EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

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Sub-Urban

TU1206-WG1-014

Vienna

TU1206 COST Sub-Urban WG1 Report

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Geologische Bundesanstalt

Geological Survey of Austria

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Vienna Municipal Department for Energy Planning

Content

1. Introduction

General description

Vienna is the capital of Austria and its cultural, economic and political centre. It is composed of 23 districts. Famous for its classical music, classicist and modern architecture, Art Nouveau buildings, imperial palaces, the State Opera, theatres, the traditional Viennese coffee houses and the Lipizzaner horses, Vienna attracts up to 6 million tourists per year. It is the home of over 100 museums and 13 universities as well as the seat of several United Nations offices (e.g. OSCE, OPEC, UNIDO and IAEA). According to the statistics of the International Congress and Convention Association, Vienna is the second most popular congress location worldwide, hosting up to 200 international conferences annually. Regarding life quality, the city was ranked as the second most liveable city worldwide in several 2015 surveys. As a global smart city, it reached third place among European cities in a 2014 ranking.

View towards Vienna from the North

Location, size, population

Vienna is located in the north-eastern part of Austria at the transition between the foothills of the Austrian Alps and the plane of the Vienna basin. The elevation ranges from 540 m asl in the West to 150 m asl in the Southeast. Flowing from North to Southeast, the river Danube crosses the central part of the city. The city area covers approximately 420 km². The population currently amounts to 1,800,000 and is expected to rise to over 2,000,000 in the next few years.

