an overview of existing systems and to integrate them into broader groundwater and energy management strategies.

### Governance Gaps

**Lengthy procedures for acquiring water rights for the thermal use of groundwater** slow down the development of new systems.

In addition, there is currently **no systematic post-installation monitoring** procedure in place, which reduces the capacity of authorities to assess long-term impacts, ensure compliance, and manage the resource sustainably.

## 3.2.6. Relevance - Ljubljana

The results of the questionnaire conducted with the stakeholders (see chapter 2.2.1.) are shown as radar chart, indicating increasing relevance of the specific topics from 1 to 5 (Figure 6).

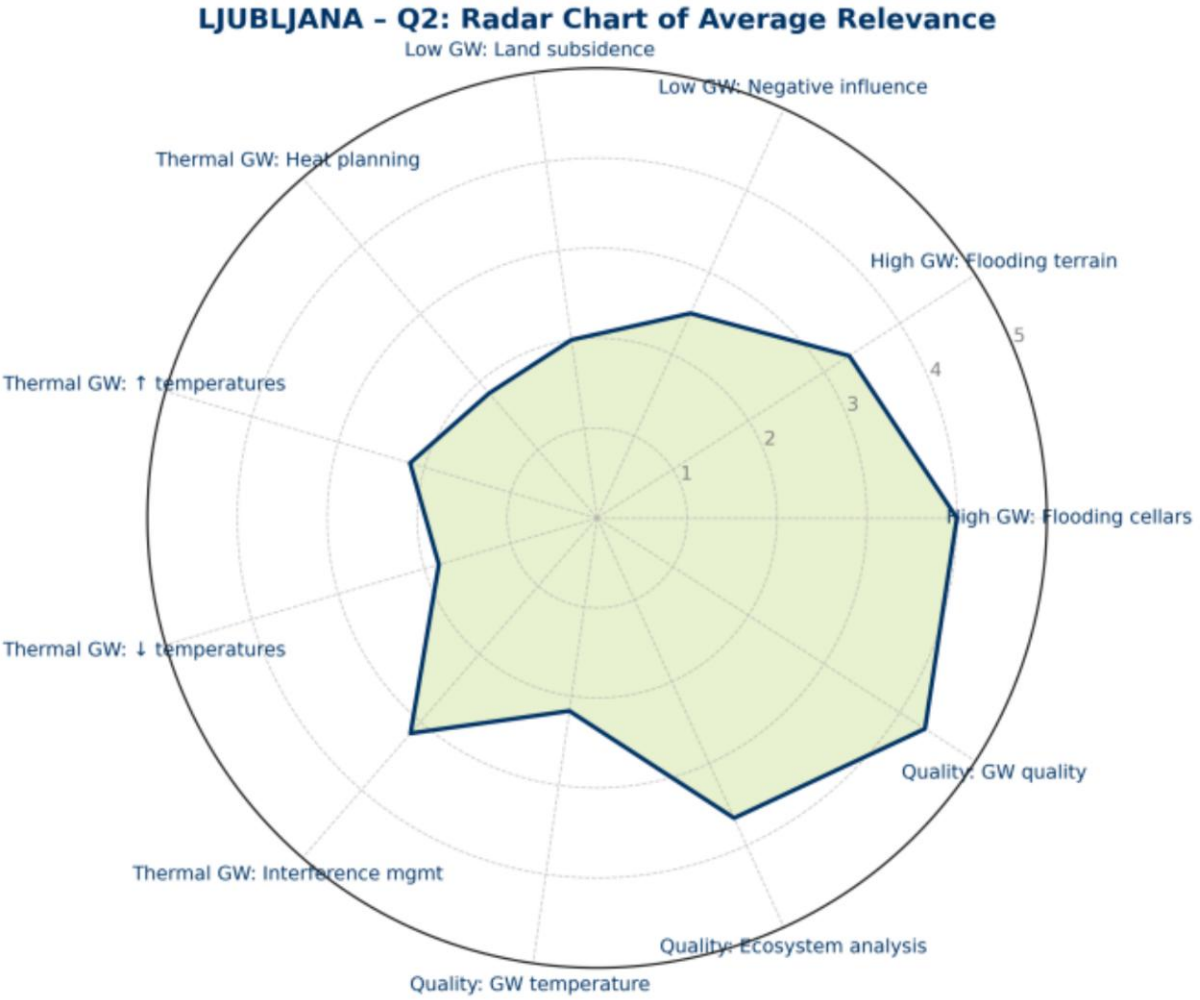


*Figure 6: Increasing relevance from 1 to 5 of groundwater topics in Ljubljana according to the stakeholder questionnaire.*

The conducted stakeholder interviews led to a better understanding of governance and data challenges which will be assessed in the MARGIN project for Ljubljana. Based on the validated results of the stakeholder questionnaire, World Café discussion and interviews held with stakeholders, three priority topics were defined as the most relevant for Ljubljana in the context of sustainable groundwater management:

- Groundwater quality and ecosystem health
- Risks of groundwater flooding and rainwater infiltration
- Thermal use of groundwater

*Table 5. Relevant topics for Ljubljana. R - Relevance score: 1 – high, 2 – medium, 3 – low (not disclosed here). GW – groundwater.*

| Topic | R | Description |
|---|---|---|
| GW quality & ecosystem health | 1 | Groundwater is the sole source of drinking water for the city; therefore, protecting its quality is of crucial importance. The influence of ecosystems and changes in physical parameters (e.g., temperature) on groundwater quality is currently not well understood. This knowledge gap limits the ability to anticipate and mitigate potential impacts arising from climate change or urbanization. Drinking water is regularly monitored for different bacteria, phytopharmaceuticals and different chemical compounds and elements. Currently no monitoring of the ecological status of groundwater is conducted.<br>Some data on groundwater fauna are available from scientific studies, but these data are limited and do not represent the entire Ljubljansko polje aquifer. Further research on groundwater communities and ecosystems, as well as the development of a shared, accessible database, is needed to establish functional ecosystem-based monitoring. |
| GW flooding and rainwater infiltration | 1 | 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.<br>• Lack of detailed maps of shallow, low-permeability layers that could be integrated into spatial planning and building construction plans<br>• Limited identification of areas suitable for stormwater and rainwater infiltration, as well as insufficient implementation of rainwater retention solutions<br>• Extensive surface sealing in urban areas, reducing natural infiltration, with little to no enforcement in practice to prevent it |
| Thermal use of GW | 1 | The thermal use of groundwater for heating and cooling is an integral component of the city's strategy to meet environmental and climate objectives, enhance the utilization of local resources, and improve energy resilience and efficiency. Ensuring the sustainable use of groundwater and preventing adverse impacts on its quantity and quality require careful planning supported by measurements, data analysis, and scenario-based simulations.<br>• The temperature of groundwater has not been systematically measured in the past, long time series not available.<br>• Limited availability of operational monitoring data for geothermal systems<br>• Lack of spatial information on thermal impact of operating geothermal systems, which is needed for planning of geothermal use.<br>• Long duration of procedures for acquiring water rights for thermal use of groundwater.<br>• No binding regulations on thermal parameters (just guidelines) |

# 3.3 Pilot city assessment - Milan

## 3.3.1 Methodology – Milan

The methodology applied in Milan followed the general approach outlined in Section 2. These methodical steps were designed to capture not only the availability and accessibility of data, but also the governance structures behind how this data is generated, shared, and used in decision-making processes. The approach was applied systematically across all participating cities. In particular, for Milan, the following steps were achieved, starting with stakeholder identification.

***Deploy online questionnaire***

The questionnaire developed within the MARGIN project was shared with the main stakeholders involved in groundwater management, governance and data handling, to establish an initial baseline for subsequent analysis. The questionnaire was sent to the following 5 stakeholders:

- Comune di Milano – Direzione Verde e Ambiente (PP)
- Città Metropolitana di Milano - Settore Risorse Idriche e Attività Estrattive
- MM S.p.A. – Settore Acquedotto
- Gruppo CAP
- Anonymous answerer

The results presened in Annex II of this document contain only answers from 3 stakeholders, while this document is built on all 5 responses received):

## 3.3.2 Stakeholders – Milan

The MARGIN project involves two partners from the City of Milan: the University of Milan-Bicocca (PP Unimib) and the Municipality of Milan (PP C-Mil). 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 groups were directly or indirectly involved in the processes analysed:

- Authorities
- Universities
- Companies with full or partial public ownership

### *Authorities*

The 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. It monitors and protects soil and water resources, manages municipal watercourses and groundwater levels, coordinates with the Integrated Water Service, and provides technical input for environmental authorizations and assessments.

The **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. It ensures that groundwater use, including geothermal applications, is consistent with strategic aquifer management objectives and in compliance with regional and EU regulations on water resources.

The **Regione Lombardia** (Lombardy Region) is the competent regional authority for defining groundwater and geothermal energy policies, strategies, and regulatory frameworks. It oversees permitting processes, establishes groundwater protection plans, and ensures compliance with the EU Water Framework Directive and Renewable Energy Directive. The Region coordinates with local authorities (on a provincial level) to ensure sustainable exploitation of aquifers for energy and water supply.

The **ARPA Lombardia** (Regional Environmental Protection Agency of Lombardy) is responsible for environmental monitoring and technical control of groundwater quality and quantity.

### *Universities*

The **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. The department supports the development of innovative and sustainable solutions for geothermal energy exploitation, ensuring compatibility with aquifer protection and regional water management frameworks.

### *Companies with full or partial public ownership*

The **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. Its role includes ensuring sustainable withdrawal rates, safeguarding drinking water quality, and implementing infrastructure measures to optimise groundwater use while mitigating overexploitation risks.

The MM S.p.A. – **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.

The Gruppo CAP is the integrated water service provider for the wider Milan metropolitan area. Its responsibilities include groundwater abstraction, treatment, distribution, and aquifer monitoring. The company actively engages in initiatives ensuring the balance between water supply needs and long-term aquifer preservation.

The 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 and optimisation of district heating and cooling networks aiming to integrate renewable energy production such as from shallow and medium geothermal resources.

## 3.3.3 Data Handling and inventory - Milan

***Data handling - Milan***

The questionnaire analysis about data handling and availability in Milan revealed highly fragmented competences, inadequate spatial and temporal resolution and poor data availability. This section provides an overview of the relevant insights.

At the question “Is there a main city department in charge of monitoring?”, 3 out of 5 answered YES, while the others 2 answered NO. Among the three positive answers, three completely different departments/authorities were identified, highlighting the actual highly fragmented monitoring and data sharing competences.

Similarly, different opinions have been collected about which other institutions conduct groundwater measurements (Table 6), and which data are available (Table 7 and Table 8).

*Table 6. Results from the questionnaire responses: "Do other institutions conduct groundwater measurements?"*

| | | | | | |
|---|---|---|---|---|---|
| Regional/National authorities | 1 | 1 | 1 | 0 | 0 |
| Water supply services | 1 | 1 | 1 | 0 | 1 |
| Industry/companies | 0 | 0 | 0 | 0 | 1 |
| Others: | 1 | 1 | 0 | 0 | 0 |

*Table 7. Results from the questionnaire responses: "Which data is collected?"*

| | | | | | |
|---|---|---|---|---|---|
| 1) Groundwater level time series | 1 | 1 | 1 | 0 | 1 |
| 2) Groundwater temperature time series | 1 | 1 | 0 | 0 | 1 |
| 3) Groundwater temperature vertical profiles | 1 | 0 | 0 | 0 | 0 |
| 4) Ecosystem data | 0 | 1 | 0 | 0 | 0 |
| 5) Chemical data, groundwater quality | 1 | 1 | 1 | 0 | 1 |
| 6) Amount of water used / groundwater discharge / water demand | 1 | 1 | 1 | 0 | 1 |
| 7) Climate observations / rainfall | 1 | 1 | 1 | 0 | 0 |

*Table 8. Results from the questionnaire responses: "Groundwater table contour maps or hydrogeological maps available?"*

| | | | | | |
|---|---|---|---|---|---|
| Groundwater table contour maps | | | | | |
| 1) Average level | 0 | 0 | 0 | 0 | 1 |
| 2) High level | 0 | 0 | 1 | 0 | 0 |
| 3) Low level | 0 | 0 | 1 | 0 | 0 |
| Other: | 1 | 1 | 0 | 1 | 0 |
| **Level at specific times (every six months, March/September)** | | | | | |
| | | | | | |
| 4) Groundwater bodies | 1 | 1 | 1 | 1 | 1 |
| 5) Hydraulic conductivity /permeability coefficient | 0 | 1 | 1 | 0 | 0 |
| 6) Permeability coefficient | 0 | 0 | 0 | 0 | 0 |
| 7) Groundwater dephth to surface | 1 | 1 | 1 | 1 | 0 |
| 8) Aquifer thickness | 0 | 1 | 1 | 0 | 0 |
| 9) Thickness of saturated zone | 0 | 1 | 0 | 0 | 0 |
| 10) Basis of aquifer | 1 | 1 | 1 | 0 | 0 |
| 11) Groundwater discharge | 0 | 1 | 0 | 0 | 0 |
| 12) Groundwater temperature maps | 0 | 0 | 0 | 0 | 0 |

Moreover, knowledge about their existence in digital format or their availability online appeared to be even more ambiguous and conflicting. This highlights the need for a comprehensive survey of the existing groundwater data collection procedures in the city of Milan, as well as a clearer analysis of data handling and governance processes.

The following Table lists all the relevant datasets identified for the MARGIN project, highlighting the owner, the updating frequency, data format and availability to the public. This collection will provide the foundation for identifying gaps in data collection, weaknesses in data management and governance processes, and will be leveraged in the subsequent work packages of the project.

## *Data inventory - Milan*

*Table 9. Available data sets - Milan*

| Parameter | Data set/data base | Short description | Status | Time | Data format | Responsible Organisation |
|---|---|---|---|---|---|---|
| General parameter | Name of the dataset or database and online-link | Short description about content of the data set | Is data updated regularly or not | Time period covered or date of creation | Point, polygon, raster, PDF, analog | Organisation/Department responsible for the data |
| **Climate data** | ARPA Lombardia \| Meteo e clima \| Form richiesta dati automatici - ARPA Lombardia | ARPA Lombardia provides climate data such as rainfall and temperature data from various rain gauge stations across the city, available at sub-hourly, hourly, or daily intervals. The length of the data series varies by station. | Regularly updated | Variable | CSV or PDF | ARPA Lombardia (Regional Agency for Environment Protection) |
| **Location of groundwater monitoring points** | https://ambientecomune.eu/ | Location of groundwater monitoring points and available measurements (depth to groundwater) | Unknown | Variable | Webgis (no download) | Gruppo CAP (Water Service Provider) and Città Metropolitana di Milano (Regional Agency for GW Resource) |
| **Groundwater level** | https://www.cittametropolitana.mi.it/open_data/dataset-pubblicati-per-categoria/ambiente/ | Interpolated groundwater level contour lines from periodic monitoring (Province of Milan). | Unknown | 2007 – 2022 (variable) | Shapefile | Città Metropolitana di Milano (Regional Agency for GW Resource) |
| **Groundwater level** | https://www.latuaacqua.it/wps/portal/latuaacqua/it/home/acqua-di-milano/scopri/cartografia | Interpolated groundwater level contour lines from periodic monitoring every 6 months (Municipality of Milan). | Annual update | Last three years | PDF | MM spa (Water Service Provider) |
| **Groundwater level** | Unimib Groundwater Monitoring Network | Groundwater level time series measured continuously with automatic devices by University of Milan-Bicocca for research activities | Not public | From 2016 | Excel | University of Milan-Bicocca |
| **Groundwater temperature** | Unimib Groundwater Monitoring Network | Groundwater temperature time series measured continuously with automatic devices and temperature-depth profiles every three months by University of Milan-Bicocca for research activities | Not public | From 2016 | Excel | University of Milan-Bicocca |
| **Base of phreatic layer** | https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/Enti-e-Operatori/territorio/governo-delle-acque/piano-tutela-acque-pta/piano-tutela-acque-pta | Interpolated elevation of the base of the phreatic aquifer body, dividing the shallow unit from deeper ones | Available | 2016 | Raster | Regione Lombardia (PTUA 2016) |
| **Groundwater usage** | https://www.dati.lombardia.it/d/a6ku-i4r8 | Location of authorized groundwater extraction wells with information on the type of use, well depth and (not for all) the average or maximum discharge | Available | Unknown | Shapefile | Città Metropolitana di Milano (Regional Agency for GW Resource) |
| **Water protection areas** | https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=41f255bdb13e4f3f9cebb3c8e63239ff | PGT 2030 mapping tool, drinking water protection zones as defined by the Legislative Decree No. 152 of April 3, 2006 (see D1.1.3) | Regularly updated | Every 5 years | Webgis | Municipality of Milan |
| **Surface Sealing** | https://www.geoportale.regione.lombardia.it/download-pacchetti?p_p_id=dwnpackageportlet_WAR_gptdownloadportlet&p_p_lifecycle=0&p_p_state=normal&p_p_mode= | Topographic database with information of land cover elements recognized from arerial image interpretation | Available | Unknown | Shapefile | Regione Lombardia |

| | | | | | | |
|---|---|---|---|---|---|---|
| | view&_dwnpackageportlet_WAR_gptdownloadportlet_metadataid=r_lombar%3A0092b7ba-c697-433b-b5f2-9f9d9b8694e3&_jsfBridgeRedirect=true | | | | | |
| **Sewer network data** | Milan City Geoportal | PGT 2030 mapping tool, stormwater/drainage infrastructure (available online) | Available | Unknown | Webgis | Municipality of Milan |
| **Sewer network data** | MM Web GIS – GeoLab | Integrated Water Service networks and stormwater system (not available to public) | Available | Unknown | Not available | MM spa (Water Service Provider) |
| **Digital Elevation Model** | Lombardy Region Geoportal (https://www.geoportale.regione.lombardia.it/) | 20x20 m DEM | Available | 2015 | Raster | Regione Lombardia |
| **Surface Water** | Lombardy Region Geoportal (https://www.geoportale.regione.lombardia.it/) SIDRO Geoportal (https://idro.arpalombardia.it/it/map/sidro/#) | RIRU, basins, minor rivers, open hydrography datasets (available online) | Unknown | Unknown | Shapefile | Regione Lombardia |

## 3.3.4 Governance analysis - Milan

The following graphs have been developed to visualize the governance and management processes related to groundwater. The processes described involve mainly the regulation, resource planning, policies and authorization procedures related to groundwater for any use (including thermal use). The relationships among stakeholders are mapped in the following two figures and described in the text.

In summary, the authorities responsible for groundwater are depicted in Figure 7. An arrow indicate that a specific authority has a direct task related to that topic. Further collaboration among stakeholders is typically conducted upon specific tasks or for single project evaluations. For a complete description of the stakeholder's roles and competences refer to chapter 3.3.2 Stakeholders – Milan.

