Chapter 2
Settings in Urban Environments

Peter Huggenberger and Jannis Epting

The history of subsurface resource use in urban areas is generally dominated by the activities during industrialization and even more so since the 1950s. If we want to understand the present condition of the quantitative and qualitative status of subsurface resources, especially concerning water resources in urban areas, we need to know the changes that occurred during this time period. Such changes include infrastructure development as the use of the subsurface for the construction of traffic lines which often interfere directly with water resources.

These changes to the subsurface structure and the numerous anthropogenic impacts make urban geological and hydrogeological issues complex. Additionally, innovative concepts for efficient management and resource protection for the subsurface are sparse. Historically, “low-level” resource management took place over a long time period. At the beginning of the last century, diseases and severe health problems made society aware of the negative impacts of intense and abusive resource exploitation. Especially in urban environments, the variety of pollution is generally more diverse compared to rural areas. This deficit causes severe problems today, when dealing with questions about the use of groundwater, the construction of traffic lines, waste disposal sites, or geothermal use of the subsurface. It also can be expected that these problems will accelerate in the near future.

About 70% of the European population lives in urban areas, which cover in total about 25% of the total European territory (EEA 1999). More than 40% of the water supply of Western and Eastern Europe and the Mediterranean region come from urban aquifers. For optimized and sustainable water resource use in urban regions, therefore, efficient and cost-effective management tools are essential to maintain quality of life and to ensure that water is available for use by future generations (Eiswirth et al. 2003). Sustainable use of soil, groundwater, and other important resources in urban areas is hence a key issue of European environmental policy (Prokop 2003).

Whereas rules for land and surface resource management exist, rules for subsurface planning and management (e.g., “invisibility” of water resources or geothermal energy) are almost absent. Due to the lack of rules for urban subsurface use, current planning procedures do not account for the interactions between different

P. Huggenberger and J. Epting (eds.), *Urban Geology: Process-Oriented Concepts for Adaptive and Integrated Resource Management,* DOI 10.1007/978-3-0348-0185-0_2,

usages of the subsurface and consequently subsurface resources use is most likely inefficient and can lead to considerable risks. One example is the observed areal subsidence in the Upper Rhine region (Adlertunnel in Basel-Landschaft, Switzerland). Another example is the observed land uplift as a result of well construction for the geothermal use of the shallow subsurface that came along with the connection of confined aquifers with rocks that are susceptible to swelling (Staufen, southwest Germany).

To develop concepts and methods for sustainable subsurface use in urban areas, environmental impact assessments not only have to include above-ground impairments, such as ground motions with effects on existing buildings and infrastructures, noise exposure and air pollution, but also the negative impacts on subsurface resources. In order to develop rules for the use of urban subsurface space, the complexity of emerging problems has to be broken down into elements. Therefore, the challenge is to integrate innovative concepts into effective, holistic plans for sustainable resource planning and management.

This chapter summarizes the settings in urban environments and highlights how they differ from rural areas. Further we focus on infrastructure development and use conflicts in urban areas, legal backgrounds as well as the general settings of the described case studies.

2.1 Infrastructure Development

Generally open space in urban areas is very rare. Therefore, the subsurface in urban areas is used more frequently for the growth of city infrastructure and traffic lines. Such constructions can temporarily affect urban groundwater systems during the construction period and permanently after completion. Subsurface constructions inevitably increase the pressure on urban groundwater resources and often involve a reduction of cross-sectional groundwater flow and aquifer-storage capacities. As a result subsurface resources are subject to ongoing adaptations under changing hydrological and technical boundary conditions.

Often infrastructure development and associated changes in land-use largely takes the pragmatic form of engineering for short-term benefits. New subsurface infrastructure often is realized under difficult geotechnical and hydrogeological conditions. In particular, tunnel construction in unconsolidated rocks and below the water table can lead to a higher risk of surface subsidence or collapse. To maintain the rapid pace of city life while ensuring that safety standards are met on construction sites, geotechnical measures such as cement injections for subsurface stabilization in unconsolidated rock are commonly used. The potential for hazards during construction is considerably high. Substances used on the construction site as remains of cement injections as well as the used substantives can lead to contamination. Furthermore, such stabilization measures may lead to adverse effects on groundwater flow regimes with regard to quantity and quality of water resources.