Location of Vienna in Austria

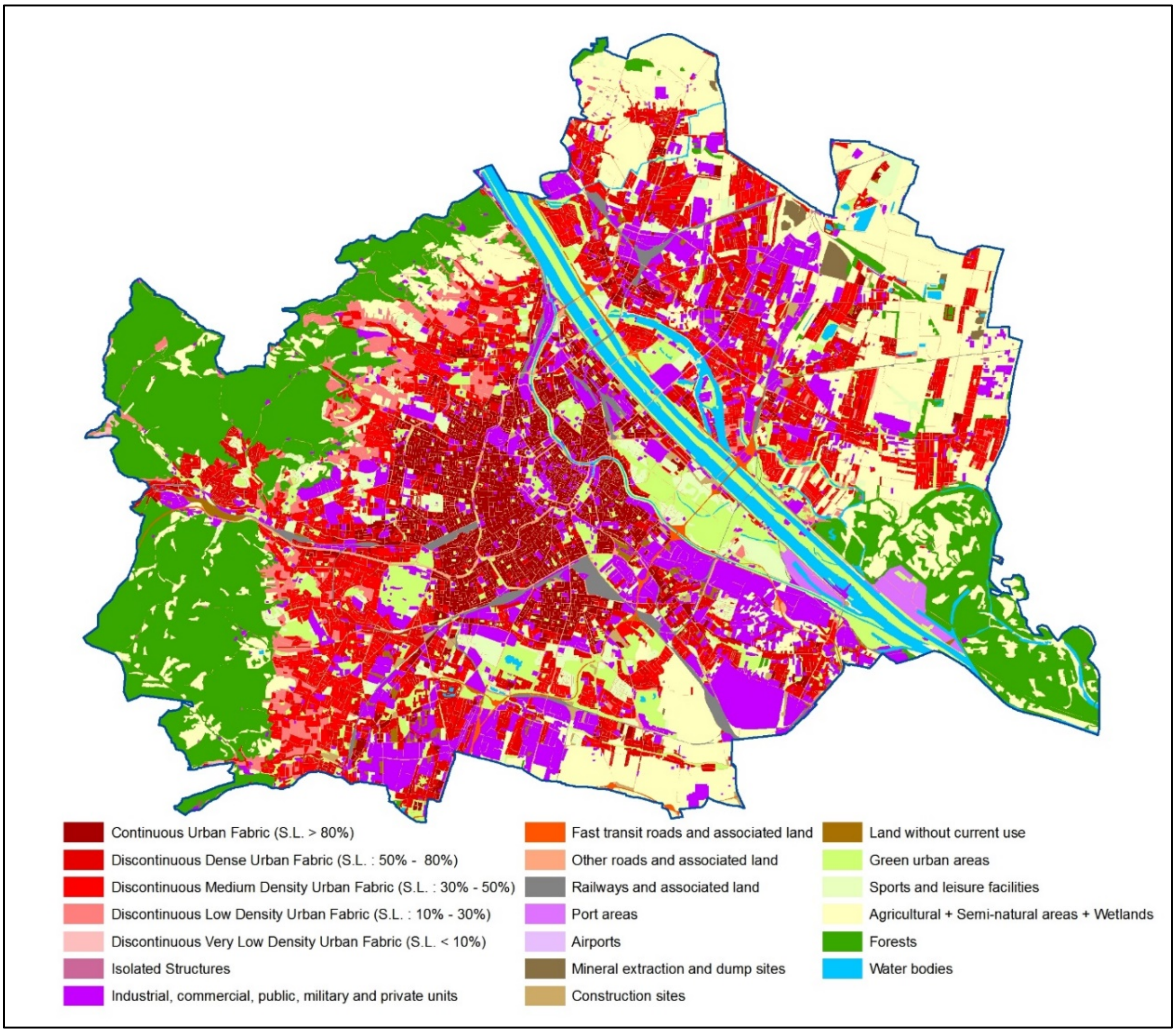
History

Over 2000 years ago, the Romans established the fortified city of Vindobona on the river Danube as a military camp to protect their empire against Germanic tribes in the North. Since 1145, the city was the centre of the Babenberg dynasty, followed by the Habsburg dynasty in 1440, when Vienna became the capital of the Holy Roman Empire. During the Siege of Vienna in 1529 and the battle of Vienna in 1683, the city fended off the Ottoman armies advancing from the East. From 1804 onwards, Vienna was the capital of the Austrian empire and hosted the Vienna congress in 1814/1815. Drawing migrants from other parts of the empire and incorporating surrounding suburbs, the city's population grew from 500,000 to 1,800,000 during the second half of the 19th century. It formed the capital of the Austro-Hungarian empire after 1867, and of the First Republic of Austria after World War I.

Following World War II, Vienna was divided into four sectors and occupied by the Allied Forces until 1955.

Land use

The forests of the Vienna Woods cover the western city area, while the central and eastern parts are covered by housing estates, industrial areas and office buildings. The area of forests, parks, gardens and green spaces amounts to > 45% of total city area. At the northern and eastern city margins, the land is used for agriculture while industrial areas are situated in the north-east, south-east and south.



Land use in Vienna according to the GMES Urban Atlas (http://www.eea.europa.eu/data-and-maps/data/urban-atlas)

Infrastructure

Completed in 2015, the new Central Railway Station forms the hub for public transport in and out of the city with 1000 trains and 120,000 passengers daily. Within the city, five underground lines, 29 tram lines and 115 bus lines transport over 900 million passengers per year. Vienna International Airport lies 16 km southeast of the city serving 22 million passengers each year. Major highways connect the city to the north, northeast, southeast, south and west.

Underground use and major projects

Constructions reaching into Vienna's subsurface include railway, subway and road tunnels, major buildings or their foundations, and constructions for underground water (and waste water) flow. Currently, major projects concern the extensions of subway lines U1 (ongoing) and U2 as well as construction of the new subway line U5 (planning phase). At the pre-planning phase for road tunnels is the building of an underground highway in the Southeast (Lobau), crossing a biosphere reserve and landscape protection area. Major construction projects of buildings reaching deeply into the subsurface include the new Central Railway Station, completed in 2015. Shallow geothermal energy use in Vienna is widespread with over 1800 facilities. Half of these represent ground heat exchangers, the other half groundwater heat pumps.