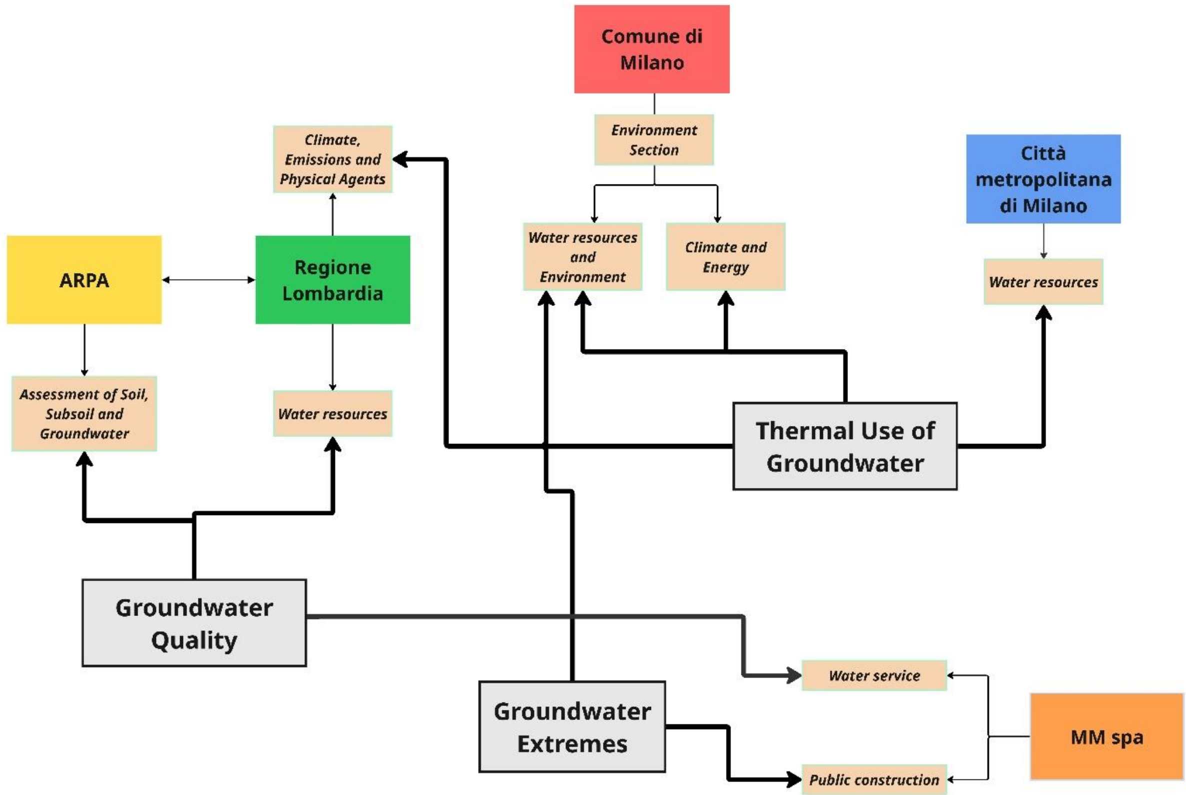


*Figure 7 – Authorities dealing with groundwater related topics in Milan and their connections.*

The following scheme summarizes the main stakeholder's roles related to groundwater management and their interactions in governance processes. These processes and their steps are argumented in the following paragraphs of this section.

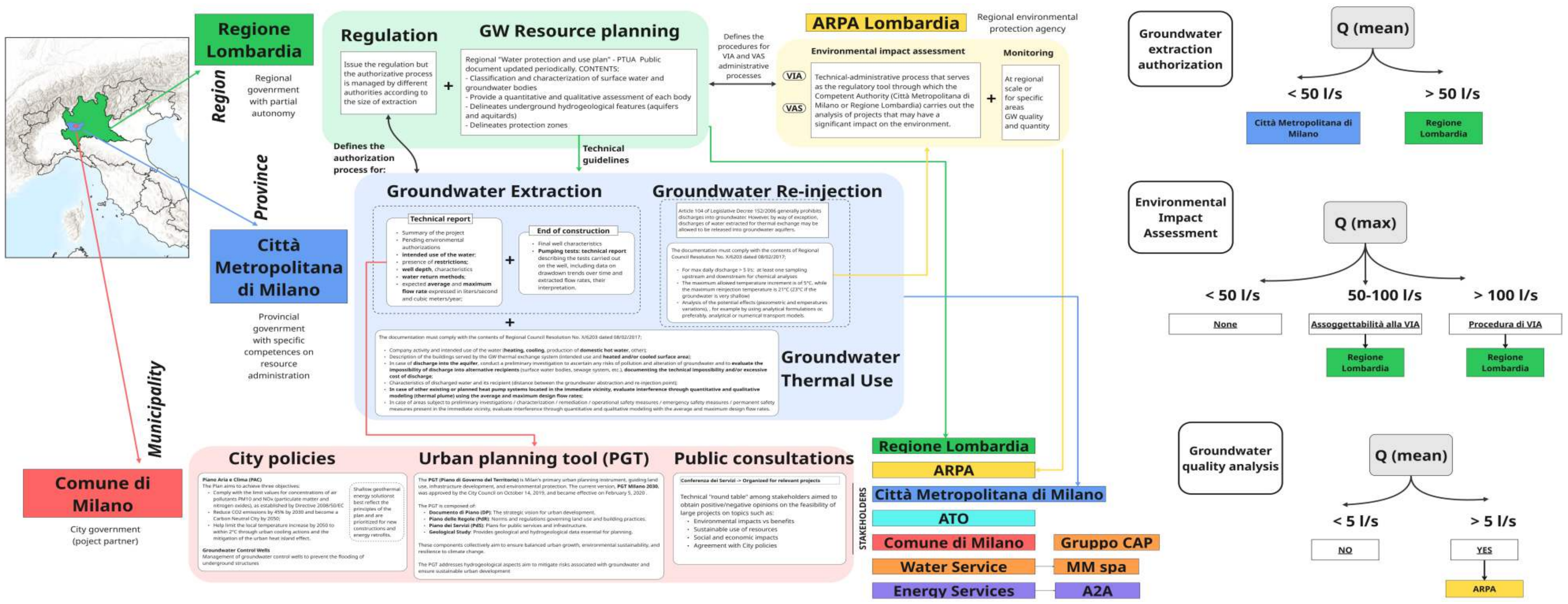


*Figure 8 – Analysis of groundwater governance processes in the Milan city and stakeholder interactions.*

From top to bottom, namely from regional to city level, the competent authorities and their roles in the groundwater governance are:

**1) Regione Lombardia** (RL), Regional govenrment with partial autonomy – Observer of the MARGIN project. RL has two main roles in groundwater management at a regional level:

Regulation entity: Issue the regulation but the authorizative process is managed by different authorities according to the size of extraction as depicted in the following Figure. Spcific regulations are defined for:

- **Groundwater extraction** and relative **authorization**: Regional Regulation No. 2 of March 24, 2006 governs the granting of groundwater extraction permits through the drilling of wells (Article 22). All public or private entities that wish to extract groundwater on their own land or on someone else's land must request a concession from the provincial authority for environment (Città Metropolitana di Milano).
- **Re-injection of groundwater:** Article 104 of Legislative Decree 152/2006 generally prohibits discharges into groundwater. However, by way of exception to this prohibition, discharges of water extracted for thermal exchange may be allowed to be released into groundwater aquifers, provided that specific authorization is granted by the competent authority following a prior dedicated investigation. Regional Regulation No. X/6203 08/02/2017 defines the requirements to be satisfied for re-injecting groundwater.
- **Regional portal** Applications for public groundwater extraction must be submitted through the online portal of the Lombardy Region called "SIPIUI." The new groundwater extraction requests are then transferred to the competent authorities according to the size of the project. Even though it is a well structured and centralized database, few data are collected in a digital way regarding groundwater, and they are not properly shared across stakeholders. As an example, provincial authorities must ask manually the data regarding groundwater extractions from the regional authority

Resource planning: The Water Protection Plan (PTA) is the **planning instrument** for the **qualitative** and **quantitative** protection of **water resources**. The PTA consists of

- **Policy Document**, approved by the Regional Council with Resolution No. 929 of 2015, which outlines the regional strategic guidelines for water resource planning.

- **Technical Document** Water Protection and Use Program (PTUA) –"Piano di tutela e uso delle acque" – is a public document updated periodically., approved by the Regional Government (RL), which effectively serves as the planning and programming document for the measures necessary to achieve environmental quality objectives.

**2) ARPA Lombardia:** Regional Agency for Environmental Protection – is responsible for the prevention and protection of the environment, supporting regional and local institutions in a wide range of activities including groundwater. ARPA collects and processes data necessary to support environmental policy decisions by the Lombardy Region, Provinces, Municipalities, and other public bodies within the regional territory.

In addition, in line with principles of public transparency, through actions of information, communication, and environmental education, it enables citizens and businesses to understand and assess the state of the environment in which they live and operate, and to easily access guidance on the activities entrusted to it.

In the context of groundwater, ARPA's responsibilities are:

- planning and managing the qualitative and quantitative monitoring of water bodies in accordance with current legislation;
- performing analyses of chemical-physical, chemical, and biological elements;
- processing monitoring data and producing related classifications;
- providing technical-scientific support to the Lombardy Region for planning and programming activities;
- participating in technical-scientific working groups on sector-related issues established by the European Commission, the Ministry of the Environment, the Higher Institute for Environmental Protection and Research (ISPRA), the Lombardy Region, and Local Authorities;
- managing and implementing monitoring networks and projects concerning territorial issues or specific features;

Moreover, ARPA conducts assessments and issues technical opinions in the following institutional procedures:

- The **Strategic Environmental Assessment (VAS)** is a process aimed at ensuring the integration of environmental considerations into all stages of a plan or program, in order to assess its potential significant effects on the environment and to promote sustainable development. The VAS is a continuous sustainability assessment process that must be integrated into the planning procedure from the very beginning. It should become an integral part of the process and serve as a key element of governance and legitimacy for decision-making. The VAS begins concurrently with the drafting of the plan and proceeds in parallel with all its phases (initial design and orientation, development and drafting, adoption and approval, implementation and management). This is essential for identifying and evaluating the environmental effects resulting from the implementation of the plan or program, with the goal of ensuring a high level of environmental protection.

- The **Environmental Impact Assessment (VIA)** is a technical-administrative process that serves as the regulatory tool through which the Competent Authority (Città Metropolitana di Milano or Regione Lombardia) carries out the analysis of projects that may have a significant impact on the environment. The aim is to ensure that the activities related to projects can be considered compatible with the principles of sustainable development and environmental protection. The VIA is based on the fundamental principle of preventive action, which holds that the best policy is to avoid or minimize the environmental impacts of projects before they are carried out, rather than trying to hinder or mitigate their effects afterwards.

**3) Città Metropolitana di Milano (CMM):**_Provincial authority with specific competences on resource administration. Manages the authorization process defined by the Regional regulations for these specific categories:

**Groundwater Extraction** CMM defines the following criteria to authorize groundwater withdrawals:

- the procedures for carrying out any preliminary testing and investigations;
- the methods for drilling, with particular reference to the maximum achievable depth and the aquifers that can be intercepted;
- the procedures and types of tests to be conducted on the aquifers during the drilling works;
- the obligation to notify the start of drilling operations and to provide the identification details of the company in charge of the works and the site supervisor;
- the deadline for the completion of works, which must not exceed one year, with the possibility of a six-month extension upon a justified request by the applicant;
- the precautions to be taken to prevent negative impacts on the hydrogeological balance;

- the precautions to be taken to prevent groundwater contamination;
- the possible requirement to install piezometers, flow meters, and other equipment suitable for monitoring the water table level and allowing water sampling by the public administration;
- the obligation to notify ISPRA – National Geological Service for wells deeper than 30 meters.

CMM also defines the contents of the technical report that must be submitted to obtain the groundwater extraction authorization. The reasons for the construction of the well / the abstraction from a spring or surface watercourse must be explained, summarizing the main project data:

- indication of current or pending environmental authorizations (AIA, VIA, VIA screening, AUA, etc.);
- location of the works (cartographic representation and Gauss-Boaga coordinates);
- intended use of the water;
- presence of restrictions (architectural/archaeological/landscape constraints, protection zones, etc.);
- well depth, drilling diameter (which must include the presence of the piezometric tube), filter positions (which must be located below or near the static level both for intake and return), presence of sampling taps on wellheads (including for returns in the case of heat pump use);
- water return methods;
- expected average and maximum flow rate expressed in liters/second and cubic meters/year;
- mixed use: specification of the flow rates for each use and the corresponding intended purpose;
- ownership of the land parcel on which the abstraction works are located.

**Groundwater Thermal Use** Additionally, CMM defines the documentation to obtain a licence for thermal use of groundwater complying the Regional regulation.

- Company activity and intended use of the water (heating, cooling, production of domestic hot water, other);
- Description of the buildings served by the GW thermal exchange system (intended use and heated and/or cooled surface area);
- Water supply methods for potable and sanitary uses;
- Description of the water cycle;
- Depth for abstraction and re-injection wells;
- Positioning of filters below or near the static level;

- Presence of sampling taps also on return wells;
- Methods for discharging the white water;
- Presence or absence of water treatment systems before use and before discharge;
- In case of discharge into the aquifer, conduct a preliminary investigation to ascertain any risks of pollution and alteration of groundwater and to evaluate the impossibility of discharge into alternative recipients (surface water bodies, sewage system, etc.), documenting the technical impossibility and/or excessive cost of discharge;
- Characteristics of discharged water and its recipient (distance between the groundwater abstraction and re-injection point);
- In case of other existing or planned heat pump systems located in the immediate vicinity, evaluate interference through quantitative and qualitative modeling (thermal plume) using the average and maximum design flow rates;

Even though a high level of detail is requested, there are no guidelines on how to assess the possible interactions between systems. In particular, applicants have not enough information to perform such analysis and the euthority doesn't collect significant data to perform a large-scale strategy.

**Groundwater Re-injection** Article 104 of Legislative Decree 152/2006 generally prohibits discharges into groundwater. However, by way of exception to this prohibition, discharges of water extracted for thermal exchange may be allowed to be released into groundwater aquifers, provided that specific authorization is granted by the competent authority following a prior dedicated investigation.

The documentation must comply with the contents of Regional Council Resolution No. X/6203 dated 08/02/2017;

- For max daily discharge > 5 l/s: carry out at least one sampling of the water abstracted upstream of the heat pump, and one sampling at a point in the circuit located downstream of the heat pump before the discharge structure
- The maximum allowed groundwater temperature increment is of 5°C, while the maximum reinjection temperature is 21°C (23°C if the groundwater is very shallow)
- Description of the potential effects on the piezometric trend and on the temperatures of the aquifer subject to reinjection, based on both the expected reinjected flow rates and the transmissivity of the aquifer, for example by using analytical formulations or, preferably, analytical or numerical transport models.

**4) Comune di Milano (CM):** City government (poject partner) pursues environmental and sustainability actions through different instruments which all contribute to shape the groundwater governance processes in the city.

- **City policies**

  The Air and Climate Plan — an operational tool to address Climate Change, improve Air Quality, and achieve sustainability goals for 2030 and 2050. It includes concrete actions to mitigate our impact on the Climate and Air, as well as to adapt the City to the effects caused by Climate Change, including increasingly severe weather events.

  Shallow geothermal energy solutionst best reflect the principles of the plan and are prioritized for new constructions and energy retrofits.

  Groundwater Control Wells – Management of groundwater control wells to prevent the flooding of underground structures. This action is taken jointly with the public water service provider MM S.p.A.

- **Urban planning tool (PGT)**

  The PGT (Piano di Governo del Territorio) is Milan's primary urban planning instrument, guiding land use, infrastructure development, and environmental protection. The current version, PGT Milano 2030, was approved by the City Council on October 14, 2019, and became effective on February 5, 2020.

  The PGT is composed of:

  - Documento di Piano (DP): The strategic vision for urban development.
  - Piano delle Regole (PdR): Norms and regulations governing land use and building practices.
  - Piano dei Servizi (PdS): Plans for public services and infrastructure.
  - Geological Study: Provides **geological and hydrogeological data essential for planning.**

  These components collectively aim to ensure balanced urban growth, environmental sustainability, and resilience to climate change.

  The PGT addresses hydrogeological aspects aim to mitigate risks associated with groundwater and ensure sustainable urban development through:

  - Hydrogeological Risk Areas: Identification of zones prone to flooding and groundwater-related hazards.

- Flood Risk Maps: Updated to align with regional flood risk management plans (PGRA).
- Regulations for Subterranean Structures: Guidelines for the construction of basements and underground facilities, particularly in flood-prone areas

The PGT is periodically updated to adapt to evolving urban needs and environmental considerations. Updates are subject to:

- **Strategic Environmental Assessment** (VAS): A process to evaluate the environmental impacts of proposed changes.
- Public Consultation: Engaging stakeholders and the public to gather input on proposed amendments.
- City Council Approval: Final adoption of changes following assessments and consultations.

- **Public consultations** (Conferenza dei servizi) Organized for relevant projects

  Technical "round table" among stakeholders aimed to obtain positive/negative technical opinions on the feasibility of large projects on topics such as:

  - Environmental impacts vs benefits
  - Sustainable use of resources
  - Social and economic impacts
  - Agreement with City policies

  The stakeholders typically involved for groundwater-related topics are:

  - Regione Lombardia
  - ARPA
  - Città Metropolitana di Milano
  - ATO
  - Comune di Milano
  - Water Service
  - Energy Services

  This procedure is an **example of a shared governance process** that aims to collect technical opinions from different stakeholders that operate with groundwater from different perspectives.

Regarding data collection and handling, the following table summarizes the main stakeholder's roles and initiatives:

| | Collected by | Elaborated by | Shared by |
|---|---|---|---|
| **Groundwater Levels** | MM spa<br>Manual measurements every 6 months | MM spa | MM spa<br>Comune di Milano<br>Periodical hydraulic head maps |
| **Groundwater Withdrawals** | Regione Lombardia<br>Total annual extracted volume | | Città Metropolitana di Milano |
| **Groundwater Heat Pumps** | Regione Lombardia<br>Total annual extracted volume<br>(no data about thermal use) | | Città Metropolitana di Milano |

*Figure 9: Roles and initiatives of the main stakeholders in Milan*

## 3.3.5 Challenges and gaps - Milan

***Thermal use of groundwater***

### Data Gaps

**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 is available to the public.

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** exists. 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.

### Governance 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 **main challenges in the governance process** can be summarized as follows:

- There is a need to develop a **database of geothermal installations** by digitizing relevant data from existing systems and automatically collecting them for new geothermal systems requests.
- 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.
- Also, there is a **lack of planning and management instruments** that could help to optimize the groundwater thermal exploitation as well as to evaluate possible interference and sustainability issues of existing and new installations.
- The adoption of such tools would help to **streamline the management of new requests** by maximizing the extractable thermal potential and minimizing issues related to mutual interference between systems.
- There is **no proper regulation on** how to deal with data collection and management of groundwater resources for thermal use. The provincial authority on groundwater resources is in charge of the authorization process but doesn't have the ability to issue the regulation which is due to the regional authority. A **better cooperation among the authorities** would help to define throughout the regulation the essential needs for a better management.

## ***Groundwater extremes***

### Data Gaps

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. A coordinated approach of the mitigation measures that have been implemented (groundwater level control wells) is lacking. Particularly, its effectiveness is not quantified. In summary, the main data gaps are:

- **Historical time series of the groundwater level** (statistically significant, at least 10 years) are not available and information on which locations have been monitored and for how long are missing. The data is owned by the integrated water service but not digitally available to the public.

- A **database of underground structures** with their depth and level of waterproofing does not exist. The public construction company at least has the information on underground tunnels and metro station's location and depth.