In some cases, changes in water fluxes and new created water ways can have negative impacts on adjacent infrastructures.

For this reason, constructions within the groundwater should be limited to the necessary. In case no other solutions are available, the question should be raised on how the impact of such constructions can be minimized. Altogether, constructions of infrastructure facilities (e.g., installation of shallow geothermal systems, subsurface dissolution mining for salt production, power lines, etc.) should take place under controlled hydraulic conditions, including the continuous measurement of hydraulics as well as further physical and chemical (T, EC, pH, Turbidity, etc.) or geotechnical parameters (inclination measurements, etc.).

In Chap. 3, we introduce some concepts for a controlled and sustainable infrastructure development in urban areas and apply them to case studies. The concepts base on the understanding of the principal hydrogeological and geotechnical processes in urban areas.

2.2 Use Conflicts in Urban Areas

Numerous use conflicts have to be considered in urban areas, such as municipal and industrial groundwater use or shallow and deep geothermal energy use. Additionally, historical aspects of the development of urban areas have to be considered (contaminated areas, infrastructure and public transportation development in the shallow unconsolidated and consolidated subsurface, water supply, subrosion processes, etc.). While some usages only temporarily affect urban groundwater systems, e.g., during scheduled operation of water use (day/night, winter/summer) or during the construction of infrastructure, other impacts are permanent, like the reduction of cross-sectional groundwater flow and aquifer-storage capacities (see above).

Competing usages in urban areas further include:

1. The extraction for drinking water supply and industrial processes.
2. Thermal groundwater use, including groundwater extractions and injections for cooling processes and heat production.
3. Water engineering measures, including flood control, construction site drainages, construction parts reaching into the aquifer and storm water management.
4. The growing use of water for modern city architecture like fountains, small streams, ponds, lakes, water-plays, etc.

It is likely that a higher density of the mentioned projects will lead to more use conflicts in the future. These different usages can result in significant changes in groundwater quality and dynamics of both local and regional groundwater flow regimes. It is an important issue of adaptive resource management (Sect. 3.1) to understand the changes due to urban infrastructure development. Further examples or topics of use conflicts are discussed in separate book chapters.

2.3 Legal Background

Although legal frameworks for subsurface protection and policy strategies have continuously been adjusted in the last decades, considerable damages to subsurface resources and groundwater flow regimes still occur. Existing legislation only partially includes the quantitative conservation of subsurface resources as well as a more restricted approval of infrastructures and incorporated construction site drainages.

There are several reasons for this discrepancy:

1. During infrastructure development, more attention is paid to purely technological and constructional problems concerning subsurface resource management rather than to issues dealing with sustainable resource use or possible interferences with historically polluted industrial areas.
2. Some projects undertaken under outdated legal frameworks, i.e., some 30 years ago, would not be approved today because more restrictive laws pertaining to subsurface resources, as well as changed perceptions and policy concerning these resources and its sustainable use, now apply.
3. Subsurface resource protection in urban areas is still focused mainly on documentation of changes in groundwater quality and flow regimes, like maintaining local flow capacities and preventing a significant lowering of the groundwater table. Less attention is paid to the prediction of future demands and to the management of subsurface resources.
4. Until now, the impacts of the various subsurface resource users were only regarded as solitary limited impacts and examinations of the interactions between them were not attempted. Other aspects, such as possible interactions with former industrial sites were often neglected.

With regards to urban aquifer systems, several legal aspects have to be considered. This includes the protection of aquifers which should not be (a) connected in such ways that quantitative or qualitative changes of the groundwater flow regime may occur and (b) essentially and permanently reduced in storage volume and cross-section for flow by constructions into usable aquifers. Often regulations include restrictions for reduced flow through capacities in the order of magnitude of 10%.

2.4 General Settings of the Outlined Case Studies

We present several case studies from the Basel area that illustrate a number of questions related to urban development (Fig. 2.1). The Basel region, which borders both Germany and France, acts as a vital regional as well as interregional traffic junction and represents one of the three designated economic centers of Switzerland. Moreover, Basel has a variety of natural environments, as well as highly vulnerable groundwater systems in river valleys and adjacent karstified areas.