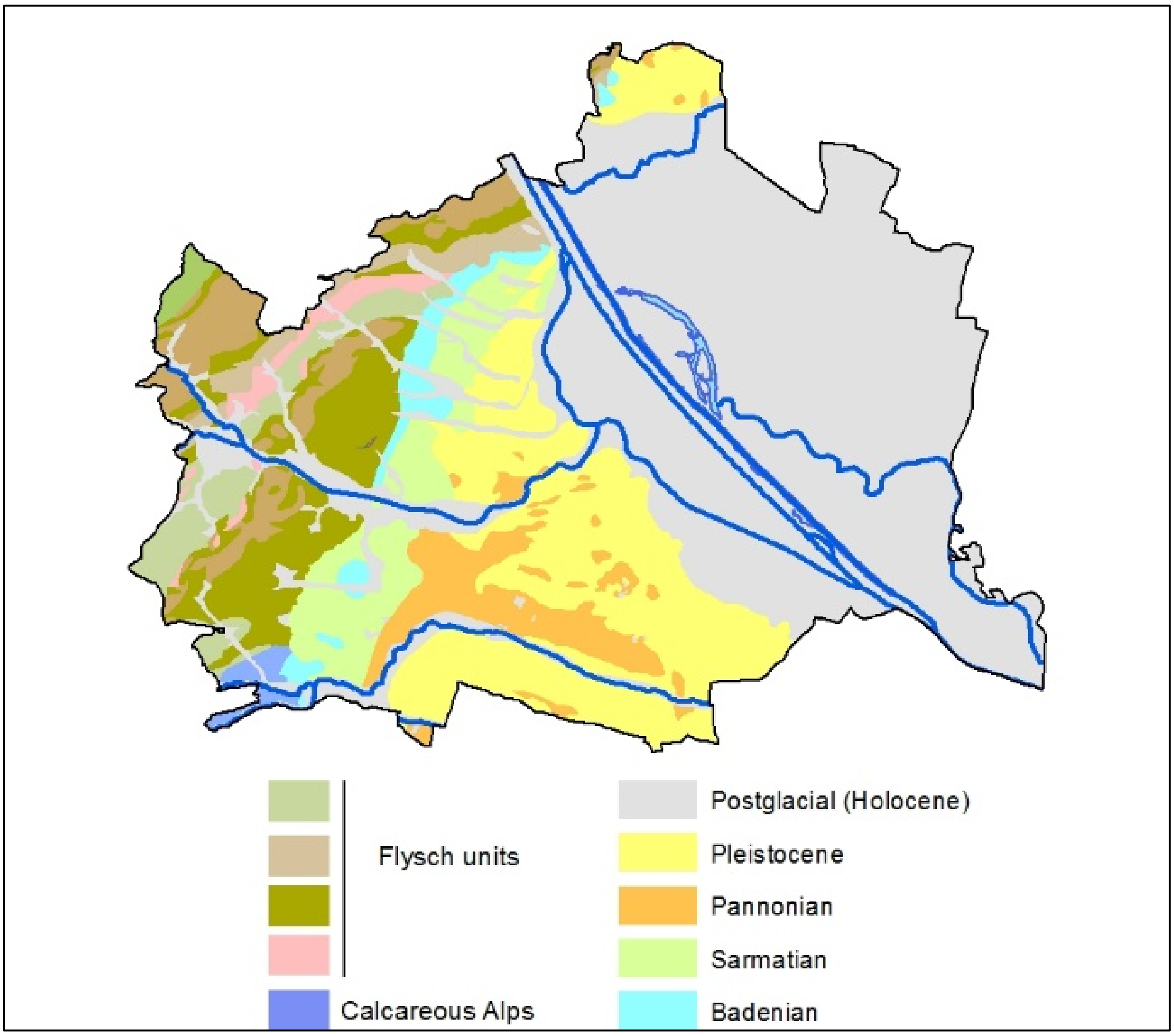
Future growth

The 2nd, 10th, 15th, 21st and 22nd districts are among the areas in Vienna with the highest population growth. The 22nd district in the Southeast of the city holds the record with 10% growth rate over the last five years. In this district, the Aspern Urban Lakeside is one of the largest urban expansion projects of Europe. A 5 hectare artificial lake, offices, apartments and a tube station within walking distance are supposed to attract 20,000 new citizens when construction is completed in 2028. In addition, the highest wooden skyscraper of the world called "HoHo Wien" will be built within 3 years, starting in 2015.

2. Geological setting

Regional setting

Geologically, the western part of Vienna belongs to the Austrian Alps while the central and eastern parts lie in the Vienna basin. The Alps are represented by flysch, i.e. nappes of sandstone, marlstone and shale ranging in age from the Lower Cretaceous to the Eocene (Wessely 2006). The Vienna basin is a tectonic pull-apart structure filled with marine to lacustrine sediments of Neogene age (Royden et al. 1985). In the city, these sediments represent erosion products from the flysch units and appear at the surface along a narrow band adjacent to the flysch zone towards the East. Still further East, Neogene sediments are overlain by Quaternary sand and gravel terraces deposited by the river Danube coming from the North and by tributaries from the East. Fine-grained overbank sediments (loam) and loess of several metres thickness cover large parts of the terraces.

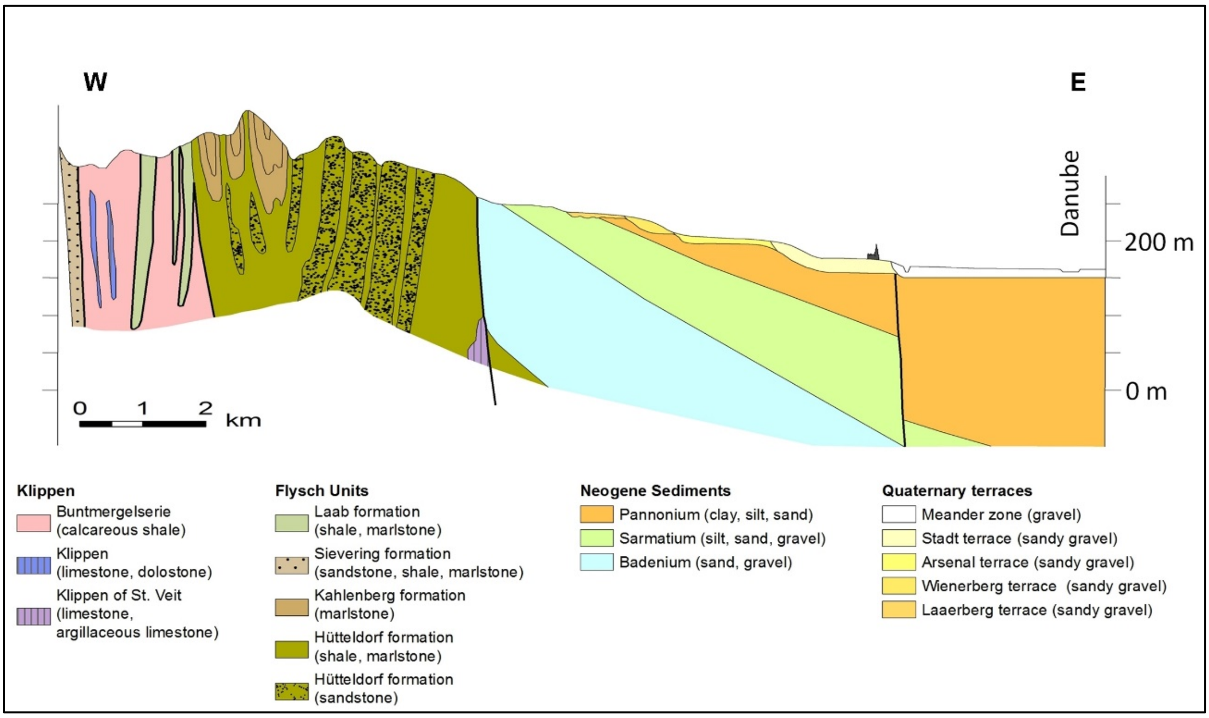


Simplified geological map of Vienna (after Schnabel, 2002)