Governance Gaps

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.

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.

### *Groundwater quality and ecosystem health*

Data Gaps

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.

***Rainwater infiltration***

Data Gaps

Groundwater recharge from infiltration in urban areas 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.

Governace 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 sewage network, reduce the efficiency of wastewater treatment plants, and lead to surface water pollution. Data related to these issues, such as hydrological data, sewage 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.

## 3.3.6 Relevance - Milan

Based on the validated results of the stakeholder questionnaire, targeted municipal interviews, and the World Cafe discussion held with local actors, four priority topics emerged as the most relevant for Milan in the context of sustainable groundwater management. These priorities reflect both the technical issues raised by departments, the governance and data challenges assessed in the MARGIN project.

Figure 10 shows the results of the questionnaire conducted with 5 stakeholders (see chapter 3.1.1.) as a radar chart. The relevance was averaged among the 5 responses scoring between 1 to 5.

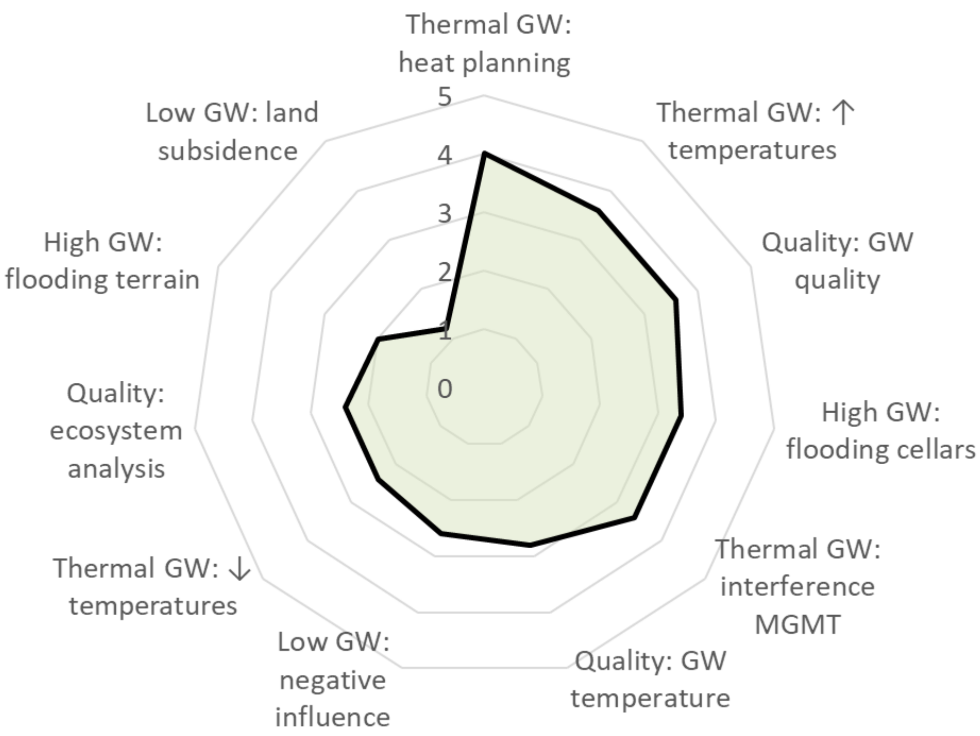


*Figure 10. Increasing relevance from 1 to 5 of groundwater topics in Milan according to the stakeholder questionnaire.*

The responses reflect the specific interests of the stakeholders who completed the questionnaire (e.g., groundwater quality was ranked as a high priority due to the involvement of the two drinking water suppliers). Together with additional stakeholder discussions the following relevant topics were identified:

- Thermal use of groundwater
- Groundwater extremes
- Groundwater quality
- Rainwater infiltration

### *Thermal use of groundwater*

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. This very rapid growth and the resulting criticalities motivated the technical agencies and the stakeholders to improve the management of the shallow geothermal resource, which is addressed in the following steps.

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 groundwater resources for thermal use.
- **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 is 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.

### *Groundwater extremes*

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.

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).

### *Groundwater quality*

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 thermal use. 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.

### *Rainwater infiltration*

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 historically has served – and continues to serve – as 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.

To integrate the findings from the stakeholder questionnaires and the insights derived from expert interviews, the synthesis table below is provided as a summary for the relevance analysis of the proposed topics.

*Table 10. Relevant topics for Milan. R - Relevance score: 1 – high, 2 – medium, 3 – low (not disclosed here). GW – groundwater.*

| Topic | R | Remarks/known issues |
|---|---|---|
| GW extremes | 1 | Underground structures flooding is becoming a frequent issue in recent years. Data collection highly fragmented among stakeholders. Extreme-level analysis not standardized for operational planning. No database of underground elements. |
| Rainwater infiltration | 2 | Natural infiltration is severely limited. Lack of coordination among surface water and groundwater (conflicting policies). |
| Thermal use of GW | 1 | Rapid increase of GWHP installations. Lack of data collection about system characteristics (water and energy). No control on the amount of water and energy really used. Lack of |

| | | |
|---|---|---|
| | | coordinated spatial planning to avoid the "first come, first served" approach. Lack of tools to comprehensively evaluate the impacts on the resource for a better management of new installations. |
| GW quality/ temperature/ ecology | 2 | Groundwater quality is regularly measured at drinking wells but information is poorly available (both for shallow and deep aquifers).<br>Groundwater temperature is not monitored by authorities.<br>Increase of the subsurface urban heat island effect needs to be monitored.<br>No groundwater biodiversity assessment exists. |

## 3.4 Pilot city assessment - Munich

### 3.4.1 Methodology - Munich

The methodical steps were designed to capture not only the availability and accessibility of data, but also the governance structures behind how this data is generated, shared, and used in decision-making processes. The general methodology is presented in Chapter 2: General assessment approach.

### 3.4.2 Stakeholders - Munich

In the city of Munich, the MARGIN project engaged a wide range of municipal departments and public authorities involved in groundwater-related planning, implementation, and data governance. The following actors were directly or indirectly involved in the processes analysed.

***Municipal authorities***

**Referat für Klima- und Umweltschutz (RKU)** - Munich's climate and environment department. The RKU drives climate protection and adaptation, coordinates the city's path to climate neutrality (2035), and handles core environmental tasks.

**Referat für Stadtplanung und Bauordnung (PLAN)** – PLAN leads citywide urban development and land-use control, it manages the city development plan (Bebauungsplan B-Plan) process and balances housing, open space, heritage, and development regulation.

**Baureferat (BAU)** – The city construction department is responsible for planning, building, and maintaining public space and municipal building projects through its divisions (e.g., civil engineering, road works, public buildings). Within the Baureferat, the **Lokalbaukommission (LBK)** is Munich's lower building control authority as well as the lower monuments and tree-protection authority. It issues and supervises building permits.

**Mobilitätsreferat (MOR)** - The Department of Mobility is responsible for planning, managing, and implementing mobility and transport policies in Munich. Its tasks include public transport coordination, cycling and pedestrian infrastructure, traffic management, parking, and the promotion of sustainable and climate-friendly mobility solutions.

**Münchner Stadtentwässerung (MSE)** – The municipal wastewater utility oversees sewage, wastewater treatment, and sludge disposal for Munich and connected municipalities.

### *State authorities*

**Wasserwirtschaftsamt München (WWA)** – Regional water management offices (Free State of Bavaria) are responsible for protection and monitoring of water bodies, river and stream development, and flood-risk management. They advise municipalities.

**Landesamt für Umwelt (LfU)** - The Bavarian Environment Agency (LfU) is the state authority for environmental protection and resource management. It provides scientific data, monitoring, and expertise on water, soil, air, climate, and nature conservation, supporting municipalities and ministries in evidence-based decision-making.

### *Utilities*

**Stadtwerke München (SWM)** - Stadtwerke München is the municipal utility company of Munich. It provides essential services including energy supply (electricity, district heating, cooling, gas), water management, public transport, and telecommunications. SWM plays a central role in Munich's transition towards renewable energy, sustainable mobility, and climate-neutral infrastructure.

**MGS – Münchner Gesellschaft für Stadterneuerung** (commissioned for Integrated Neighbourhood Concepts (Integrierte Quartierskonzepte – IQK) and renovation management (Sanierungsmanagement))

### *Universities and research facilities*

**Technical University of Munich (TUM)** - As one of the largest universities in Germany, TUM significantly contributes to groundwater science, esp. with its chairs of hydrogeology and hydrology. Within the MARGIN project, it conducts governance mapping, stakeholder questionnaires and interviews, and consolidates validated evidence and produces analytical reporting for MARGIN.

## 3.4.3 Data handling and inventory - Munich

In this section, the analysis is divided into two main parts.

First, we review the responses of **Sections A and B to the questionnaire**, which specifically addresses issues related to **data handling**. This provides an initial overview of how different actors perceive the current situation regarding data management and exchange.

Second, we compile and evaluate a **detailed inventory of the datasets** available for the city of Munich. The analysis of this inventory considers the following aspects:

-Name and content of the dataset
-Responsible institution or department
-Data format and structure (e.g., digital, analogue, raster, point, etc.)
-Update frequency and temporal coverage
-Accessibility (public, internal, restricted)
-Existing documentation or references

This systematic assessment enabled the identification of **gaps in data availability, quality, format, and ownership**, which form the basis for the subsequent governance and strategy analysis.

### *Data availability and handling*

Data availability and handling are covered by questions Q3-Q5 in the questionnaire. Crucial points besides the actual collection of the data are the data availability in digital formats and online as well as the accessibility to all relevant stakeholders.

Table 11 assesses the quality of data-handling by summarising the measured criteria and the digital and online availability.

| | |
|---|---|
| high data status | **high**: data are measured, available as machine-readable digital file and accessible openly online. |
| medium data status | **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 status | **low**: data are not measured, not digitally available, not online available, or there is no clear owner/awareness. |

*Table 11: Assessment of data-handling using criteria measured, digital and online availability.*

| Data / map | measured | digitally available | online available | data status |
|---|---|---|---|---|
| **Groundwater level series** | yes | yes | only WWA portal | Medium |
| **Groundwater temperature series** | yes | yes | partial[1] | 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 |

[1] some data can be founded in the portal

| | | | | |
|---|---|---|---|---|
| **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 |

**Measuring responsibilities:** According to the table, most groundwater and climate data are measured by state and municipal institutions, mainly LfU (Bavarian Environment Agency), WWA München, SWM, and the German Weather Service (DWD).
These agencies ensure systematic measurement of groundwater levels, temperature, rainfall, and geospatial parameters, showing a strong monitoring framework for physical data.

However, ecosystem data and water use/abstraction are not measured by any institution, revealing clear responsibility gaps in environmental and resource-use monitoring.

**Leadership clarity:** A city-wide coordination mandate is not unanimously recognised.

**Dataset coverage:** The table reveals that dataset coverage is strong for physical and hydrogeological parameters, such as groundwater levels, temperature, rainfall, and permeability, where data are consistently measured and available in digital form. In contrast, coverage is weak or absent for ecosystem, water-use, and recharge datasets, which remain incomplete or only modelled.

**Accessibility:** Data accessibility is generally limited. Most datasets are measured and digitally available, but access is restricted to institutional portals (LfU, WWA, SWM) or available only as PDFs or view-only maps. Only a few datasets, mainly climate and rainfall data from DWD, are fully open and machine-readable. Overall, accessibility remains partial and uneven, with few datasets publicly available online.

**Operational implications:** Because most data are not openly accessible, institutions cannot easily share or combine information. This limits cooperation between city and state agencies, makes it harder to plan based on evidence, and slows innovation and transparency. In short, data exist but are underused, reducing their value for managing groundwater and climate-related challenges.

### Summary of groundwater data handling according to Questionnaire

The results show that Munich has a solid technical base for groundwater data, with most datasets being measured and digitally available. However, online access is still very limited, as many datasets remain restricted to internal portals or PDF formats.

Data collection is strong for physical and hydrogeological parameters, but weak for ecosystem and water-use information, where no clear responsibility exists. Overall, groundwater data handling is technically advanced but institutionally fragmented, meaning that data are produced but not fully shared or integrated for effective management and planning.

### *Data inventory*

(see next page)

*Table 12: Data inventory*

| Parameter | Data set/data base | Short description | Status | Time | Data format | Publicly available | Responsible Organisation |
|---|---|---|---|---|---|---|---|
| General parameter | Name of the dataset or database | Short description about content of the data set | Is data updated or static (not updated regularly) | Time period covered by data or date of creation | Point, polygon, raster, PDF, analog | Report/paper, describing the data (short citation here) | Organisation/Deptarment responsible for the data |
| **Hydrogeology** | | | | | | | |
| **Groundwater level time series** | GKD Bayern – Bavarian Hydrological Service | The most direct source for groundwater level time series in Munich is the GKD Bayern portal. It provides daily groundwater level measurements from monitoring stations across Bavaria. Provides daily measurements for the last 12 months. Data includes groundwater level (in meters above sea level, m NN), depth to groundwater | Updated regularly (daily values for the last 12 months) | Rolling window of the last 12 months | Interactive web graph + downloadable CSV, PNG, or PDF | Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Gewässerkundlicher Dienst Bayern (via LfU / Bayerisches Landesamt für Umwelt) |
| | Wasserwirtschaftsamt München – Groundwater Overview | Official Bavarian Water Authority (WWA) provides a city-wide overview of groundwater monitoring. Refers to selected stations with time series, especially relevant for planning, flooding, construction, or research. | Partially (overview = static, links to live stations) | Varies per station. Different time periods covered. Ongoing and historic measurements | HTML + links to GKD (CSV, PDF export possible) | Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Wasserwirtschaftsamt München (WWA München) |
| | City of Munich – Official Groundwater Data Page | Describes over 2,000 monitoring wells in the city. Refers to time series availability and relevant parameters like temperature, depth, conductivity, etc. Mentions a comprehensive monitoring report that includes time series data (Zeitreihen) per station. | irregularly | Different time periods covered. Ongoing and historic measurements | csv-format | Not applicable online — data must be requested; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Referat für Klima- und Umweltschutz (RKU), Abteilung Stadtklima |
| | Full Monitoring Report | PDF with time series data | No (static report) | 2016–2020 (last known edition) | Full PDF document with time series plots and tabular summaries | Full PDF document with time series plots and tabular summaries | Referat für Klima- und Umweltschutz (RKU), Abteilung I/3 |
| **Groundwater temperature time series** | City of Munich – Groundwater Monitoring Report (PDF) | A technical report published by the Referat für Klima- und Umweltschutz (RKU) presenting measured groundwater parameters, including temperature. The data is static (not updated online) and represents a snapshot of monitoring results, likely between 2016–2020. It includes charts and station-wise summaries but no downloadable raw datasets. | irregularly | unspecified | PDF | PDF | RKU, City of Munich |
| | City of Munich – Groundwater Monitoring | Describes monitoring wells in the city. Refers to time series availability | No (static report) | Varies per station. Different time periods covered. Ongoing and historic measurements | csv-format | Not applicable online — data must be requested; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be | RKU, City of Munich |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | city-internally downloaded | |
| | TUM Study – Urban Groundwater Temperature Patterns | A scientific study conducted by the Technical University of Munich (TUM) analyzing groundwater temperature from 752 wells in urban areas, including Munich. It explores spatial and vertical variations in groundwater temperature but does not offer public access to time series data. It's a one-time study, not a live monitoring system. | Static | Varies per well | Research article, Gis data (shape files) | Research article Not applicable online - Digital available per request to TUM; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Technical University of Munich (TUM) |
| | Bavarian Long-Term Comparison Study (1990s vs. 2019) | This academic research compares groundwater temperature profiles across Bavaria — including Munich — between the early 1990s and 2019, identifying evidence of groundwater warming due to climate change. The data comes from two points in time (no continuous time series), published in a research article. Conducted by Martin Luther University Halle-Wittenberg. | No | Early 1990s vs. 2019 | Research article | Research article | Martin Luther University Halle-Wittenberg |
| **Groundwater temperature vertical profiles** | LfU Bayern – Temperature-Depth Profiles | LfU has been conducting quarterly temperature-depth profile measurements since 1990 in ~350 wells across Bavaria, including the Munich area. It's the most reliable institutional source for vertical temperature data. | No | Since 1990, quarterly (Feb, May, Aug, Nov) | Internal database (not open access); summary webpage | Not applicable online - digital avialabe per request to LfU; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | LfU Bayern (Bayerisches Landesamt für Umwelt |
| | City of Munich – Groundwater Data Page | Provides general info and static average groundwater temperature (~12 °C), but no vertical profile data is available online. | Static | no clear year indicated) | Website + optional data request | | Referat für Klima- und Umweltschutz (RKU), Stadt München |
| | TUM Scientific Study – Urbanization-Induced Warming | Academic study analyzing temperature-depth profiles in 752 wells across Munich. Focuses on thermal dynamics and anthropogenic influences. Profiles used for modeling. | Static, not updated | data collection over several periods (from 2014 ongoing) | Research article (PDF), digital data csv-format | Research article (PDF), Not applicable online - Digital available per request to TUM | Technical University of Munich (TUM) |
| **Groundwater table contour maps**<br><br>**Average level** | Groundwater Contour Map 1990 | Historic contour lines showing groundwater table levels from<br>1990 across Munich. | Static | 1990 | PDF (map); GIS data (shape-file) | City of Munich groundwater info page, RKU; Digital available per request to RKU | Referat fur Klima- und Umweltschutz (RKU) |
| | Average Highest Groundwater Level Map | Map showing the average maximum recorded groundwater levels used in planning and risk assessments. | Static | Long-term average (year not specified) | PDF (map) | City of Munich groundwater info page, RKU; digital available per request to RKU | Referat fur Klima- und Umweltschutz (RKU) |
| **High level**<br><br>**Low level** | HW 1940 Maximum Groundwater Level Map | Historic map representing the maximum groundwater level reached in 1940 flooding events. | Static | 1940 | CAD (DXF/DWG),; ); GIS data (shape-file) | City of Munich groundwater info page, digital availabe per request at RKU | SG 1/1 GeodatenService, Landeshauptstadt Munchen |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Medium Low Groundwater Level Contour map | Map showing city-wide Medium Low Groundwater Contours in high resolution | Static | 2014 | GIS-data (shape-files) | City of Munich groundwater info page, RKU; BayerischerUmwelt Atlas, Digitally availabe per request to LfU or TUM;<br>Included also in the Groundwater Management Software **GEO.KW-Tool** – data can be city-internally downloaded | Bayerisches Landesamt für Umwelt (LfU) Technical University of Munich (TUM)) |
| **Hydrogeological maps** | | | | | | | |
| **Groundwater bodies** | 3D Hydro-Geological Model – Munich | 3D Geological model based on >20,000 interpreted boreholes modelling the lithological classes of the subsurface. Hydrogeological bodies were classified and mapped. | Static | Published 2016 | PDF (scientific report), digital data (voxel, ascii) | Digital availabe per request to LfU or TUM | Technical University of Munich (TUM) Bayerisches Landesamt für Umwelt (LfU) |
| | Maps of top and bottom of hydrogeological bodies (units) | Maps showing the top and bottom surface of the identified groundwater bodies in the qarternary and tertiary deposits base don the 3D geological modell | Static | Published 2016 | PDf, digital GIS-data (shape files and raster) | Digital availabe per request to LfU or TUM | Technical University of Munich (TUM) Bayerisches Landesamt für Umwelt (LfU |
| | Maps of hydraulic interaction zones in the city of Munich | Maps showing the hydraulic intersection (hydraulic windows) between different groundwater bodies. | Static | Published 2016 | PDf, digital GIS-data (shape files and raster) | Digital availabe per request to LfU or TUM | Technical University of Munich (TUM) Bayerisches Landesamt für Umwelt (LfU |
| **Hydraulic conductivity /permeability coefficient** | Hydrogeological Concept Model – Munich | Conceptual model based on >20,000 interprete d boreholes (730 selected). Includes hydraulic conductivity estimation to support urban groundwater use (e.g., geothermal). | Static | Published 2016 | PDF (scientific report), digital data(voxel, ascii), GIS -data (point shape-files) | Digital availabe per request to LfU or TUM; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Technical University of Munich (TUM) Bayerisches Landesamt für Umwelt (LfU) |
| | WWA München – Pumping Test and Monitoring Stations | Bavarian Water Authority (WWA) maintains ~140 groundwater stations that monitor levels, quality, and indirectly assess permeability. No raw data online. | Partially updated | Current | Physical network (no online map) | Institutional info on WWA Munich | Wasserwirtschaftsamt München (WWA München) |
| | Hydraulic conductivity point data set - Pump test analysis data | Point data set derived from analyses frompumping tests provided by the WWA and RKU | Static | Published 2016 | GIS -data (point shape-files,) | Digital availabe per request to LfU or TUM; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Technical University of Munich (TUM) Bayerisches Landesamt für Umwelt (LfU) |
| | Hydrogeological Expert Report – Untergrundplan LHM | Technical report using subsurface database (Untergrundplan-LHM) including permeability and geology for city planning. | Static | Based on 2021 version of LHM-DB | PDF | | RKU – Environmental Department, Munich |