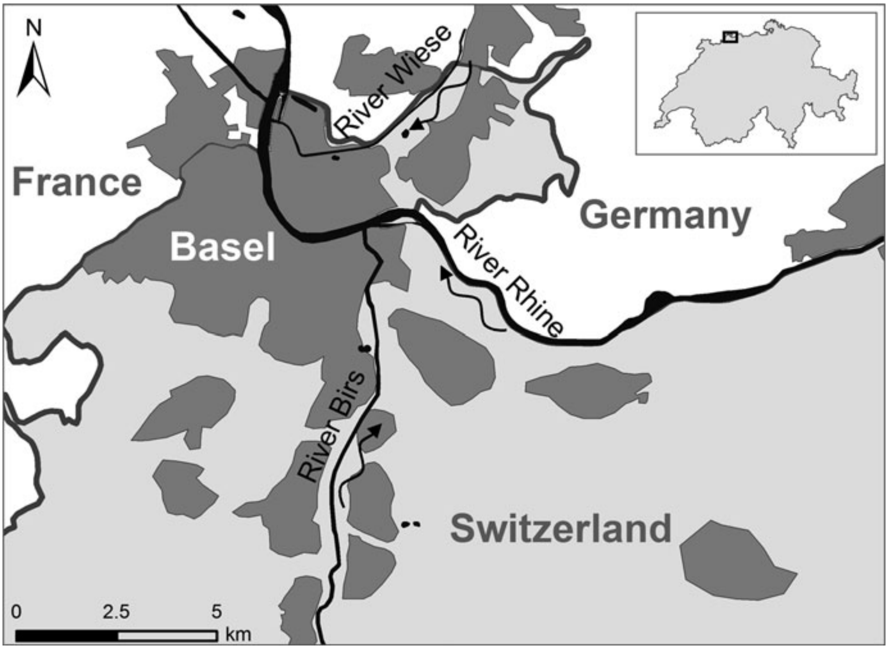

Fig. 2.1 The urban agglomeration of Basel

The subsurface geological composition and structure is summarized in the following box. The existence of evaporites and mixtures of marl-bearing evaporites in the Triassic formations as well as the fact that Basel is located in the seismologically most active area of central Europe comes along with the potential occurrence of geohazards. Some of these hazards are natural; others are triggered by human activities. We use the presented case studies to develop and to test strategies which support a sustainable long-term development of the urban environment and subsurface resources.

Geological Setting of the Basel Area

A general overview of the geology in the Basel area is given in Fig. 2.2, with the stratigraphic units defined in Table 2.1. The dominant tectonic feature is the eastern master fault of the Southern Rhine Graben separating the Rhine Graben and Tabular Jura. The vertical offset at the border fault of the Rhine Graben is about 1,400 m. Within the Rhine Graben (on the down-thrown side), the Mesozoic strata (Triassic to Jurassic; UPM, MES, PCB) are covered by 500–1,000 m of Cenozoic sediments. Three main Graben structures can be distinguished in the Basel area. The Cenocoic sediments in the area were deposited in the asymmetric syncline of St. Jakob-Tüllingen (SJT) adjacent to the main border fault. To the west the Rhine Graben then rises to the Horst of Basel (HB). Further west follows the "Allschwil fault zone" (AF), which sets