Subsurface structure of the City

The Alpine units appearing west of Vienna are offset along N-S trending faults and lowered to a depth of 5400 m below sea level towards the east. The units relevant for urban activities, i.e. within a few hundred meters below ground, comprise from top to bottom

- Holocene loess and loam: fine-grained sediments with an average thickness of 2 m, at most 23 m, which occur in isolated areas mainly in the eastern half of the city
- Pleistocene / Holocene river terraces: sandy gravel beds with an average thickness of 10 - 30 m, which cover the central and eastern parts of the city
- Neogene clay and silt layers with intercalated sand and gravel horizons



W-E cross-section through Vienna (modified from Pfleiderer 2012)

Urban Soil

Urban soils in built-up areas in the central and eastern parts of the city mostly constitute anthropogenic accumulations rather than material derived from in situ weathering of underlying sediments. In contrast, most of the flysch zone in the western part of Vienna is covered by forest soils with distinct soil horizons. All over the city, top soils are monitored in 3-year intervals by the Vienna Magistrate - Department of the Environment – collecting samples at 286 locations and analysing heavy metal contents as well as PAH concentrations (Kreiner 2004).

Groundwater

Within the Vienna city area four hydrogeological units can be distinguished:

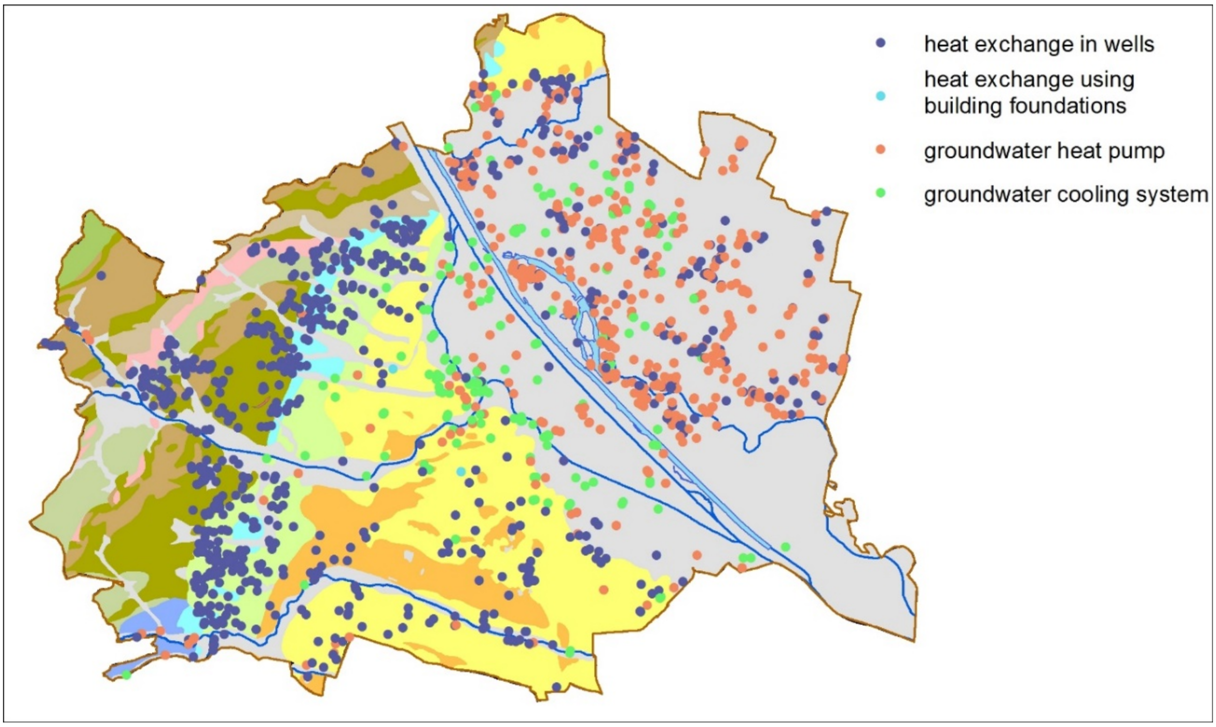
- Fractured aquifers in flysch units with local groundwater occurrences of low yield.
- Porous aquifers in coarse-grained layers within Neogene sediments with local groundwater occurrences of low yield at the surface but including confined units with high yield at depth.
- Porous aquifers in older gravel terraces with local groundwater occurrences of moderate yield.
- A porous aquifer in the youngest gravel terrace of the Danube river with a continuous groundwater body of very high permeability and yield.