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|---|---|---|---|---|---|---|---|
| | Geologica Bavarica, TUM (2022) | Hydraulic conductivity (kf) for Quaternary gravel aquifer in Munich; average ~$1.7\times10^{-2}$ m/s, range from $3.0\times10^{-5}$ to $5.0\times10^{-2}$ m/s. | Static (one-off study) | 2022 | PDF report | Geologica Bavarica Band 122 | Technical University of Munich (TUM) / Bayerisches Landesamt für Umwelt (LfU) |
| **Groundwater depth to surface** | Average Groundwater Depth (Flurabstand) | Map showing average distance between land surface yand groundwater table across Munich (Staus 1990)<br>Map showing average distance between land surface yand groundwater table across Munich (Staus 2014) | Static | Long-term average (year not specified) | PDF, Web viewer GIS data (shape-files, raster) (status 2014) | City of Munich groundwater info page, RKU<br>Lfu UMweltatalas Bayern (status 2014); Digital availabe per request to LfU or TUM; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | City of Munich (RKU)<br>Bayerisches Landesamt für Umwelt (LfU)<br>Technical University of Munich (TUM) |
| | GKD – Distance to Surface (e.g., München KP 16) | Real-time monitoring of distance to groundwater surface across<br>specific measurement stations. | Updated regularly (daily data) | Last value July 2025 (rolling 12 months) | Web interface with CSV download | | GKD Bayern offers live, station-based data such as for "München KP 16", showing real-time depth from surface to groundwater level; data is updated daily and downloadable. |
| **Aquifer thickness** | Aquifer Thickness (saturated) map | Map showing city- wide aquifer thickness in high resolution | Static | 2014 | GIS-data (shape-files, raster) | City of Munich groundwater info page, RKU; BayerischerUmwelt Atlas, Digital availabe per request to LfU or TUM; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Bayerisches Landesamt für Umwelt (LfU)<br>Technical University of Munich (TUM) |
| **Basis of aquifer** | Aquifer basis Isoline map | Map showing the isolines from the quarternay aquifer basis based on the interpretation of 20.000 boreholes in the framework of the GEPO project from TUM | Static | 2016 | GIS-data (shape-files, raster) | City of Munich groundwater info page, RKU; BayerischerUmwelt Atlas, Digital availabe per request to LfU or TUM; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Technical University of Munich (TUM) |
| **Infrastructure** | | | | | | | |
| **Sewage system** | Municipal Sewage System | Overview of Munich's sewer network length, treatment plants, and retention capacity | Updated regularly | Ongoing / Recent updates | digital dataset (dxf) | for internal use by MSE) | Münchner Stadtentwässerung (MSE) |
| | Operational & Planning Details | Drainage fees, underground planning, property-specific sewage layouts | Static (per request) | Current data per individual request | Web portal / Appointment | City drainage planning portal | MSE / City Building Dept. |
| | Sewer Network Stats | Network length, coverage, and plant capacities | Updated annually | 2022 stats reported | Web article | MSE 2022 Annual Report (via Wiki) | MSE / City reports |

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|---|---|---|---|---|---|---|---|
| | Stormwater Infrastructure | Locations and capacities of stormwater retention and overflow basins | Updated annually | 2022 Annual Report | Web report / PDF | MSE Annual Report 2022 | MSE / City Reports |
| **District heating system** | SWM – District Heating System Overview | Overview of Munich's district heating system, including network length (~900 km) and service coverage estimates. | Updated regularly | Current / ongoing | GIS dataset (shape-file) | SWM internal use | Stadtwerke München (SWM) |
| **Construction Sites** | Dataset about construction site with temporally groundwater use | Documentation about construction sites affecting groundwater and using groundwater abstraction | Uncomplete singular dataset | No update | GIS dataset (shape -file) | Internal dataset from BAU und WWA | BAU and WWA |
| **Culvert wells** | Overview of the location for culvert wells for the subway in the city | Spatial overview of culvert well constructed for subway lines to guarantee groundwater flow | Actual dataset | Updated regularly | GIS dataset (shape -file) | Internal dataset from BAU und SWM | BAU and SWM |
| **Buildings basement reaching groundwater levels** | Overview of the location from buildings reaching the groundwater | Spatial dataset mapping buildings with deep basement reaching the groundwater. Locatin and depth of the buildings are mapped | Uncomplete singular dataset | No update | GIS dataset (shape -file) | Internal dataset from BAU und WWA | BAU and WWA, TUM |
| **Climatology** | | | | | | | |
| **Climate observations / rainfall** | DWD Climate Data Center (CDC) | Free, regularly updated daily and monthly precipitation datasets for Munich airport station. | Updated regularly | Historical to present | CSV / Structured (via FTP) | DWD Climate Data Center Documentation | Deutscher Wetterdienst (DWD) |
| | DWD Munich (Airport) Precipitation Tables | Daily and monthly rainfall totals and climate tables for Munich airport observation station. | Updated regularly | Modern observation period | HTML tables | DWD Local Climate Precipitation Tables | DWD |
| | Munich Climate Statistics (1955–2020) | PDF report including detailed rainfall amounts and days with precipitation for Munich over several decades. | Static (published) | 1955–2020 | PDF report | Münchner Statistik, Quarter IV, 2021 | Statistical Office Munich |
| | Meteo Physik Munich – Quicklook Data | Hourly climate observations for Munich, including rainfall in mm for specific dates like June 2020. | Updated per period | June 2020 (example dataset) | HTML (hourly table) | UoM Meteorology Dept. Quicklook data | LMU Meteorology Department |
| | Munich Rainfall Overview (General) | Annual rainfall estimates (~1000 mm/year) with seasonal patterns for Munich. | Static | Average climate data | Web summary | Climate-data.org City Overview | Independent Climate Data Site |
| | Munich Precipitation data measurements | At ten stations distributed in Munich the MSE collect permanently precipitation data | Permanent measrements | Ongoing | Csv data/Excel data | Not public available, internal dataset | MSE |
| **Surface information** | | | | | | | |
| **Surface sealing** | Munich Sealing Map (GeodatenService) | Digital map showing sealed surfaces across Munich's city area | Updated irregularly | starts from 1984 | Digital data GIS-data (shape-file) or PDF | City geodata portal listing "Versiegelte Flächen" | GeodatenService, City of Munich, RKU |
| | Sealing Degree Reports (Statistical Office) | Quantitative stats: e.g., 44% of Munich's area is built or paved (buildings + roads) as of 2017. | Static (as of 2017) | March 2017 | PDF (report) | Grau, Grün und Blau – Bodennutzung München (Statistical Office) | Statistical Office, City of Munich |
| **Digital elevation model** | DGM 1m – Munich Digital Terrain Model | High-resolution digital elevation model (terrain only, no buildings/vegetation) at 1 m resolution. | Periodically updated (every year) | As of at least 2023 | Raster (Digital Terrain Model) | GIS portal metadata listing DGM 1 m layer | City of Munich / GeodatenService; Landesvermessungsamt |
| | Bavarian Elevation Models (Open Data) | Bavaria-wide DTM models (DGM10, DGM25, etc.) from official geodata. | Periodically updated | Not specified | Raster (DTM) | Wiki overview of elevation data availability in Bavaria | State Surveying Agencies (Bayern) |
| | National DGM – Germany Standard Grid Sizes | National digital elevation grid layers: DGM10, DGM25, DGM50, DGM200, DGM1000. | Updated periodically | Ongoing / national standards | Raster (various grid resolutions) | AdV national report on DEM grid standards | AdV / Federal Survey System |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | NextGIS DEM – Munich Region | Downloadable DEM at 30 m resolution; includes elevation contours and raster data. | Likely static snapshot | Time of extraction (not specified) | Raster (30 m grid), contours | NextGIS metadata page for Munich DEM | NextGIS (Third-Party Platform) |
| **Amount of water used / groundwater Discharge / water demand** | Groundwater utilizations | Permissions report from all utilizations | Reports Updated recently | All existing utilizations | Reports at WWA; Digital Data, GIS-data (point-shape file) | Not public available, internal database (Wasserbuch) at LfU-and WWA | WWA and LfU |
| | Groundwater utilization using over 100,000 m3/y | Operators must annually report about the amount of abstraction and, if a thermal use, about the temperature spreading, respectively the injection temperature. | Reports Updated recently | all existing utilizations over 100,000 m3/y | Reports pdf, ongoing digitalization into a digital database | Not public available, internal database (Wasserbuch) at LfU-and WWA | WWA and LfU |
| | Groundwater-Based Thermal Energy Use | Over 3,000 groundwater heat pump systems operating in Munich, collectively generating ~300 GWh thermal annually. | Reports Updated recently, digital point data from 2020 | all existing utilizations | Reports at WWA; Digital Data, GIS-data (point-shape file) | Digital availabe per request to LfU or TUM; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | City-wide energy infrastructure |
| **Temperature maps** | Groundwater Temperature Map (2014) | Map showing groundwater temperatures of the Quaternary aquifer in Munich; measured at 1 m below water table at low-flow conditions. | Static (snapshot) | April 2014 standard condition | GIS dataset (shape -file, raster) | City of Munich groundwater info page, RKU; BayerischerUmwelt Atlas, Digital availabe per request to LfU or TUM; Included also in the Groundwater Management Software **GEO.KW-Tool**– data can be city-internally downloaded | Technical University of Munich (TUM) / Bayerisches Landesamt für Umwelt (LfU) RKU |
| | Geoportal München – Temperature Layers | Interactive map layers in the city's GeoPortal, including groundwater temperatures for geothermic assessments. | Depends on update | Likely current | Web-based layers | GeoPortal listing for geologic/environmental data | GeodatenService, City of Munich |
| | Thermal Influence Study (Böttcher 2022) | Academic analysis of urban thermal influences on groundwater temperature in Munich, identifying anthropogenic heat effects. | Static (study) | Published 2022 | Digital data, GIS data (raster) | Digital availabe per request to TUM | Technical University of Munich (TUM) |
| **Chemical data, groundwater quality** | Munich Daily Water Consumption | Approximately 300,000 m³ of drinking water is consumed per day in Munich; ~230 litres per person. | Updated regularly | February 2025 | PDF | SWM published analysis report | Stadtwerke München (SWM) |
| | PFAS Reports – WWA München | Regional monitoring of PFAS in groundwater at sites like airport, Moosach, and rivers. | Updated periodically | Up to mid-2024 | PDF (reports/maps) | WWA Munich PFAS monitoring initiative | Wasserwirtschaftsamt München |
| **Groundwater microbiology samples (observation wells)** | Groundwater Quality Monitoring – Munich | Ongoing monitoring of groundwater wells in Munich; includes physical and chemical parameters, unclear if microbial data is consistently included. | Updated regularly | Ongoing – Weekly sampling | PDF Report, digital data, internal data at RKU | Grundwasserüberwachung Gesamtbericht – RKU München | Referat für Klima- und Umweltschutz (RKU), Landeshauptstadt München |
| | Urban Groundwater Quality Study (2025) | Integrated sampling of groundwater wells (~100 wells citywide) including microbial and invertebrate indicators. | Static (study) | Pre-2025 | Samplig data; Excel data | Becher et al., 2025 – Journal of Hydrology; Bruder 2021; data available per request from TUM | Technical University of Munich (TUM), Tecnical University Vienna, RKU |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Groundwater fauna samples (observation well** | Urban Groundwater Quality Study (2025) | Integrated sampling of groundwater wells (~100 wells citywide) including microbial and invertebrate indicators. | Static (study) | Pre-2025 | Samplig data; Excel data | Becher et al., 2025 – Journal of Hydrology; Bruder 2021; data available per request from TUM | Technical University of Munich (TUM), Tecnical University Vienna, RKU |

*Analysis of the data collection inventory*

During the evaluation of Munich's dataset inventory, aspects such as content, responsible institutions, formats, update cycles, accessibility, and documentation were reviewed. This assessment revealed key gaps in data availability, quality, format, and ownership,

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.

*Table 13: Assessment of data-inventory and principal deficiencies of datasets*

| 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.<br><br>Measured and digitally available at source level (RKU, TUM), but not maintained as a dynamic, machine-readable | Medium |

| | | |
|---|---|---|
| | 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 integrated into the municipal Geoportal, preventing the creation of a unified, up-to-date thermal monitoring layer. | Medium |
| **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 |

The assessment of Munich's groundwater-related data catalogue demonstrates that the city possesses an extensive and technically mature data landscape. Most datasets are measured, digitally available, and institutionally maintained, confirming a high overall level of data generation and quality assurance across hydrogeological, climatic, and infrastructure domains.

However, data accessibility and interoperability remain limited. While several key datasets, such as groundwater level time series, digital elevation models, surface sealing, and rainfall data (DWD), reach Medium–High status due to their measurement continuity and digital formats, many other categories fall into Medium or Low due to restricted access, static formats (PDFs, view-only layers), or unclear stewardship.

Institutional data silos persist between municipal (RKU, MSE, BAU), state (LfU, WWA), and research entities (TUM). Although internal tools such as the GEO.KW-Tool provide structured digital access for municipal users, there is no unified open-access platform integrating hydrological, geological, and infrastructure datasets. This fragmentation limits data reuse for planning, modeling, and policy design, particularly regarding thermal groundwater use, infiltration monitoring, and groundwater–infrastructure interactions.

Thematic gaps are most evident in biological and microbiological datasets, which exist only as isolated academic studies and lack systematic monitoring or institutional ownership (Low status). Conversely, hydrogeological parameters (levels, conductivity, aquifer geometry) and climatic inputs (rainfall, DEMs, sealing) are well-developed but remain internally managed and not openly accessible.

In summary, Munich's groundwater data system demonstrates high measurement capability but medium governance maturity.

### *Combined Overview for Questionnaire and Data Inventory*

Both the questionnaire and the data inventory analysis confirm that Munich has a strong technical foundation for groundwater data management, with most datasets being regularly measured, digitally stored, and maintained by state agencies such as LfU, WWA, SWM, and DWD. This reflects a high level of technical reliability and well-established monitoring systems for physical parameters such as groundwater levels, temperature, rainfall, and permeability.

However, both assessments highlight similar weaknesses. Data accessibility is limited by institutional boundaries, many datasets are available only through restricted portals, PDFs, or view-only layers, which reduces interoperability and prevents consistent data sharing across city and state levels. At the same time, thematic coverage remains uneven: while physical and hydrogeological data are well developed, ecosystem, water-use, and recharge data are either incomplete, modelled, or not measured at all, with no clearly assigned institutional responsibility.

These findings reveal a parallel message from both the questionnaire and the data inventory: Munich's groundwater data system is technically advanced but institutionally fragmented. To fully unlock its potential, efforts should focus on improving open accessibility, clarifying responsibilities for unmeasured datasets, and strengthening coordination mechanisms between municipal and state actors. This would transform a technically robust but closed system into an integrated, transparent, and operationally useful framework for sustainable groundwater management.

low impact
medium impact
high impact

**low**: Data exists but access depends on clearance (KRITIS/privacy); without authorisation, lack of access can block progress.

**medium:** Applicable to some datasets or departments; resulting problems are moderate (manual retyping, occasional outdated info) and fixable with process changes.

**high:** Affects many datasets or departments and can cause serious or repeated problems (duplicate fieldwork, conflicting figures, weeks of delay).

*Table 14: Identification of data gaps*

| Gap | Weakness | Observed Evidence | Potential Effects | Risk |
|---|---|---|---|---|
| **Lack of open accessibility** | Most datasets are restricted to internal portals or PDFs (no open API or download). | Questionnaire and catalogue show limited online access via WWA, LfU, and SWM portals. | Limits data sharing, slows coordination, and prevents transparent decision-making. | **High** |
| **Fragmented institutional ownership** | Overlapping responsibilities between LfU, WWA, RKU, and SWM; unclear stewardship for ecosystem and water-use data. | Repeated in both questionnaire and catalogue: no single coordinator for environmental datasets. | Leads to duplicated efforts, inconsistent datasets, and weak accountability. | **High** |

| | | | | |
|---|---|---|---|---|
| **Uneven thematic coverage** | Strong data on physical parameters but missing ecosystem, water-use, and microbiological data. | Ecosystem and abstraction datasets not measured; catalogue and Q1 confirm absence. | Gaps in understanding full groundwater system; limited support for integrated planning. | **High** |
| **Non-standardized data formats** | Different formats (PDF, CSV, shapefile, internal databases) hinder integration. | Observed in catalogue: DWD data are open CSVs, others only PDFs or view-only layers. | Requires manual retyping or conversion; increases human error and delays. | **Medium** |
| **Limited data updating frequency** | Many datasets are static (2014–2016) or updated irregularly. | Identified in catalogue: temperature maps, aquifer models, and reports outdated. | Risk of using outdated data for policy or modelling; reduces data credibility. | **Medium** |
| **Restricted KRITIS data (infrastructure layers)** | Critical infrastructure datasets (sewer, heating) protected for security/privacy. | MSE and SWM datasets accessible only internally; no external clearance. | Delays in cross-departmental planning and risk analysis; blocks progress without authorization. | **Low** |
| **Insufficient linkage between measured and modelled data** | Model-based datasets (e.g., groundwater recharge) not connected to observed series. | Recharge map not measured | Reduces model reliability and validation capacity. | **Medium** |

The analysis shows that high risks are linked to limited open accessibility, fragmented institutional ownership, and missing thematic data (ecosystem and water-use), which significantly affect coordination and transparency.