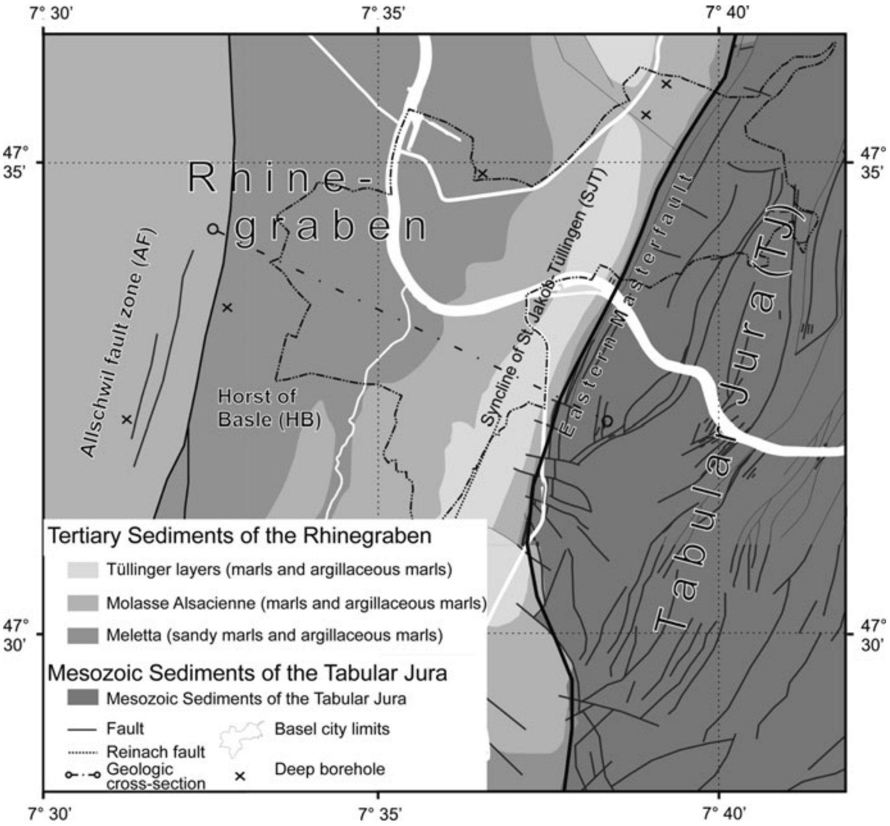

Fig. 2.2 Geological overview of the Basel area (modified after Noack et al. 1999)

Table 2.1 Stratigraphic units represented in the 3D-model and their abbreviations

Abbreviation	Stratigraphy
QUA	Quaternary sediments
TUE	Tüllingen layers (Tertiary); marls and argillaceous marls
ALS	Molasse Alsacienne (Tertiary); sandy marls
MEL	Meletta layers (Tertiary); sandy and argillaceous marls
UPM	Lower Tertiary/first Mesozoic sediments; Sannoisien (Tertiary) and upper Mesozoic sediments down to Lias
MES	Lower Mesozoic; Mesozoic sediments of the Lias and older
PCB	Lowest Mesozoic sediments (“Buntsandstein”), Paleozoic sediments (“Rotliegendes”) and crystalline basement

off the Graben sediments in the order of 500 m. The profile in Fig. 2.3 illustrates these structures.

The sedimentary composition of the Cenozoic layers to the west of the Rhine Graben master fault is known by outcrops located predominantly at the Graben

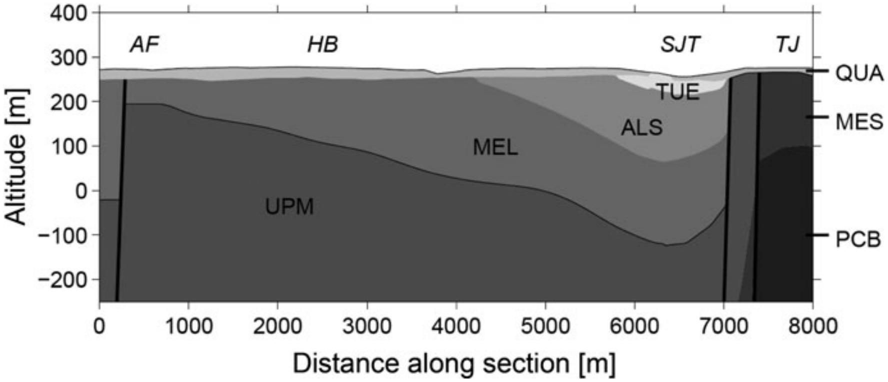

Fig. 2.3 Stratigraphic units below the surficial Quaternary sediments in the Basel area (line of section shown in Fig. 2.2). The *three letter codes* for the stratigraphic units are explained in Table 2.1. The dominant seismic contrast inside the Rhine Graben is between the units MEL and UPM, indicated with a line in the section (Kind 2002)

borders, six deep drill holes (>1,000 m), and a dense network of more than 10,000 boreholes (0 to <1,000 m) drilled, e.g., for geotechnical and groundwater investigation purposes (Sect. 4.1). The following formations can be distinguished in the boreholes (Table 2.1): argillaceous marls and clays of the Meletta layers (MEL, max. 350 m thick), the sandy “Molasse Alsacienne” (ALS, max. 350 m thick) and Tüllinger layers (TUE, max. 200 m thick) which consist of calcareous to argillaceous marls alternating with freshwater carbonates.