Groundwater quantity and quality is monitored in Vienna by the Vienna Magistrate - Department of Water Management- which maintains a network of over 1000 monitoring stations for measurements of the water table and over 60 monitoring stations for hydrochemical sampling and analysis.

Drinking water in Vienna is to a large extent supplied by Alpine karst springs captured up to 100 km southwest of the city. About 390,000 m^3 of spring water per day flow along two major galleries (First and Second Vienna Spring Water Mains) by gravity, i.e. without the use of pumps. Only in cases of water main repairs, pipeline damage or extremely high water consumption during hot spells, a small portion of consumed water is supplied by groundwater from the Vienna basin.

Geothermal Energy

Usage of shallow geothermal energy is widespread in Vienna with over 1800 facilities. The types of usage are controlled by the distribution of groundwater bodies. Ground heat exchangers (closed loop) are installed in wells within the flysch zone, the Neogene sediments and older gravel terraces with little groundwater yield. In contrast, groundwater heat pumps (open loop) for heating and cooling are mainly found in the Holocene gravel aquifer. Ground heat use through pile foundations or collectors exists only rarely.



Usage of shallow geothermal energy in Vienna (modified from Götzl et al. 2014)

3. Urban planning and management

City administration and planning

The following Municipal Departments are involved in urban planning and management:

- The Department for Urban Development and Planning defines high-level goals and strategies, develops site planning for future housing, workplaces and recreational areas, and designs traffic concepts.
- The Department for District Planning and Land Use is responsible for zoning plans of individual districts, the assessment of construction projects, and organizes the participation of citizens in the planning and implementation of urban development measures.
- The Department for Energy Planning is responsible for coordinating and controlling energy concepts and for developing pilot projects to promote new energy technologies and to increase energy efficiency. The department also coordinates the subsidies for photovoltaic, solar-thermal collectors and geothermal facilities (heat exchangers, groundwater heat pumps, seasonal heat storage facilities).
- The Department for Water Rights has among its many tasks the issuing of permits for the use of surface water and groundwater. It maintains a registry of water rights including water withdrawals, waste water discharge, water protection areas, flood zones and landfill sites.

Departments and offices involved in urban planning in Vienna

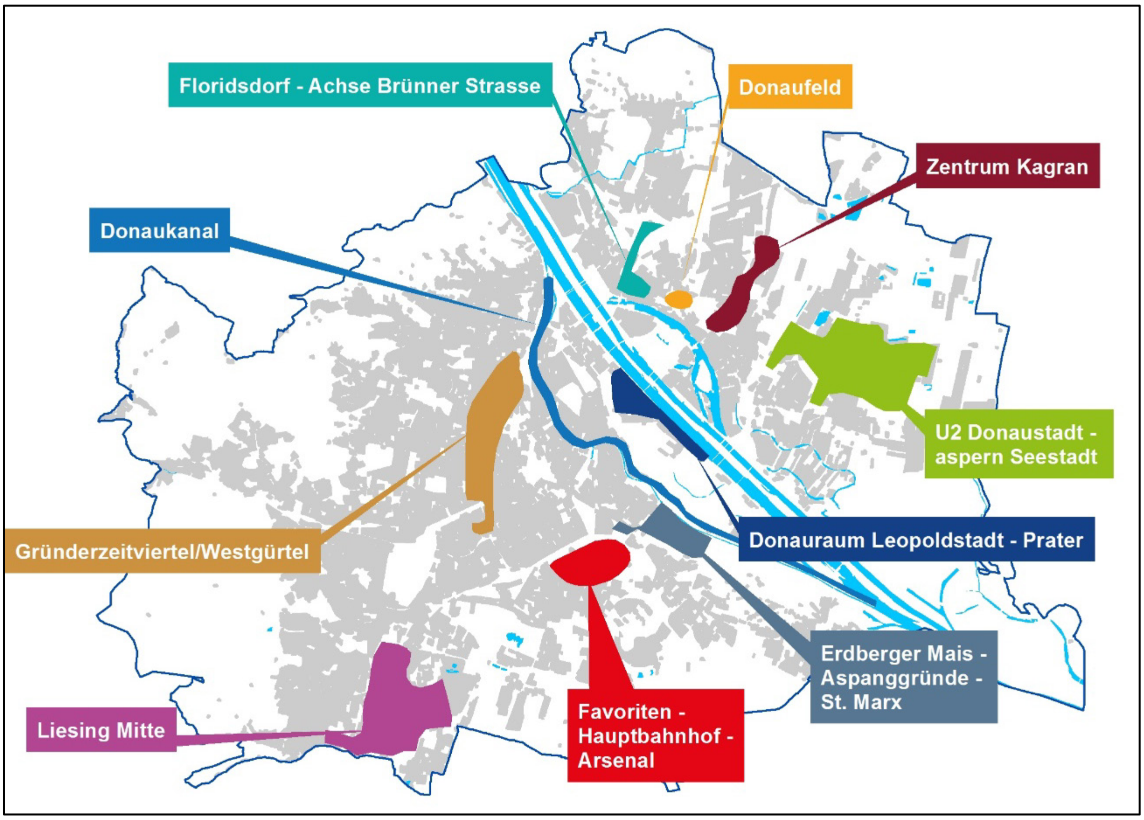
Steering - Chief Executive Office	***Tasks, Responsibilities***
Chief Executive Office - Executive Group for Construction and Technology (MDBD)	Steering, authority for urban planning and urban development, consultation of the politicians, approvals
Chief Executive Office - Executive Group for Construction and Technology – Planning Office (MDBD-GP)	Guidelines, decisions, steering the operative level (defining tasks of departments), steering the planning process
Chief Executive Office - Executive Group for Construction and Technology – Infrastructure Office (MDBD-GIS)	Assessment of infrastructure (costs and needed measures), recommendations, consultation of related municipal departments
Operative - Administrative Group Urban Planning, Traffic &Transport, Climate Protection, Energy and Public Participation	
Municipal Department for Urban Development and Planning (MA18)	Strategic planning, Urban Development Plan, urban research, support of the planning process, statement / input in the planning process
Municipal Department for District Planning and Land Use (MA21)	Land-use and building plan, executing the planning process
Building Inspection (MA37)	Inspection, checking, building permission
Operative - Administrative Group Environment	
Municipal Department for Environmental Protection (MA22)	Statement / input in the planning process, permission for nature protection or noise protection or air protection, authority for Environmental Impact Assessment (EIA)
Special bodies not subject to directions	
Viennese Ombuds-Office for Environmental Protection (WUA)	Check for Strategic Environment Assessment (SEA)