Medium risks relate to outdated datasets, inconsistent formats, and weak linkage between measured and modelled data, causing delays and reducing reliability but fixable through improved procedures. Low risks concern KRITIS-protected infrastructure data, where access restrictions are justified but can slow cross-departmental work. Overall, the main challenge is institutional fragmentation and restricted access, not data absence.

### 3.4.4 Governance Analysis

#### *Rainwater Infiltration*

##### Governance process description

Munich's Sponge-City concept is organized in two phases.

> **-Phase 1 – Planning** sets the regulatory and technical baseline, led by PLAN with RKU, with inputs from MSE, BAU, and WWA. This phase is based the city's development plan (B-Plan).
>
> **-Phase 2 – Installation** is divided into A) City-scale/Public spaces, where BAU leads civil works, MSE acts as the hydraulic authority, and RKU participates in case waterlaw permits are required; and B) Private buildings/parcels, where MSE approves and tests property drainage in parallel with LBK building permits and, as needed, RKU issues waterlaw permissions.

Each track advances through defined decision gates from kick-off to technical review, construction/supervision, functional testing and approval, and, where applicable, storm-water fee adjustment. The accompanying governance **flowcharts 1, 2 and 3** track the detailed steps and departmental roles, which are described in the following sections.

##### Main Actors involved

**PLAN**: Leads urban planning and coordinates the B-Plan process, ensuring land-use frameworks integrate infiltration and climate-adaptation measures.

**RKU**: Responsible for climate and environmental assessments, water-law permits, and integrating adaptation requirements into planning and implementation.

**MSE**: Acts as hydraulic authority, approves and supervises property drainage systems, defines technical criteria for infiltration, and manages storm-water fees.

**BAU**: Executes civil works in public spaces (streets, schools, municipal buildings) and oversees construction quality, safety, and maintenance.

**WWA**: Regional water authority providing expert opinions, technical advice, and regulatory guidance on groundwater protection and infiltration feasibility.

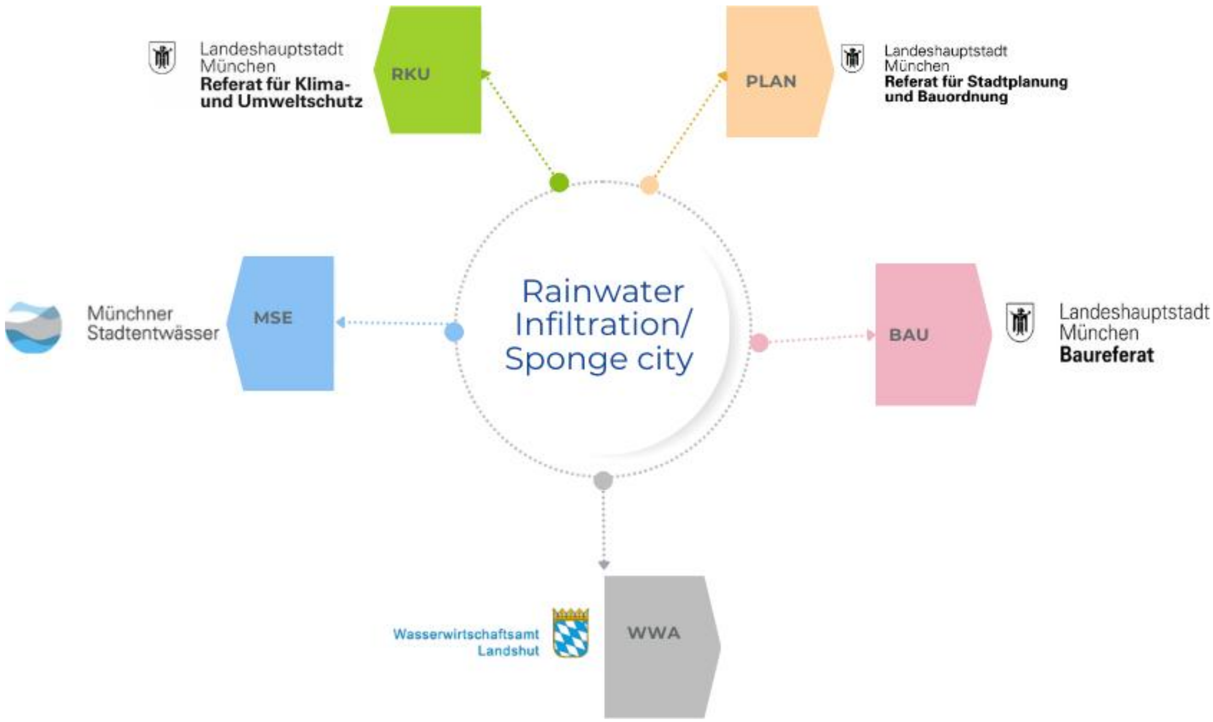
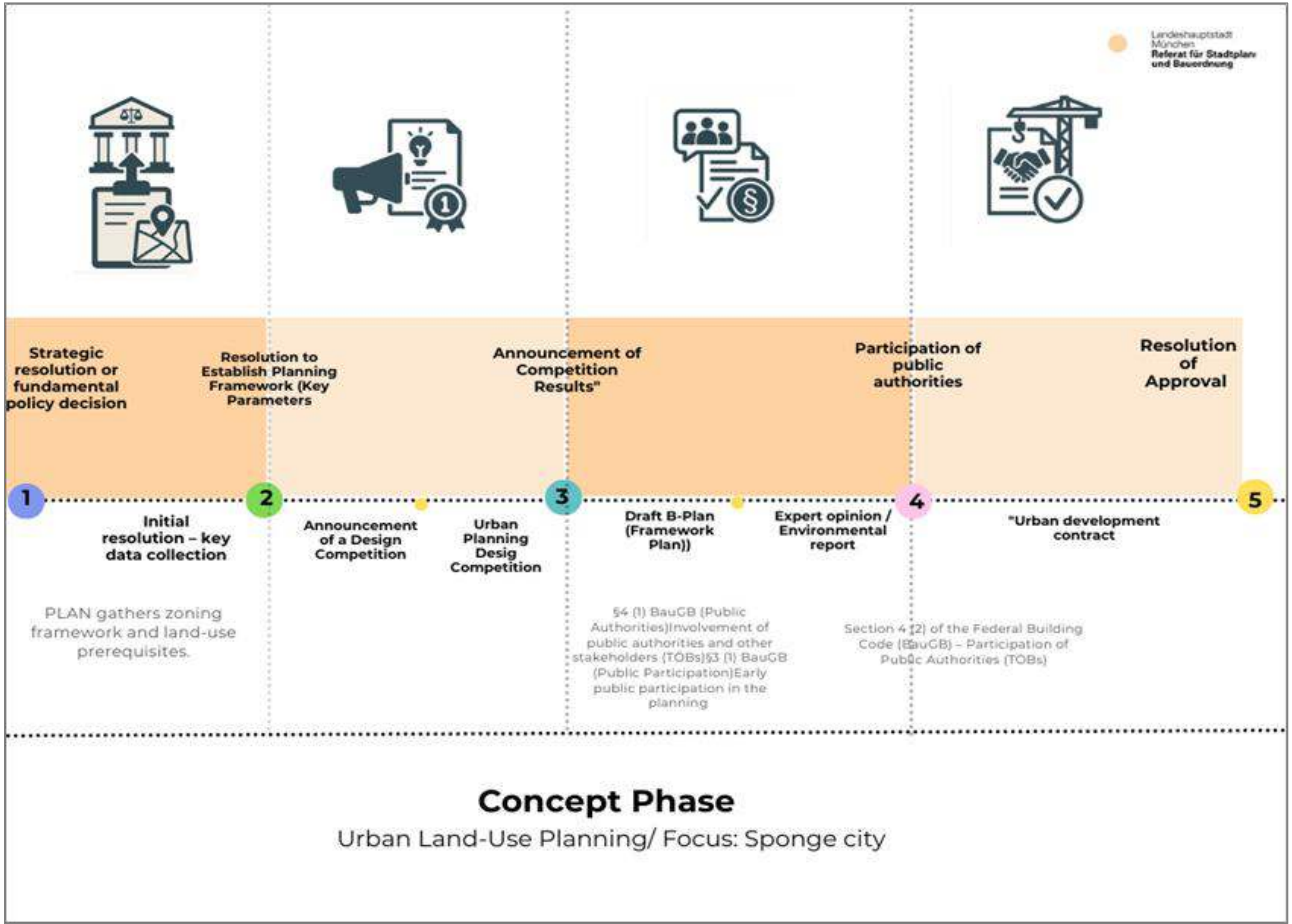


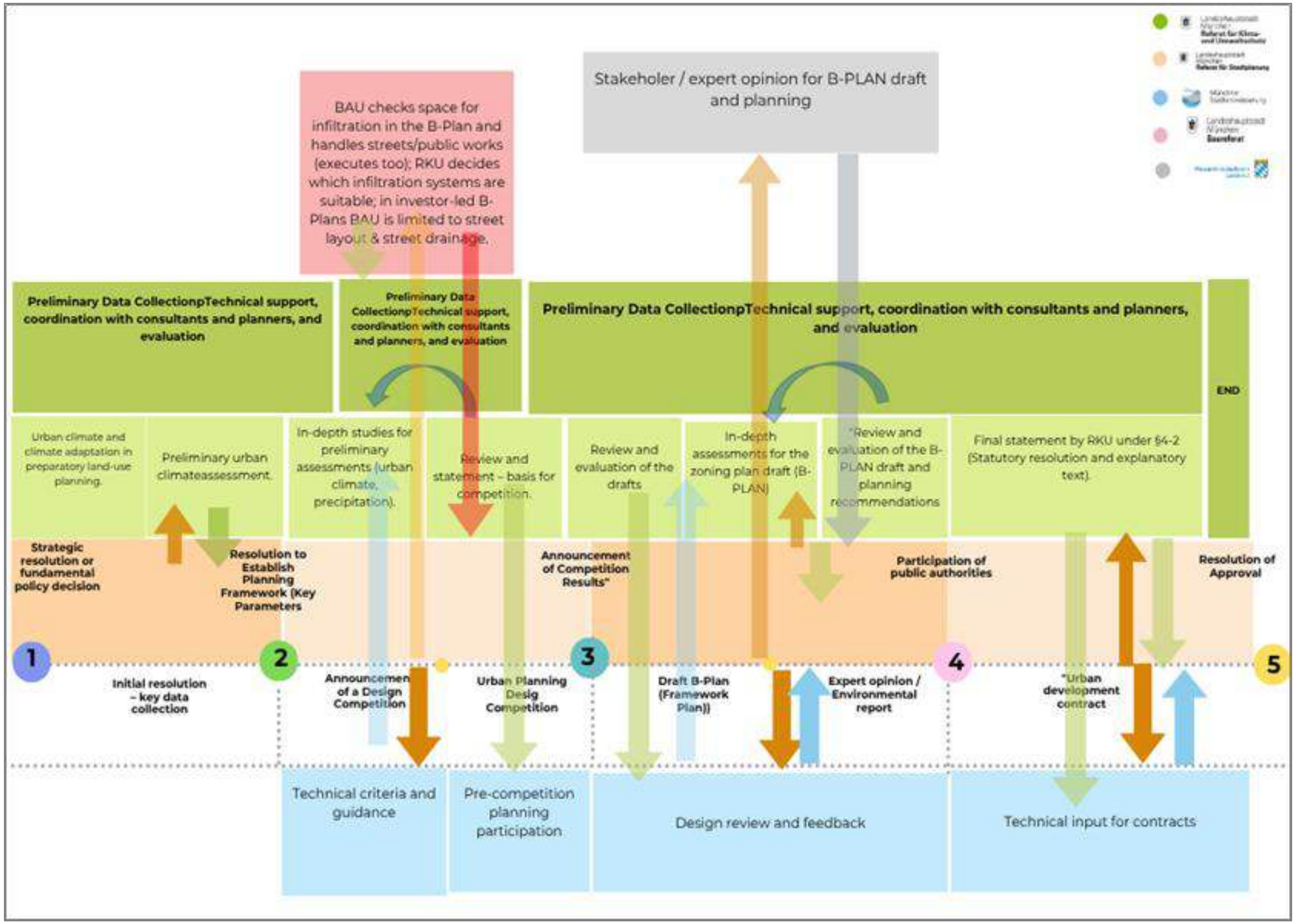

*Figure 11: City departments that are involved in the sponge city strateg*

*Figure 11: Governance Process of the sponge city strategy - phase I: concept phase for PLAN*



A) Planning Phase on City-Scale

*Figure 12: Governance Process of the strategy – phase I: concept phase for all sponge city departments*



### Step 1: Strategic Resolution / Fundamental Policy Decision

- **PLAN (lead):** initiates the resolution and coordinates baseline data collection.
- **RKU (close partner):** conducts the preliminary urban-climate assessment and integrates climate-adaptation aspects into preparatory land-use planning.
- **Nature of work:** preliminary data collection, technical support, coordination with consultants/planners, and initial evaluation.

### Step 2: Resolution to Establish the Planning Framework (Key Parameters)

Announcement of a Design Competition and the Urban Planning Design Competition

- **PLAN ↔ RKU (close interaction):**
- **RKU:** produces in-depth studies for preliminary assessments (urban climate, precipitation) and issues the formal review/statement that underpins the competition brief.
- **MSE:** provides technical criteria and guidance; participates in pre-competition planning.
- **BAU:** verifies during the B-Plan process that sufficient space is reserved for potential infiltration measures; RKU assesses which infiltration systems are technically suitable. BAU plans street drainage and public buildings (e.g., schools) and acts as executing entity for public works. In standard investor-led B-Plans, BAU's role is limited to street layout and street-drainage planning.

### Step 3: Announcement of Competition Results

Draft B-Plan (Framework Plan) and Expert opinion / Environmental report

- **PLAN:** prepares the Draft B-Plan framework and commissions expert opinions for the environmental report.
- **RKU:** reviews and evaluates the drafts, conducts in-depth assessments for the zoning plan draft (B-Plan), and issues planning recommendations.

- **MSE:** undertakes design review and provides technical feedback.
- **WWA:** participates as stakeholder/expert, providing an expert opinion on the B-Plan draft and planning. (Legally mandated to cooperate; RKU may accept or rebut the opinion.)
- **Collaboration:** RKU, WWA and MSE may produce overlapping expert inputs at this stage; alignment of content and data sources is therefore essential.

4

### Step 4: Participation of Public Authorities

Urban development contract

- **PLAN (lead):** coordinates the contract process.
- **RKU:** issues the final statement under § 4-2 (statutory resolution).
- **MSE:** provides technical input to the contract where needed.

5

### Step 5: Resolution of Approval

- The final plan is approved, closing the planning phase.

### Data Governance insights

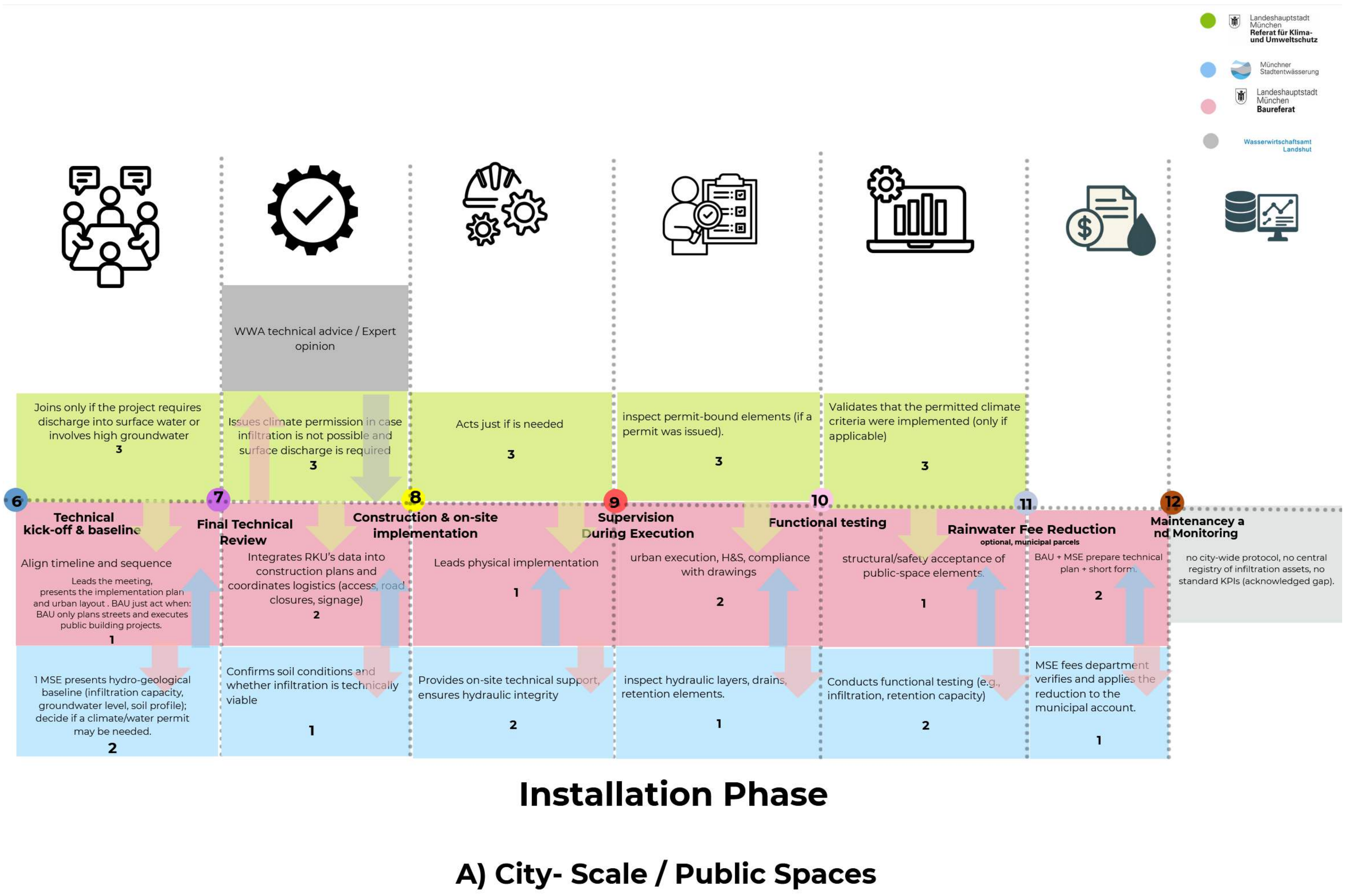
Groundwater monitoring wells are operated by RKU, MSE, SWM and BAU within a common database. RKU holds primary access, updates the shared database, and (in practice) handles most groundwater-data requests.

B) Installation Phase on Scale/Public Spaces

City-

*Figure 13: Governance Process sponge city strategy – phase II: phase for city-scale/public*

*of the installation spaces*



### Step 6: Technical Kick-off and Coordination

The installation phase opens with a kick-off convened by BAU, which aligns programme, construction sequencing and safety logistics for the street or public-space site. MSE presents the hydrogeological baseline—indicative infiltration capacity, groundwater levels and soil profile—and flags any constraints that could require alternative discharge. RKU attends when non-infiltration is likely, to pre-assess the need for a water/climate permit. The meeting closes with a shared workplan and a division of technical responsibilities.