Current Urban Development Plan

In 2014, the City Administration launched the current Urban Development Plan (STEP 2025) defining planning objectives and guidelines for urban development. STEP is a key instrument for coordinated spatial planning and covers issues such as land development, the transport network, environmental challenges and efficient use of resources. For instance, STEP 2025 specifies whether an area is in the future designated as green space or for traffic purposes, for commercial buildings or housing construction. Politicians at city and district level, experts, members of the business community, representatives of the surrounding region and the urban population are systemically tied into the process. The STEP 2025 is an umbrella strategy for further detailed concepts with respect to mobility, green and open spaces and many more. For the first time, STEP 2025 requests an integrated urban and energy planning concept.

Current projects

Currently, ten target development areas are defined in STEP. Actions to be taken include constructing new hospitals, housing and workplaces, renewing existing buildings, transforming underused areas, reviving open spaces and diversifying mobility. Following a period of defining common objectives, identifying development measures, and coordinating the planning, these target areas will be transformed into regular development areas where concrete projects are implemented.



Target areas of Vienna urban development (2014).

Examples of recently implemented or ongoing projects include (a) the new Vienna Central Station where all long-distance rail services now converge, (b) the Infrastructure Initiative which will invest in projects to ensure that key services like drinking water supply, waste water management and energy provision keep pace with urban growth, or (c) the Public Transport Expansion which will extend one existing and construct one new underground railway line.

Challenges for underground planning

Examples of cases where the geological subsurface becomes relevant for underground planning, include the construction of subway lines and groundwater management.

Currently, one subway line (U1) is being extended towards the southern city limit. In 2009 during the planning phase, one exploratory drill hole encountered a small natural gas reservoir in Neogene sediments at 38 m depth. Although shallow gas accumulations are to be expected in this area, this particular occurrence came as a surprise. A follow-up study showed that precise forecasting is possible through expert seismic studies (Schreilechner & Eichkitz, 2013), but routine subsurface investigations are too coarse to recognize such occurrences. The three-dimensional extent of sand and gravel layers within the Neogene sediments is not known in detail for the entire city area.

The extension of another subway line (U2) and construction of a new line (U5) are currently in the planning phase. Detailed 3D modelling is carried out by the Vienna City Administration – Department of Bridge Construction and Foundation Engineering. Tunnelling in Neogene sediments poses no challenges as the material is fairly homogeneous and expected to contain virtually no groundwater along the planned subway lines. Tunnelling in groundwater-bearing gravel terraces can also be easily handled by geo-engineers. Challenging situations may arise when traversing the Pleistocene / Neogene boundary with silt and clay layers in the lower part and groundwater-bearing sand and gravel layers in the upper part of the tunnel tube. Therefore, precise knowledge of this boundary is vital.

An example where groundwater management issues became relevant, was the construction of a hydro dam in the Danube river at the south-eastern city limits at Freudenau. Damming the river resulted in higher water levels which would have affected the groundwater table especially in the western vicinity of the Danube. To prevent a rise in groundwater levels, the river was hydrologically separated from the accompanying groundwater body. This stopped infiltration of river water into the groundwater. To prevent a drop in groundwater levels, pumps were installed along the river course. These pumps now constantly replenish the groundwater body with Danube river water and artificially keep a steady groundwater table. River water quality is constantly monitored in order to prevent aquifer contamination.

4. Case study – Geothermal potential maps for Vienna

The use of shallow geothermal energy in Vienna included over 1,800 facilities in 2013 and is increasing rapidly. Therefore, the Department of Energy Planning commissioned a study to evaluate the geothermal potential for heating / cooling and seasonal heat storage in the shallow subsurface of Vienna. This study was carried out by the Geological Survey of Austria (Götzl et al., 2014) and was only possible with an existing 3D model, in particular with the knowledge of geological structures, depth to water table and hydrological properties contained in the model.