### Step 7: Final Technical Review and Execution Planning

At this stage, MSE issues the go/no-go decision on infiltration, confirming technical feasibility and defining hydraulic criteria such as sizing, overflow routes, and connection points. In parallel, BAU prepares final execution drawings and site logistics, including street closures, detours, access, and signage. If infiltration is not feasible or subject to groundwater/surface-water regulations, RKU issues the necessary water-law permit, with WWA providing expert input as needed. The step concludes with a single agreed solution—either infiltration or an alternative discharge—alongside all permits and construction-ready documentation.

### Step 8: Construction and On-Site Implementation

Civil works proceed under BAU's lead—permeable pavements, vegetated swales, infiltration trenches and sub-surface retention. MSE supports on site, resolving deviations from preliminary conditions and validating field adjustments to hydraulic details. RKU intervenes only if permitted conditions must be modified. All decisions and test results are documented in real time to ensure traceability.

### Step 9: Inter-Departmental Technical Supervision

Quality control is shared. BAU supervises urban execution and occupational safety; MSE inspects hydraulic layers, drainage elements and retention volums. Findings are documented in coordinated inspection notes; non-conformities are corrected before functional testing.

### 10 Step 10: Functional Testing and Provisional Acceptance (Abnahme)

MSE verifies hydraulic functionality (e.g., infiltration capacity/leak tests) and issues the test protocol; BAU confirms structural integrity and public-space safety as part of works acceptance; and, where a water-law permit applies, RKU verifies compliance with permit conditions before commissioning. The acceptance (Abnahme) follows once these checks are complete

### 11 Step 11: Stormwater Fee Reduction for Municipal Parcels (Optional)

If a city-owned parcel or building site installs measures that measurably reduce runoff to the sewer, BAU and MSE submit a short dossier (technical plan + form). The MSE fee unit checks eligibility and applies any stormwater-fee reduction to the city's account. Street right-of-way alone is usually not a parcel-based fee object; in projects that combine street works with an adjacent municipal parcel, only the parcel portion is eligible for a reduction.

### 12 Step 12: Operation, Maintenance and Monitoring

Post-handover responsibility for routine Operation or Maintenance lies with BAU and/or MSE, depending on the project agreement. At present, there is no city-wide protocol for post-implementation monitoring, no central registry of infiltration assets and no standard KPI (Key Performance Indicators) set. Departments acknowledge this as an institutional gap.

### Governance insights

**Groundwater Data: 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.

**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.

**Post-implementation monitoring gap** No city-wide asset registry, inspection cadence or KPIs (Key Performance Indicators) exist for installed infiltration measures.

C) Installation Phase for Private Buildings

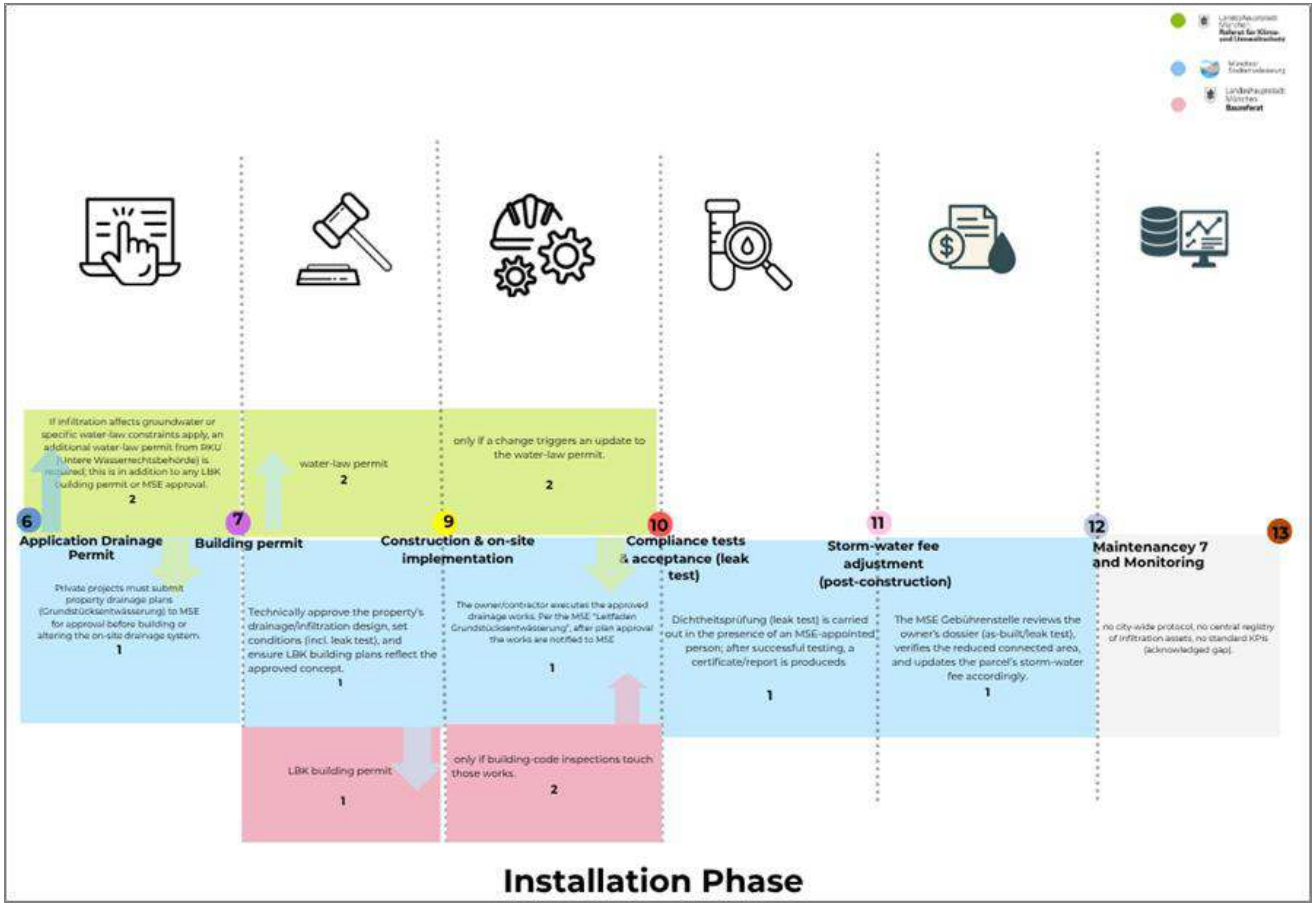



*Figure 14: Governance Process of the sponge city strategy –phase II: installation phase for private buildings*

6

### Step 6: Drainage concept and permit (before construction)

Private projects must submit property drainage plans (Grundstücksent-wässerung) to MSE for approval before building or altering the on-site drainage system. After plan approval, works are registered with MSE, and leak testing is planned. This stage is where the infiltration concept is checked and detailed.

- If infiltration affects groundwater or specific water-law constraints apply, an additional water-law permit from RKU (Untere Wasserrechtsbehörde) is required; this is in addition to any LBK building permit or MSE approval
- Certain infiltration forms are not allowed (e.g. Sickerschächte/ Sickerbrunnen) and runoff from some metal roofs may not infiltrate. Design must respect these constraints.

7

### Step 7: Building permit (LBK) and permit interplay

Where the project also requires a LBK building permit, that runs in parallel; the RKU water-law permit—if needed—sits on top of LBK/MSE decisions (it does not replace them). This clarifies why applicants sometimes handle three permit streams: MSE (drainage), LBK (building), RKU (water law).

8

### Step 8: Construction & on-site execution

The owner/contractor executes the approved drainage works. Per the MSE "Leitfaden Grundstücksentwässerung", after plan approval the works are notified to MSE; construction oversight and leak testing are coordinated with/observed by an MSE-appointed person.

9

### Step 9: Compliance tests & acceptance (leak test)

Dichtheitsprüfung (leak test) is carried out in the presence of an MSE-appointed person; after successful testing, a certificate/report is produced. This closes the technical compliance loop for the private drainage works.

10

### Step 10: Stormwater fee adjustment (post-construction)

Munich levies a storm-water fee (Niederschlagswassergebühr) for parcels that discharge runoff to the city network. If a project disconnects surfaces (e.g., via infiltration/retention), the fee basis can decrease, provided the change is documented and recognised under the Entwässerungsabgabensatzung (EAS). (In practice: owners submit documentation so MSE can adjust the parcel's charged area.)

**Involved city departments**

- **MSE:** approves property drainage plans, sets/validates infiltration design, coordinates leak testing, and administers storm-water fees.
- **LBK:** building permit where applicable (separate from drainage/water law).
- **RKU (waterlaw):** issues additional waterlaw permits (e.g., works in groundwater; infiltration constraints).

**Governance insights**

Official city webs 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 one-page Standard Operating Procedure (SOP).

Post-installation monitoring not standardised: The MSE 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.

Stormwater fee reduction sits outside the permit flow: In principle, the smaller the connected area, the lower the stormwater 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.

**Policy – Incentive Insight: 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 rehabilate. 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.

### ***Thermal use of Groundwater*** *(Strategy: Heating Plan & Quartier Strategy)*

**Governance process description**

This section describes Munich's approach to the planning phase of its Municipal Heating Plan, and the Quartier (neighbourhood) Strategy. It outlines how the city translates its overarching heat-transition goals into spatially targeted actions, starting from suitability mapping at the building block (Baublock) level and moving into neighbourhood-scale engagement and concept development. The section explains the roles of key municipal actors, the sequence of planning activities, and the integration of groundwater-related considerations, particularly where groundwater heat pumps or district heating networks are viable. It also highlights how the Quartier Strategy serves as a bridge between city-wide heat planning and locally tailored implementation.

**Main Actors involved**

**City Departments**

- **PLAN** – Stadtplanungsreferat
- **RKU** – Referat für Klima- und Umweltschutz
- **MOR** – Mobilitätsreferat
- **BAU** – Baureferat

**Utilities and Technical Authorities**

- **SWM** – Stadtwerke München
- **MGS** – Münchner Gesellschaft für Stadterneuerung

**Water and Regional Environmental Authorities**

- **WWA** – Wasserwirtschaftsamt München
- **LfU** – Bayerisches Landesamt für Umwelt

**Political and Governance Bodies**

- **Lenkungskreis Quartier** (Steering Committee)
- **Stadtrat** (City Council)

**Bezirksausschüsse** (District Committees) External / Civil Society

- **Stakeholders and Local Residents**
- **Civil Society Organisations**

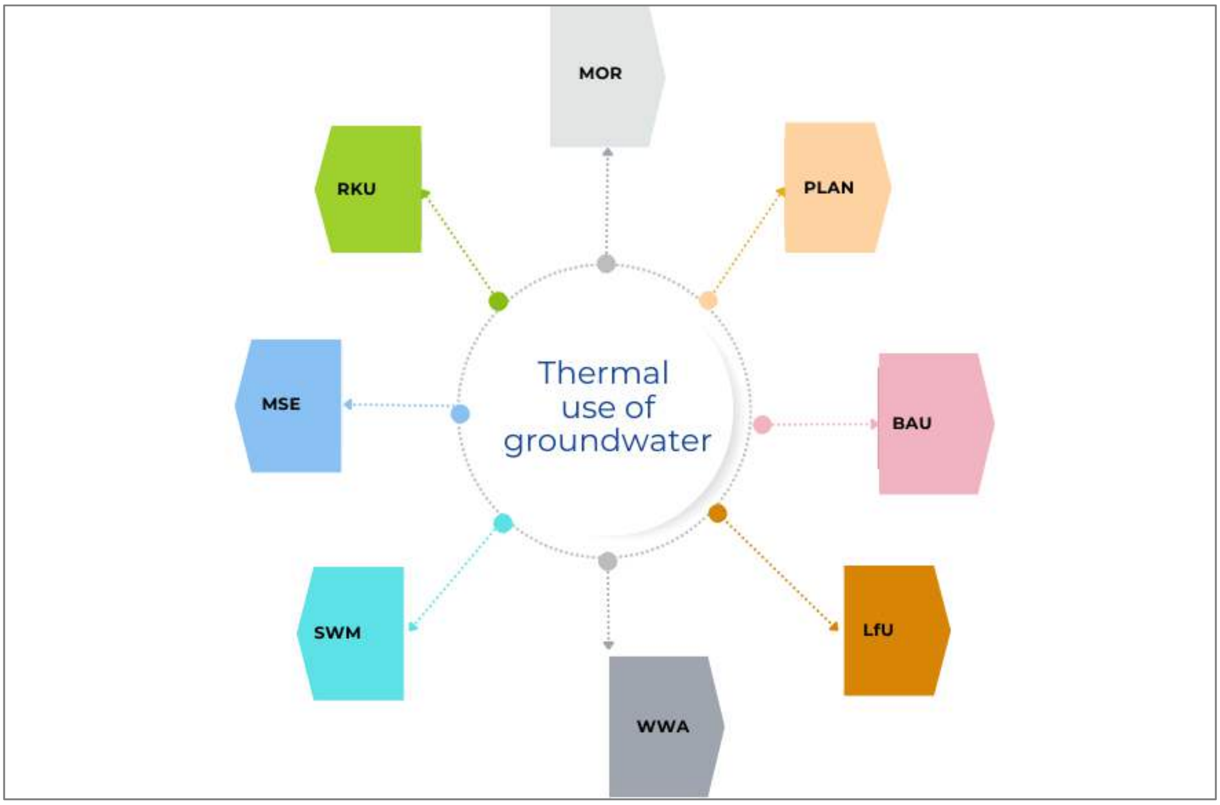



*Figure 15: Main stakeholders involved in the governance process for thermal use of groundwater*

## A) Planning Phase on City-Scale: The Municipal Heating Plan

### 1 Step 1: Baseline Assessment

RKU, together with PLAN, establishes the authoritative city-wide baseline of heat demand and supply. BAU contributes underground building information and demand estimates for public assets. SWM supplies energy-consumption datasets. PLAN provides the digital city model (buildings/zoning) and ensures spatial accuracy. WWA flags groundwater-risk areas and permit requirements (WHG §§8–15) and shares current groundwater-use records. MSE adds sewer network plans where relevant. LfU provides state drilling/borehole and groundwater layers. The result is a consolidated baseline approved by the working group.

**Data Integration**

RKU standardises formats and metadata and integrates all inputs into the heat demand model (Wärmebedarfsmodell), coordinating with PLAN for spatial alignment and traceability. The outcome is a validated baseline dataset, ready for potential analysis.

### 2 Step 2: Potential Analysis

RKU and PLAN identify technically and economically realisable geothermal potential. The baseline is confirmed, economic-viability filters are applied, and contributors add targeted layers: PLAN maps free parcels/blocks and checks zoning feasibility. BAU supplies observation-well measurements and the district-heating construction/ phasing map. SWM matches potentials with network expansion/densification and provides service-line maps. WWA overlays groundwater suitability and protection zones (advisory). MSE flags sewer constraints where relevant. LfU contributes drilling/borehole datasets. The output is the official map with suitable areas the official (Eignungsgebiete) prepared for publication.

### 3 Step 3: Scenario Modelling

RKU, together with PLAN, converts suitability into implementable options. RKU compiles the modelling package. PLAN confirms spatial feasibility and alignment with urban-development priorities. SWM tests connection options, checks network capacity and sequences feasible expansion/densification. The result is a set of mapped scenarios for district-heating expansion, shallow-geo/heat-pump zones and hybrids, with risks, prerequisites and phasing, plus a recommended pathway.

### 4 Step 4: Decision-Ready Document and Political Approval

RKU and PLAN produce the 2045 city-wide target scenario with mapped technology mix, KPIs and implementation priorities, and submit it to the City Council for review, discussion and vote. Once approved, the target becomes part of Munich's heat transition strategy (Wärmewendestrategie), and the suitable areas (Eignungsgebiete) are published on the city's GeoPortal to guide implementation.

### Governance Insights

The current heat-planning governance is robust. RKU serves as the single data coordinator, domain inputs are clearly assigned (PLAN, SWM, BAU, LfU, MSE), and outputs are published via the GeoPortal. This design addresses many coordination issues seen in other governance workflows.

B) Quartier Startegy

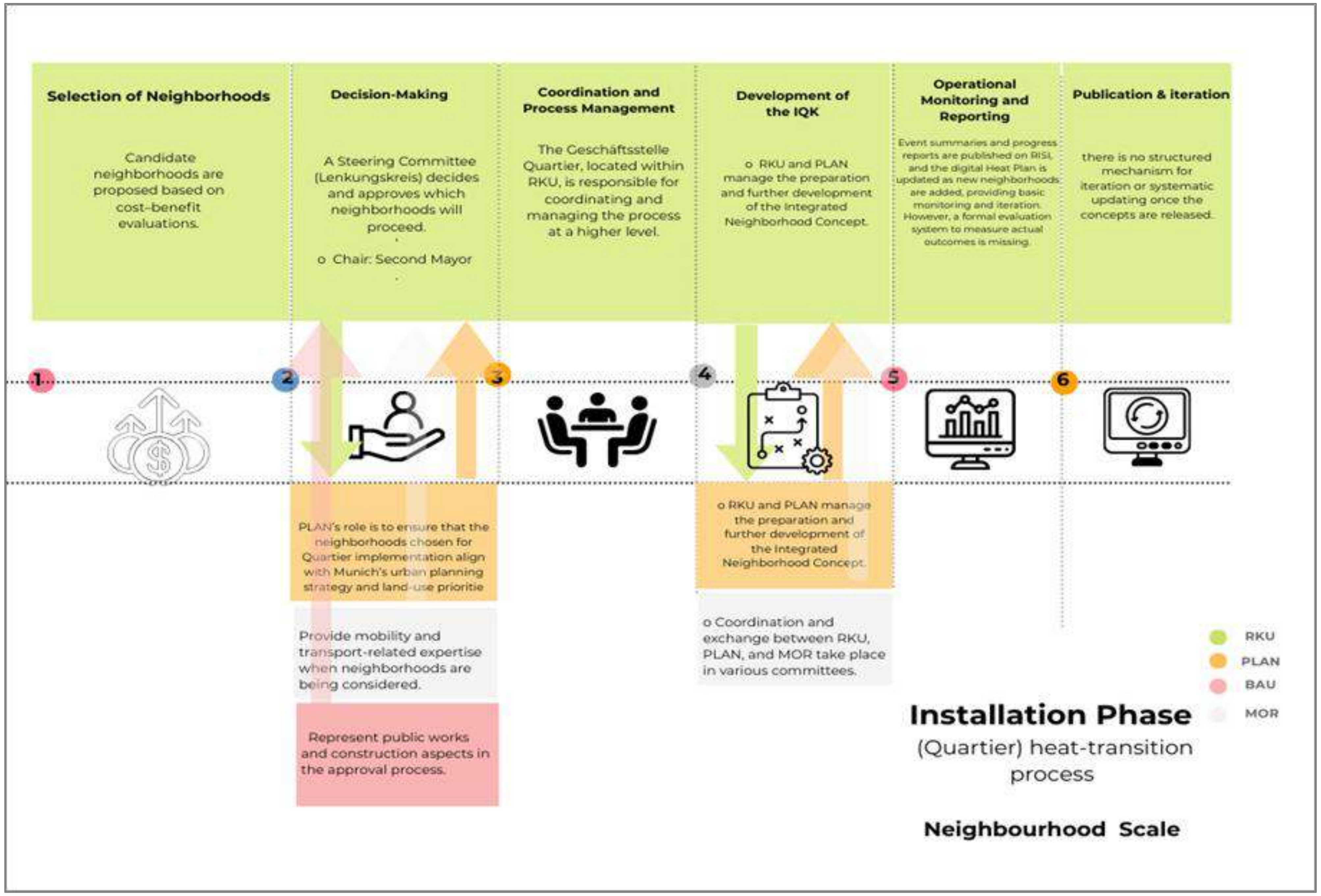



*Figure 16: Governance Process for thermal use of groundwater – phase II: installation phase for (Quartier) heat-transition on neighbourhood scale*

Implementation phase on neighbourhood level (Quartier Strategy): The City of Munich is advancing its Quartier Strategy through the development of Integrated Neighbourhood Concepts (**Integrierte Quartierskonzepte – IQK**). These concepts provide a framework for sustainable neighbourhood development and are applied in selected districts of the city. Neighbourhoods are identified through a cost-benefit-analysis, ensuring that resources are directed to areas with the highest potential impact. Once candidate neighbourhoods are identified, they enter a defined governance and implementation process.