Aims and methods

Aims of the study included a compilation of relevant data stored in various administrative departments, generation of geothermal potential maps for the entire city area, detailed studies in five pilot areas (coinciding with urban development areas), as well as the formulation of optimized management measures for geothermal energy usage. The aim of the Vienna City Administration was to provide maps to Vienna's citizens indicating where the use of geothermal energy is possible and which type of usage is advisable.

Geodata

Relevant data sets included:

- a multi-layered geological map containing lithologically homogeneous areas (Hofmann & Pfleiderer, 2003)
- a 3D geological model (Pfleiderer & Hofmann, 2004)
- a hydrogeological map derived from the geological map
- additional borehole logs from a digital database maintained by the Department of Bridge Construction and Foundation Engineering
- geothermal rock parameters derived from literature and thermal response tests
- groundwater table and temperature data collected by the Department of Water Management
- water usage data from the Department for Water Rights including geothermal usages
- air and soil temperature data from the Central Office for Meteorology and Geodynamics

For the pilot areas, additional detailed information on geological surfaces, layer thicknesses, height of the water table and groundwater temperature data were provided by private contractors.

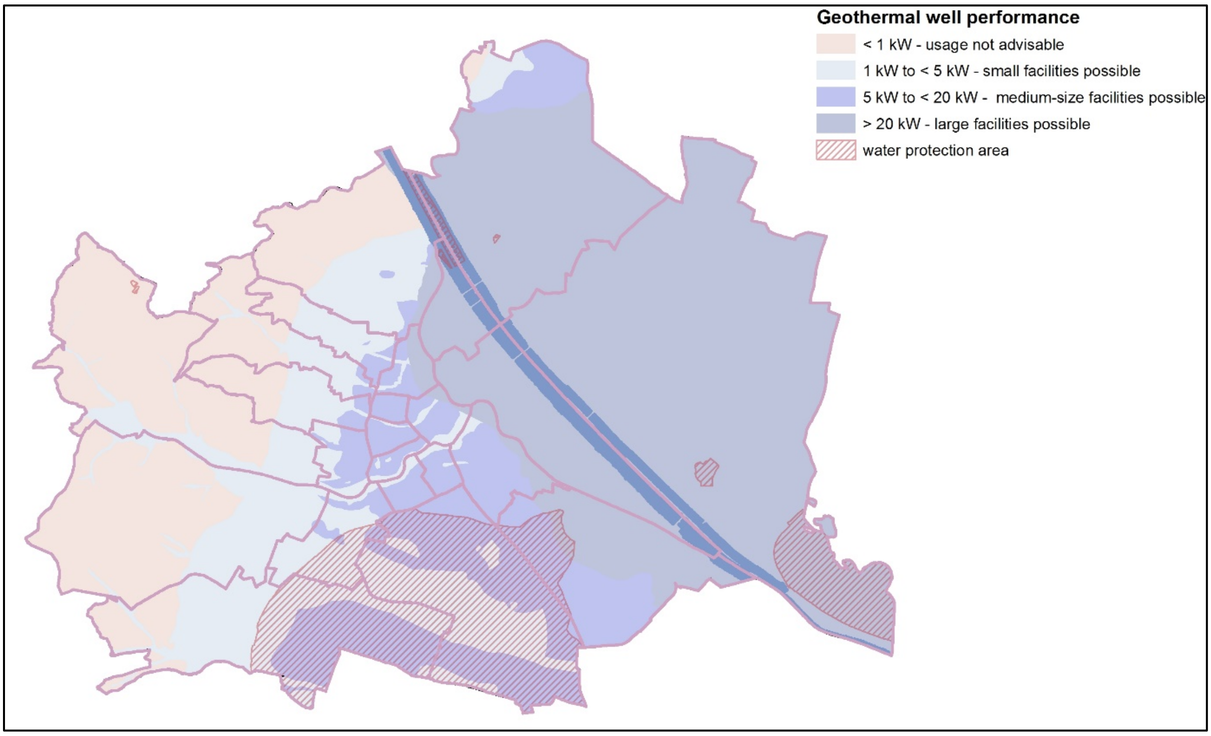
Modelling

Lithological units in boreholes were attributed with thermal conductivity and volumetric heat capacity values using look-up tables for dry, partly saturated and fully saturated conditions. Using water table data, the thermal conductivity of rock units in the subsurface model were calculated using routines programmed in MATLAB®. Thermal conductivities were transformed to well performance assuming standard well geometries and pump operation (Swiss Norm SIA 384/6). On the basis of the lithologically homogeneous areas, geothermal potential maps were produced at a scale of 1:25,000. Additionally, in areas of dense data coverage, raster interpolation was carried out in Surfer® without considering homogeneous areas. The latter approach enabled the identification of local inhomogeneities within units, but could not be used for the entire city area.