The implementation of the Quartier Strategy is coordinated across several municipal departments and actors through clearly defined steps.

1

**Step 1: Selection of Neighbourhoods**

Candidate neighbourhoods are proposed based on cost–benefit evaluations.

2

**Step 2: Decision-Making**

A Steering Committee (Lenkungskreis) with representatives from PLAN, RKU, MOR and BAU decides and approves which neighbourhoods will proceed.

3

**Step 3: Coordination and Process Management**

The Geschäftsstelle Quartier, located within RKU, is responsible for coordinating and managing the process at a higher level.

4

**Step 4: Development of the IQK**

RKU and PLAN manage the preparation and further development of the Integrated Neighbourhood Concept. Coordination and exchange between RKU, PLAN, and MOR take place in various committees.

## 5 Step 5: Data Exchange

Access to departmental data is provided via the municipal administration's internal GeoPortal.

### Stakeholder Involvement

A wide range of stakeholders participate in the Quartier Strategy to ensure effective implementation and local acceptance.

- City Departments (RKU, PLAN, MOR): Coordinate and manage the integrated neighbourhood approach.
- External Contractor (MGS): Develops the IQKs and is commissioned to implement them.
- Bezirksausschüsse (district councils): Ensure alignment with neighbourhood-level priorities and governance.
- Stakeholders and Civil Society: Engage in both the planning and implementation phases.

### Data Handling

For the elaboration and implementation of the IQKs, relevant data is transferred to the external contractor (MGS). The data package includes existing energy infrastructure, demand analysis and potential analysis.

This transfer allows MGS to develop and subsequently implement the concepts in close cooperation with the responsible city departments.

### Insights

While the process is well-structured, several bottlenecks remain, particularly in relation to data governance. Data Protection Acts (especially DSGVO) pose significant challenges. Sharing of data is often restricted or only possible under strict conditions due to privacy regulations, protection of critical infrastructure and unbundling rules.

These restrictions complicate both the internal exchange of information and the transfer of data to external contractors, slowing down the process and creating additional administrative burdens.

*Groundwater Extremes*

**Governance process description**

Currently, there is no unified or codified process for managing groundwater extremes in Munich. The following overview assembles the existing institutional, data and tool landscape as a foundation for formalising a city-wide workflow.

**Institutional basis and monitoring network**

The City of Munich operates a permanent monitoring network for shallow and deep groundwater with more than 2,000 active measurement sites across the municipal area. The Bavarian Environment Agency (LfU) and the Groundwater Data Portal of Bavaria (GKD) provide time series of piezometric levels from representative stations, with download and visualization functions. The Regional Water Authority Munich (WWA) channels access to regional data and produces historical level assessments.

**Official cartographic products to identify extremes and vulnerability**

Several maps with groundwater level information are available at the GeoPortal Munich:

- Average maximum groundwater level (Mittlerer höchster Grundwasser-stand): key to identifying areas prone to high groundwater table
- Average depth to groundwater (Mittlerer Grundwasserflurabstand): essential for assessing basement flood risk and construction constraints.
- Historical isopiezometric lines (Grundwasserstandslinien) for 1990
- Map of measurement stations with access to station-specific time series.

In addition, the HW 1940 service issued by the GeodatenService provides official statements for planning and building permits. HW 1940 refers to the assumed highest groundwater level in Munich, derived from historical data and modelling, corresponding to a reference level around the year 1940.

**Maps implementation**

In this phase, official data and maps are connected to specific sector needs:

- **Urban planning and construction**: use of HW 1940 and reference maps for B-Plans, basement design, and construction restrictions.

- **Sewerage and drainage**: using groundwater level data to avoid pipe flotation and infiltration of parasitic water.
- **Shallow geothermal energy**: groundwater levels checked for feasibility and compliance with permits.
- **Incident management for high groundwater**: use of GKD data for prevention and response to basement flooding after prolonged rainfall.

**Roles and responsibilities**

- **RKU and GeodatenService**: management of official groundwater data and maps; responding to information requests.
- **LfU, GKD and HND**: regional data portals and analysis.
- **WWA Munich**: regional water authority and technical point of contact.
- **Municipality**: management of drilling notifications (Bohranzeigen).

**Operationalising "groundwater extremes"**

- **High extremes**
  - Basis: average highest groundwater map + depth to water + high percentiles (P90–P95) from time series.
  - Product: risk polygons and sentinel stations by district.
- **Low extremes**
  - Basis: average groundwater dynamic map + low percentiles (P5–P10) from time series.
  - Product: zones with abnormal drawdown and alerts for works depending on water table depth.
- **Seasonal dynamics**
  - Basis: aggregated monthly data from long-term time series.
  - Product: calendar of critical months for construction scheduling.

**Insights**

Analogous to the topics Rainwater infiltration and Thermal groundwater use, Munich seems to have a process for groundwater extremes (very high/low water tables). In the planning phase, the city should govern and use its existing monitoring network (> 2,000 stations) together with state time series (LfU/GKD), and define how data are collected, exchanged and archived. Core inputs are groundwater level time series and official municipal products (e.g., average highest groundwater, depth-to-groundwater; *HW 1940* statements for planning/permits), complemented by context layers (e.g., construction/deep foundations, sewer assets, registered geothermal/infiltration sites, flood interfaces). These inputs can be interpreted into decision products such as areas with risk of high groundwater (from published maps), and, where needed, derived analyses such as indicators for low groundwater levels or seasonal patterns from state series. Publication and maintenance should be coordinated with GeodatenService/GeoPortal (clear ownership and update cycles). In the implementation phase, the products should feed planning, permits and works (basements, sewer rehab, geothermal feasibility), with incident roles defined for cellar/groundwater flooding. WWA and LfU provide expert input and long-term series. Water-rights procedures (e.g. for geothermal use or rainwater infiltration) follow city/state channels, while official groundwater statements are issued by the city's GeodatenService.

### 3.4.5 Challenges and Gaps

***Rainwater Infiltration***

#### Governance Gaps

**Stormwater fee disconnected from process:** The fee adjustment comes late, is optional, and does not provide meaningful incentives, especially in consolidated, historic districts where different measures are needed.

**No end-to-end SOPs (Standard Operating Procedure):** Roles, timing, and required documents are not fully defined for each phase of implementation.

**Fragmented workflows:** Heavy reliance on email/PDF exchanges, without a Common Data Environment (CDE), leads to version drift and no single source of truth.

**No real-time log for approvals and inspections:** without time stamps or tracking, delays and waiting times stay hidden.

**Overlapping tasks:** WWA's technical opinions often duplicate analyses already prepared internally. While this can act as independent validation, without formal integration it risks becoming redundant, adding workload, and even creating conflicting versions. Case officers themselves are unsure whether this input is a net positive or a burden.

**Lack of strategic alignment:** Each department fulfils its technical responsibilities, but there is no unifying sub-strategy that aligns their actions toward a single vision.

**No post-implementation oversight:** Infiltration measures lack systematic monitoring or an asset registry to track performance over time.

**Uncoordinated permits:** Approvals by MSE, LBK, and RKU for private projects are processed in parallel but without orchestration.

**Unclear authority at some process stages**: Decision-making responsibilities are not clearly defined in some interfaces, such as between BAU and MSE during construction works.

## Data gaps

**No up-to-date, city-wide groundwater depth map:** Munich has static maps and live point data, but no integrated, regularly updated depth-to-groundwater layer for the whole city, which is crucial to decide where infiltration is safe (no basement flooding, no sewer interaction).

**Hydrogeological capacity data are static and not open:** Storage and hydraulic conductivity datasets that are key for infiltration, but they are old (2014–2016), static and only available on request / internally (GEO.KW). There is no open, regularly updated layer of infiltration capacity.

**Surface sealing data not fully open and only partly up to date**: The spatial pattern of sealed vs. permeable surfaces is essential for sponge-city planning, but the best GIS data are not openly downloadable, and the quantitative report is static (2017).

**Stormwater / sewer infrastructure is KRITIS and internal only**: Detailed information on where stormwater currently goes (pipes, retention basins, overflows) is not accessible outside MSE, making it difficult to plan combined sewer + infiltration strategies or assess relief effects on the network.

**Recharge is only modelled, not measured and not online**: There is a modelled recharge layer, but no measurement-based validation and no open access. For sponge-city design, this means uncertainty about real infiltration volumes and where models might over- or underestimate recharge.

**Construction and basement datasets are incomplete and static**: For infiltration planning, it is important to know where groundwater already interacts with basements or temporary dewatering, but these datasets are fragmentary and outdated, so they cannot be used reliably for risk analysis.

**No explicit dataset on locations of decentralized infiltration measures:** The city cannot map where infiltration is already implemented and where new measures are still possible, which limits monitoring and optimisation of the sponge-city strategy.

*Table 15: Overview of data and governance gaps*

| Process Gap (Governance) | Connected Data Gap | How They Reinforce Each Other |
|---|---|---|
| Fragmented workflows (no common data environment) | Hydrogeological capacity data are static and not open | Without a shared platform, departments work with outdated infiltration capacity maps, reproducing analyses and reinforcing data fragmentation. |
| No post-implementation oversight | No explicit dataset on locations of decentralized infiltration measures | The absence of a monitoring or asset registry prevents tracking of installed infiltration systems, making evaluation and maintenance impossible. |
| Uncoordinated permits between departments (MSE, LBK, RKU) | Stormwater / sewer infrastructure is internal (KRITIS) | Restricted access to stormwater infrastructure data limits joint assessment of infiltration feasibility and network impacts. |
| Unclear responsibilities and decision authority | No up-to-date, city-wide groundwater depth map | Without defined responsibility, departments use inconsistent or outdated groundwater depth data, creating uncertainty in safe infiltration zones. |

### Policy–Incentive Gap

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 such as 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 this scale needs block-level programmes, 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.

### *Thermal groundwater use*

Governance Gaps

a) 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.

b) 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**: While event summaries and updates are published on city platforms and the digital Heat Plan is continuously updated with new suitability and investigation areas, there is no structured monitoring framework to evaluate outcomes once measures are implemented in neighbourhoods. Follow-up is mainly limited to documenting process milestones rather than systematically tracking effectiveness. Without formal monitoring, the city lacks a feedback loop to verify whether Quartier measures deliver intended impacts and to inform future neighbourhood strategies.

**Publication and Iteration Gap**: Although Integrated Neighbourhood Concepts (IQKs) in Munich are formally published, for example, the final report of the Sankt-Michael-Straße (Maikäfersiedlung) IQK is publicly available, there is no structured mechanism for iteration or systematic updating once the concepts are released. While digital tools such as the energy utilisation plan (Energienutzungsplan, ENP) and the neighbourhood development tool (Quartiersentwicklungstool, QET) support the preparation of IQKs, they do not provide a framework for continuous feedback, public review, or regular revision after publication. Without a defined process for iteration, IQKs risk becoming static documents, limiting adaptive learning, stakeholder engagement, and long-term effectiveness.

### 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.

### *Groundwater extremes*

#### 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.

## 3.4.6 Relevance

Drawing on the validated stakeholder questionnaire, targeted municipal interviews, and a World Cafe with local actors, three priority topics emerge for sustainable groundwater management in Munich. They capture both the technical situation and the governance/data issues identified within the MARGIN project.

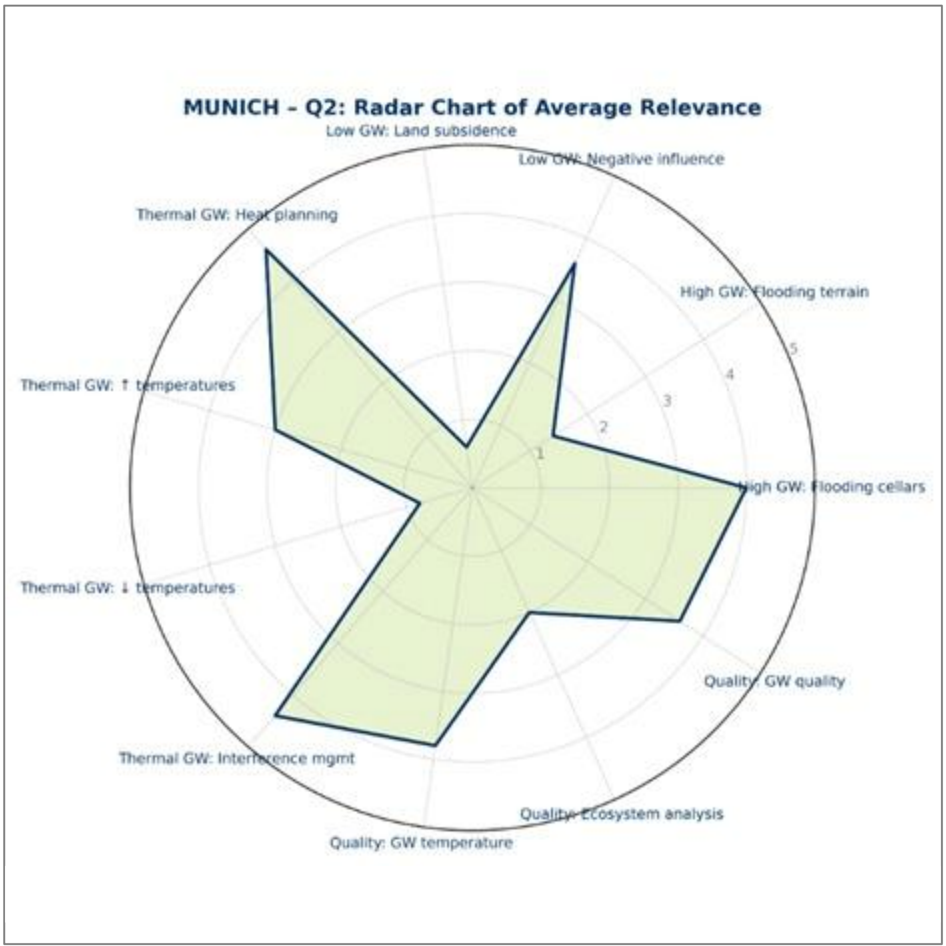



*Figure 18: Radar chart of relevant groundwater topics in Munich*

### ***Groundwater extremes***

Munich exhibits a dual pattern: persistently high groundwater tables in several northern districts and climate-related declines elsewhere. Elevated levels cause cellar flooding, uplift pressures on structures, and construction constraints, and they limit rainwater infiltration by increasing the likelihood of groundwater mounding and backflow into basements. Depressed levels reduce recharge and yields, leading to drying of wells and constraining groundwater-dependent uses. Given strong spatial and seasonal variability, site-specific assessment and monitoring are essential. This cross-cutting issue sets the boundary conditions for the following two topics.

### *Rainwater infiltration - Sponge City Concept*

Munich implements the Sponge City strategy for sustainable rainwater management city-wide. Within this framework, rainwater infiltration is a key mechanism, but its feasibility and safety are highly site-specific. In shallow groundwater areas, infiltration can induce groundwater mounding and basement backflow. In deeper groundwater areas, the volumetric contribution may be insufficient to materially augment aquifer storage. Prior to this assessment, elements of governance and data handling such as baselines, monitoring, and permitting criteria, were not fully specified, limiting the city's ability to evaluate effectiveness and risk of this strategy.

### *Thermal use of groundwater*

Munich manages the thermal use of groundwater through the city-wide Heating Plan, which defines strategic suitability, criteria, and limits, and the Quartier (district) Strategy, which translates these guidelines into neighbourhood-level diagnostics and implementation. Within this framework, groundwater-source heat pumps and cooling systems must be planned and operated with regard to spatially variable groundwater levels, baseline temperatures, and protection-zone constraints, while balancing competing uses (public supply, construction dewatering, rainwater infiltration) and complying with water-law requirements. Defining responsibilities, streamlining interdepartmental workflows, and setting clear permitting rules, together with stronger data management, will enable the sustainable thermal use of groundwater and coherent implementation under both the Heating Plan and the Quartier Strategy.

*Table 16: Rating of relevant topics in Munich*

| Topic | Relevance in the city | Remarks/known issues |
|---|---|---|
| Groundwater extremes | 3 | Munich faces contrasting groundwater challenges, persistently high groundwater tables that cause flooding and construction problems, alongside declining levels that limit recharge and sustainable use. These conditions make site-specific monitoring crucial. In another hand, governance and data gaps remain: ownership and responsibilities are unclear, procedures are not codified, and there is no integrated, real-time monitoring or alert system connecting groundwater, rainfall, and surface data. Existing datasets are often fragmented, outdated, and spatially incomplete, while current groundwater-extreme measures are poorly coordinated with related programmes such as infiltration management, sewer planning, and geothermal development. |
| Rainwater infiltration | 2 | Munich promotes rainwater infiltration under the Sponge City strategy, but its effectiveness and risks depend strongly on local groundwater conditions, while governance remains underdeveloped and lacks systematic monitoring for assessing effects on groundwater levels. A policy gap shows for different incentives for consolidated and emerging areas. Also, thematic maps , which are essential for accurate and informed decision-making , are missing. |
| Groundwater heating/cooling | 3 - 2 | Munich's Heating Plan and Quartier Strategy regulate groundwater-based heating and cooling, requiring careful management of variable groundwater conditions and strong governance to ensure sustainable and coordinated use. However, despite the stablished governance framework and good data coordination, there are still gaps , particularly the absence of thematic maps that are essential for better decision-making and for supporting the spatial planning of thermal us of groundwater. |

# 4. Cross-city comparison

For the general overview of the questionnaire 1 results, please review ANNEX II.

## 4.1 Groundwater extremes

Groundwater extremes present diverse challenges in urban areas, ranging from flooding of underground infrastructure to difficulties in managing fluctuating water tables. A comparative analysis of the four case study cities was conducted trying to highlight the most relevant city-specific challenges, governance and data gaps, as well as existing good practices that can inform more resilient groundwater management strategies.

Table 17 synthesizes the findings from the assessment of groundwater extremes issues in each city. The information was extracted and consolidated from stakeholder inputs and the respective city analyses.

- From this comparison, several common conclusions can be drawn. All cities experience groundwater extremes that manifest either as flooding of underground structures (Ljubljana, Milan) or management of fluctuating groundwater table (Munich, Linz). Governance gaps, particularly the absence of clear responsibilities, integrated strategies, and timely data sharing, emerge as a recurring theme across all cases. Data fragmentation and delays in accessibility also limit effective risk management.
- On the positive side, each city demonstrates valuable practices: Ljubljana promotes infiltration-based solutions, Munich has an extensive monitoring network and sectoral applications such as high groundwater products applied in urban planning. Strong cooperation between regional and research institutions provides a solid technical basis for early warning and modelling, while internal data integration through the GEO.KW platform ensures consistent access and analysis. Linz benefits from a centralized data management system, and Milan recognizes groundwater flooding as a major urban issue with targeted mitigation measures. Collectively, these experiences show that resilient groundwater management in urban areas requires a combination of robust monitoring, transparent data access, cross-sectoral integration, and clear governance frameworks.

*Table 17 – Comparison of data handling and governance practices accross the four pilot cities for the groundwater extremes topic*

| City | Main challenges | Key gaps | Good practices |
|---|---|---|---|
| *Linz* | • Limited data accessibility<br>• Reliance on delayed publications. | • Annual or delayed data publication; lack of data sharing; limited detailed groundwater maps; fragmented data ownership and poor sharing between stakeholders | • Centralized Hydrographic Data Management System (HyDaMS); development of extreme groundwater datasets (HGW100). |
| *Ljubljana* | • Flooding due to shallow low-permeability layers, surface sealing, limited sewer capacity, extreme rainfall. | • Lack of detailed maps of vulnerable layers; limited identification of infiltration zones; poor regulation to reduce surface sealing. | • Recognition of rainwater infiltration/retention as dual-purpose (flood mitigation + recharge) |
| *Milan* | • Rising groundwater flooding underground structures (basements, metro, tunnels)<br>• GW rebound after industrial decline. | • No long-term monitoring strategy; lack of risk surveys for underground structures; fragmented governance; fragmented data ownership and poor sharing between stakeholders. | • Recognition of problem by city/public utilities; existing control wells (though not yet systematically assessed). |
| *Munich* | • Managing both high and low groundwater extremes; coordination across multiple city sectors; lacking of monitoring systems connected to the strategies. | • Unclear ownership, no codified procedures, and absence of a real-time, integrated monitoring and alert system linking groundwater, rainfall, and surface data. Existing datasets are fragmented, outdated, and spatially incomplete, while groundwater-extreme measures are not aligned with related programmes such as infiltration, sewer, or geothermal planning | • Extensive monitoring network (>2,000 stations) and official groundwater maps integrated into planning and permitting. Strong inter-agency cooperation between LfU, WWA, and TUM, providing a solid technical basis for early warning and modelling strategies. Internal data integration through the |

| | | |
|---|---|---|
| | | GEO.KW platform, supporting consistent access and analysis. |

## 4.2 Rainwater infiltration

- **Munich**
  Munich shows a solid technical foundation but faces key gaps in coordination, data accessibility, and policy alignment. Fragmented workflows, outdated and restricted datasets, and lack of systematic monitoring limit evidence-based planning and long-term optimisation of infiltration measures. Incentives also remain weak in consolidated areas where retrofits are needed most, although they perform well in new developments. At the same time, strong interdepartmental cooperation, clear technical mandates, joint inspections, and early integration of climate objectives stand out as good practices. Emerging data governance initiatives and the planned tree-planting programme further demonstrate commitment to improving infiltration, evapotranspiration, and adaptive water management in Munich.

- **Ljubljana**
  Ljubljana faces extensive surface sealing across urban areas, with little enforcement to prevent or reverse it. Stakeholders highlight flooding risks due to low-permeability layers, limited sewer capacity, and weak implementation of infiltration/retention measures. The city lacks detailed infiltration maps and systematic identification of suitable areas, which prevents effective integration into planning and construction.

- **Milan**
  Milan also suffers from extensive soil sealing, but its context is aggravated by climate extremes: intense rainfall overloads the combined sewer system, reducing treatment efficiency and causing surface water pollution. At the same time, reduced infiltration lowers aquifer recharge, threatening a highly productive groundwater system used for drinking water, industry, and irrigation. Milan has strong digital data platforms for surface hydrology (hydrology, sewer, discharge), which are well-collected and shared with planners, but not for the rainwater infiltration management. Even though for new and redevelopment projects there is a first-infiltration approach, no data are systematically collected to quantify the effects.

**Overall**

All three cities struggle with soil sealing and limited infiltration, though in different ways:

- Munich shows strong technical capacity and cooperation but still faces gaps in data access, missing thematic maps, coordination, and policy alignment, particularly for retrofitting infiltration in built-up areas.
- Ljubljana has weak enforcement and missing maps.
- Milan faces sealing and climate extremes, it has a recent infiltration approach but not quantified yet

A joint response should focus on:

1. De-sealing and green infrastructure programmes for consolidated districts.
2. Infiltration-first mandates for emerging districts.
3. Stronger incentives tailored to context, beyond generic fee reductions.
4. Integrated monitoring and data platforms for city-scale quantifications.
5. Complete the missing thematic maps to support better decision-making and more effective incentive design.

*Table 19: Comparison of data handling and governance practices accross the four pilot cities for the rainwater infiltration topic*

| ***City*** | **Main Challenges** | **Key Gaps** | **Good Practices** |
|---|---|---|---|
| *Linz* | • - | • - | • - |
| *Ljubljana* | • Extensive surface sealing<br>• flooding risks from low-permeability soils<br>• limited sewer capacity<br>• weak enforcement of infiltration/ retention requirements | • Absence of detailed infiltration maps and systematic identification of suitable infiltration areas | • - |
| *Milan* | • Extensive soil sealing<br>• climate extremes (intense rainfall and drought)<br>• sewer system overload<br>• reduced aquifer recharge<br>• risks to groundwater supply and water quality | • Lack of systematic data collection on rainwater infiltration management and effects | • Strong digital platforms for hydrological and sewer data collection and sharing<br>• infiltration-first requirement for new and redevelopment projects. |
| *Munich* | • Measures and incentives are not adapted to the different needs of emerging vs. consolidated/historic districts<br>• Fragmented workflows, inaccessible and outdated datasets, and the absence of clear monitoring prevent data-driven coordination. | • Munich lacks up-to-date, open, and integrated datasets on infiltration capacity, surface sealing, stormwater infrastructure and groundwater depth,; most data are static, fragmented, or restricted, limiting the city's ability to assess safe infiltration zones, validate recharge, and monitor implemented measures | • Clear governance with defined roles and phases;<br>• early integration of climate adaptation in planning<br>• . clear technical responsibilities across departments, and joint inspections ensuring functional performance of measures |

| | | |
|---|---|---|
| | | • Stormwater fee incentives support nature-based solutions.<br>• new data governance efforts (RKU megadata catalogue, GeoKW) aim to improve data quality and coordination<br>• The upcoming tree-planting programme further strengthens infiltration, evapotranspiration, and urban cooling goals. |

## 4.3 Thermal use of groundwater

In all four cities, the thermal use of groundwater is regarded as a highly relevant topic. Linz identifies it as one of the most critical groundwater issues, particularly due to rising temperatures and potential conflicts between installations. Ljubljana embeds geothermal use in its climate and energy strategy, underlining its importance despite limited monitoring and regulatory support. Milan faces the most dynamic growth, with hundreds of new systems each year, making thermal groundwater use both highly relevant and urgent for sustainable management due to potential conflicts between installations and groundwater warming. Munich goes a step further by integrating geothermal use into its municipal heating plan and Quartier strategy, underscoring its strategic role in the city's long-term energy transition, though some governance and data gaps remain to be addressed.

Table 20 synthesizes the findings from the assessment of thermal use issues in each city. The information was extracted and consolidated from stakeholder inputs and the respective city analyses.

Across all four cities, the most common gaps are missing systematic groundwater temperature monitoring, lack of comprehensive digital databases of installations, weak post-installation monitoring, and fragmented governance structures. While Munich demonstrates advanced practices by integrating geothermal use into its city-wide heating and neighbourhood strategies, it still faces data governance bottlenecks.

Looking forward, cities can benefit from:

- Standardized digital registries of geothermal systems, with mandatory parameters;
- Systematic groundwater temperature monitoring networks;
- Clearer governance coordination between municipal, regional, and state actors;
- Post-installation feedback mechanisms to ensure sustainable long-term use;
- Cross-city knowledge transfer, with Munich's integrated approach serving as a model for aligning technical, governance, and citizen engagement dimensions.

*Table 20 – Comparison of data handling and governance practices accross the four pilot cities for the groundwater thermal use topic.*

| ***City*** | **Main challenges** | **Key gaps** | **Good practices** |
|---|---|---|---|
| *Linz* | • Thermal groundwater use in Linz is growing, but management remains analog and fragmented.<br>• Permitting is split between municipal and regional authorities, with differences in data access. | • Submission and archiving are paper-based, and only partial digital integration exists via the Water Information System (WIS).<br>• No overview of existing thermal plumes and possible conflicts between installations<br>• Limited digital data access for city authority<br>• Missing potential maps for sustainable planning | • Groundwater temperatures are monitored |
| *Ljubljana* | • Management of shallow geothermal wells is weakened by insufficient monitoring and governance gaps.<br>• Licencing procedures are lengthy, and thermal parameters are regulated only through guidelines, not binding rules. | • No systematic groundwater temperature datasets<br>• Missing operational and spatial data on geothermal system impacts<br>• Long permitting processes, no binding regulations | • Thermal use of groundwater implemented into city climate-energy strategy. |
| *Milan* | • Milan is experiencing rapid growth of groundwater heat pumps (GWHPs), with 300–400 new systems annually. This expansion highlights the city's potential but also its weak regulatory and data framework. | • No central database of GWHP systems<br>• No overview of existing thermal plumes<br>• Missing temperature monitoring and thermal potential mapping<br>• Lack of tools for conflict management and optimization | • Thermal use of groundwater implemented into city climate-energy strategy. |

| | | | |
|---|---|---|---|
| | • Governance is fragmented, with split responsibilities between provincial and regional authorities. | | |
| *Munich* | • Governance challenges include unclear responsibilities, dependence on external contractors, no –updating of key datasets and limited post-implementation monitoring. | • Weak monitoring and feedback after implementation<br>• Unclear responsibilities and over-reliance on external contractors<br>• Missing feedback and iteration: IQKs and Quartier strategies are published but not systematically updated or evaluated post-implementation.<br>• Data protection barriers (DSGVO)<br>• The groundwater temperature datasets not update. Incomplete linkage between thermal use and hydrogeological capacity data.<br>• A possible vulnerability lies in the quality and coordination of datasets before ingestion by RKU, which otherwise ensures reliable and well-managed data integration | • Munich integrates geothermal use into its municipal heating plan and Quartier strategy, linking technical planning with governance and citizen engagement. Suitability maps and public portals provide transparency.<br>• Centralised coordination of data in charge of RKU.<br>• Robust methodological sequence in governace process, planning phase.<br>• Public decision-support instruments<br>• groundwater management system (GEO.KW WebAPP) including many of relevant data and evaluation methods.<br>• Stakeholder Involvement (District Councils and Residents |

## 4.5 Groundwater quality

Groundwater quality is a complex topic that is ever present in urban areas due to the importance of clean groundwater for communal or industrial applications and its potential for thermal exchange. Three of the four cities (Linz, Ljubljana and Milan) have rated the topic highly and elaborated further on it regarding data and governance gaps, with Munich being the exception. In addition to physical and chemical groundwater quality, ecosystem management was also determined to be a relevant topic in the aforementioned three cities. The following table presents a comparative analysis of the four cities showing the main challenges, key governance- and data-related gaps and good practice examples which are already in use as presented in the deliverable by each city.

The Table 21 synthesizes the findings from the assessment of groundwater extremes issues in each city. The information was extracted and consolidated from stakeholder inputs and the respective city analyses.

One thing that became clear in this comparison is that each city completely lacks ecological groundwater monitoring. Conducting ecological monitoring in urban areas could provide additional data on groundwater fauna and microbial conditions in the pilot cities. Another observed gap is the restricted sharing of groundwater quality information among stakeholders; while specific datasets exist, certain stakeholders may not have access to or awareness of this information. Groundwater temperature monitoring also remains a challenge due to its relevance for thermal installations and infrastructure. Existing goo practices include regulated chemical and physical groundwater monitoring, with much of the resulting data being made publicly accessible.

*Table 21 – Comparison of data handling and governance practices accross the four pilot cities for the groundwater quality topic.*

| ***City*** | **Main Challenges** | **Key Gaps** | **Good Practices** |
|---|---|---|---|
| *Linz* | • Fragmented data ownership and access, subpar communication between stakeholders<br>• Reliance on individual stakeholders for site-specific data | • No data on groundwater ecosystem monitoring (only limited microbiological data)<br>• Limited data sharing across stakeholders, mostly isolated databases | • Comprehensive monitoring of chemical and physical parameters on multiple levels (national, regional, municipal)<br>• Publicly available annual reports and database entries (H2O database). |
| *Ljubljana* | • Limited understanding of ecosystem-climate interactions<br>• Data sharing between institutions<br>• Knowledge about existing groundwater quality data | • No data on groundwater ecosystem monitoring, emphasis on chemical data<br>• Low stakeholder awareness and public engagement for planning and infrastructure | • Centralized monitoring by ARSO ensures consistent data collection<br>• Data on groundwater quality available as annual reports |
| *Milan* | • High urbanization pressure, need to balance drinking water and other uses with thermal energy applications | • No data on groundwater ecosystem monitoring<br>• No assessment of groundwater temperature impacts from urbanization<br>• Narrow focus on hydrochemistry | • Institutional setup with clear roles for groundwater quality monitoring (MM S.p.A., ARPA Lombardia) |
| *Munich* | • Impact of changing climate on groundwater temperature | • Ecological monitoring has been conducted only once and has not been established as a continuous or systematic process.<br>• Fragmented and incomplete baseline data for groundwater temperature | • Clear recognition of climate change impacts on groundwater<br>• Site-specific awareness of groundwater variability guiding management |

## 4.6 Synthetic gap comparison

The comparative assessment of groundwater-related challenges in Linz, Ljubljana, Milan, and Munich across the four selected topics: groundwater extremes, rainwater infiltration, thermal use of groundwater, and groundwater quality, reveals both shared issues and city-specific dynamics. Despite differences in hydrological settings and governance structures, the analysis highlights recurring gaps such as fragmented responsibilities, limited data accessibility, insufficient monitoring networks, and weak integration of groundwater considerations into broader urban planning. At the same time, each city demonstrates valuable practices that can serve as reference points for others, ranging from centralized data systems and infiltration-based solutions to advanced integration of geothermal use into energy strategies.

The following tables showcase all the gaps identified across the thematic areas. This gap comparison provides a consolidated understanding of where progress is being made and where coordinated improvements are still urgently needed to ensure resilient and sustainable groundwater management in the pilot cities. A tick mark indicates the presence of a gap in that city.

| **Groundwater Extremes** | **Linz** | **Ljubljana** | **Milan** | **Munich** |
|---|---|---|---|---|
| Insufficient groundwater level monitoring (spatial or temporal resolution) | x | x | x | |
| Groundwater level data not shared (or in an unusable format) | x | | x | x |
| Lack of detailed maps of vulnerable layers | | x | x | |
| Fragmented governance | x | x | x | x |

| Rainwater Infiltration | Linz | Ljubljana | Milan | Munich |
|---|---|---|---|---|
| No quantification of infiltration on groundwater budget | | x | x | x |
| Lack of detailed maps of suitable infiltration areas( infiltration capacity, surface sealing, stormwater infrastructure and groundwater depth) | | x | | x |
| Fragmented mesures | | x | x | x |
| Lack of monitoring to assess the effectiveness of the strategy (e.g., Sponge City) | | | | x |
| Static data, fragmented, or restricted | | | | x |

| Thermal Use of Groundwater | Linz | Ljubljana | Milan | Munich |
|---|---|---|---|---|
| Insufficient groundwater temperature monitoring (spatial or temporal resolution) | | x | x | x |
| Missing (or restricted) dataset about existing geothermal systems | x | x | x | x |
| No detailed groundwater thermal potential maps | x | | x | |
| Lack of tools to identify existing thermal plumes and possible conflicts between installations | x | x | x | |
| Fragmented governance about shallow geothermal wells | x | x | x | |
| Regulation does not cover all aspects | | x | x | |
| Weak monitoring and feedback after implementation | x | x | x | x |

| Groundwater Quality | Linz | Ljubljana | Milan | Munich |
|---|---|---|---|---|
| Limited data sharing of groundwater quality data | x | | | |
| Limited or no data on groundwater ecosystem monitoring | x | x | x | x |

# 5. Conclusion and outlook

This comprehensive assessment of data handling practices and governance workflows across the Alpine pilot cities Linz, Ljubljana, Milan and Munich reveals significant challenges and promising opportunities to advance with sustainable groundwater management. The developed five-step approach connects technical data requirements with institutional realities, providing comprehensive knowledge about the status quo related to groundwater sustainability management in Alpine cities. At the same time, it became clear, that engaging stakeholders and discussing their roles and challenges helps strengthen the cooperation between city departments, utilities, and other actors.

## 5.1 Key findings and cross-city patterns

Despite varying administrative structures, similarities emerged across all cities. All cities share fragmented data ownership across multiple institutions, limited digitization of critical datasets, and coordination gaps between municipal and state-level authorities. The assessment revealed that essential datasets are consistently scattered across multiple data custodians, with limited availability in machine-readable formats suitable for modern analytical tools.

All four investigated topics thermal use of groundwater, groundwater extremes, groundwater quality and ecosystem health, and rainwater infiltration management showed at least medium relevance. All cities identified high groundwater levels and thermal groundwater use as their high priority topics. Groundwater ecosystem health was identified as high relevance in Ljubljana and Linz, and rainwater infiltration reached the relevance score high only in Ljubljana.

## 5.2 Transferability

The general approach demonstrates strong transferability across different administrative structures, data availability levels, and local priorities through its modular design. Cities can adapt the individual steps to their specific contexts while maintaining the overall analytical structure, leading to comparable results.

The focus of MARGIN on porous aquifer systems enhances its applicability to other Alpine valley cities with similar hydrogeological conditions. However, the assessment approach can be easily applied also in fractured and/or carstic aquifers, which play a role in the Alpine region, by adding and discussing relevant data and governance workflows.

The application of the general approach within MARGIN allowed it to be refined and adjusted for use in Alpine cities with similar hydrogeological conditions beyond the project. This demonstrates its transferability to other regions. To increase user-friendliness, the approach will be implemented in the MARGIN “Gamebook”, which will make it even easier for cities to apply the methodology in practice. Minor modifications, such as the development of a more sophisticated relevance scoring system, could further improve the methodology.

## 5.3 Outlook

Overall, this methodology provides crucial basis to integrate groundwater sustainability into urban management, enabling Alpine cities to respond to future pressures from climate change and urbanisation.

The assessment establishes the basis for subsequent MARGIN work, that will follow in the potential and risk assessment phase. The relevance matrices directly informed that the topics of thermal groundwater use and high groundwater levels need prioritization and they will be focused on in the upcoming MARGIN activities.

The data gap analysis identified that new measurements are needed specifically about groundwater temperatures, water levels and groundwater biology, which enables targeted field campaigns. The governance analysis revealed which institutional relationships require strengthening, enabling implementation strategies that work within existing administrative structures. This is critical information for the later and final implementation phase of MARGIN.

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# 7. Annexes

Annex I: Questionnaire

Annex II: Template for Interview Questionnaire