Results and applications

Geothermal potential maps for heat exchangers were derived for three depth intervals: (a) the top 30m below ground, (b) the top 100m below ground and (c) the top 200m below ground. These maps show the geothermal well performance grouped into three categories (good for average thermal conductivity > 1.9 W/m/K, medium for average thermal conductivity 1.6 – 1.9 W/m/K and moderate for average thermal conductivity < 1.6 W/m/K). For groundwater heat pumps, the maps show the average well performance grouped in ranges of < 1kW, 1 – 5kW, 5 – 20 kW and > 20kW.

All produced maps are available online in the Vienna city map and also hosted in the open government data portal of the city of Vienna for open use.



Geothermal well performance for groundwater heat pumps in Vienna (modified from Götzl et al. 2014).

Currently, permissions for the installation of heat pumps in Vienna are granted on a first-come-first-serve basis. During the study presented here, it became apparent that conflicts of use already exist as thermal plumes downstream of neighbouring heat pump locations overlap. Results of this study could therefore form the basis for concepts of a future geothermal resource management.

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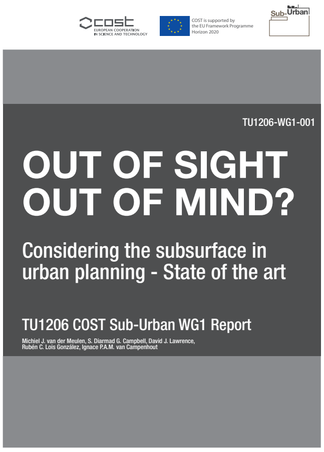

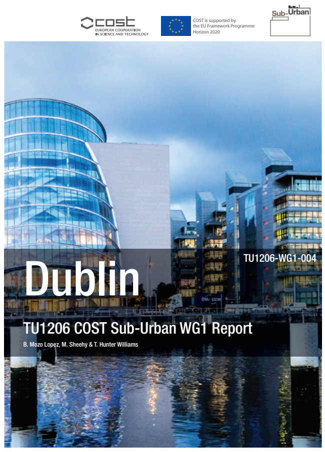

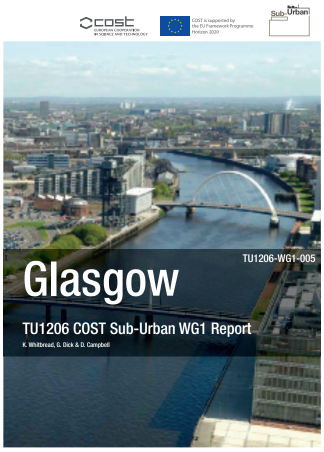

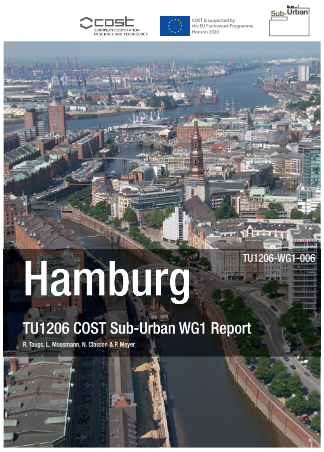

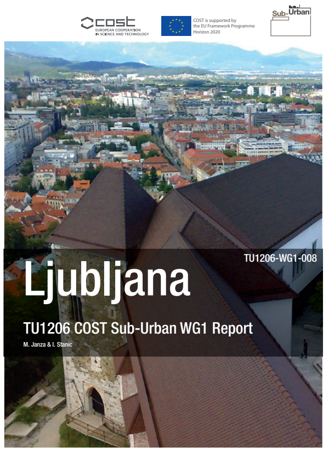

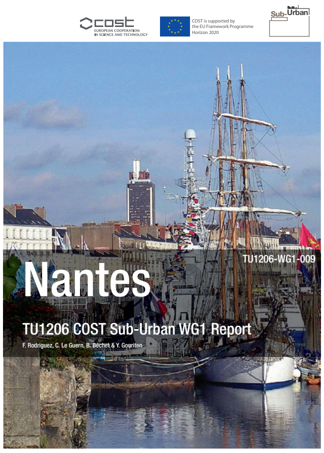

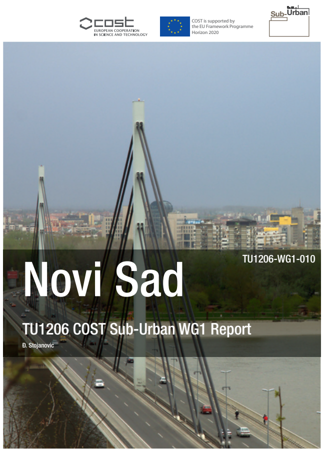

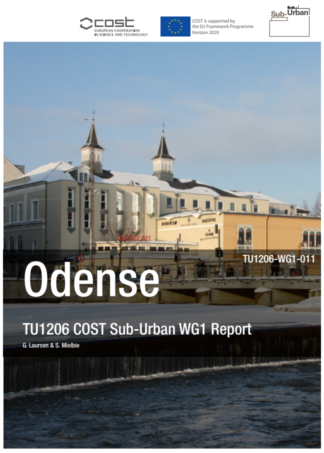

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