To the east of the Rhine Graben master fault the Dinkelberg block as a part of the Tabular Jura is bounded by larger faults such as the Rhine Graben master Fault, the Kandern Fault, the Werratal Fault, and the Zeinigen Fault. The block boundary is poorly defined in the South. The entire Dinkelberg block is characterized by a set of NNE–SSE striking narrow Graben structures. The southern part of the Dinkelberg block, the ESE–WNW striking Adlerhof Anticline, represents a compressive structure.

The basement rocks from the southern Black Forest have been affected by regional metamorphism, large-scale thrust tectonics, and extensive magmatic activity during the Variscan orogeny (e.g., Hann and Sawatzki 2000). At the end of the Variscan orogeny numerous intramontane basins were formed, as for example the so-called Permo-Carboniferous Basin of Northern Switzerland from the Burgundy to the Lake Constance. With the onset of the Triassic transgression, coastal and marine conditions developed. The principal decollement horizons of the Jura Mountains are Middle and Late Triassic evaporites. From the Late Triassic until the end of the Mesozoic, marine conditions prevailed resulting in a sedimentary stack between 1,000 and 1,500 m thick, consisting mainly of limestones, marls, and clays. Cretaceous deposits occur only west of the study area. Tertiary deposits are conserved in the Bresse and Rhine Graben as well as in the Molasse Basin. In the Jura

Mountains, erosional remnants of Tertiary deposits are only found within synclines (Allenbach and Wetzel 2006).

Due to the slight dip of the Triassic and Jurassic strata to the Southeast, there are areas, where subrosion altered the mechanical behavior of the evaporite zone, which at several locations can resemble more to a unconsolidated rock sequence. The Hauptmuschelkalk is one of the main aquifers in the area and often shows characteristic karst phenomena, which also altered locally the mechanical behavior of this unit (Sect. 5.4).

The Quaternary sediments were deposited in the main river valleys Rhine, Birs, and Wiese on a late- to post-Tertiary erosional surface. They consists mainly of fluvial gravels that are up to 40 m thick which locally are covered by Loess. During deglaciation and Holocene times, a series of river terraces formed, separated from each other by terrace bluffs. The geometry of the surface morphology gives some indication on the development of the valley fills. Due to the high permeability and porosities, the fluvial gravel deposits represent the most productive groundwater reservoirs in the area. Pronounced sedimentary structures and textures in the gravel deposits are important for the interpretation of the complex groundwater flow field and flow regime.

The Basel area includes a series of important local and regional scale water supplies, several floodplains in densely populated river valleys, as the floodplains of the Birs River (12 km^2) and the Wiese River (6 km^2) as well as the heavily industrialized area in the floodplain of the Rhine River (64 km^2). All sites represent important groundwater production areas in park-like natural recreation environments, surrounded by urban agglomeration, industry, contaminated sites and traffic. Drinking water supply competes with other interests or demands such as river training, flood control, recreation as well as urbanization and changes of land-use.

In the last 10 years, these sites have been equipped with extensive groundwater monitoring systems. At the same time, high-resolution geological and hydrogeological models were set up and calibrated with long-term datasets that allow comprehensive investigations of subsurface resources, groundwater flow regimes, and the description of relevant boundary fluxes. The models have predictive capabilities and have already been successfully used for scenario development. These already existing tools provide substantial contributions to the understanding of hydrogeological processes and are the basis for hypothesis testing.

References

Allenbach RP, Wetzel A (2006) Spatial patterns of Mesozoic facies relationships and the age of the Rhenish Lineament: a compilation. Int J Earth Sci (Geol Rundsch) 95:803–813. doi:10.1007/s00531-006-071-0

EEA (1999) Environment in the European Union at the turn of the century. European Environment Agency, Copenhagen, Denmark

Eiswirth M, Hötzl H, Cronin A, Morris B, Veselič M, Bufler R, Burn S, Dillon P (2003) Assessing and improving sustainability of urban water resources and systems. RMZ Mater Geoenviron 50:117–120

Hann HP, Sawatzki G (2000) Neue Daten zur Tektonik des Südschwarzwaldes. Jber Mitt Oberrhein Geol Ver 82:363–376

Kind F (2002) Development of microzonation methods: application to Basel, Switzerland, Ph.D. thesis, ETH Zürich, Available in electronic form from http://www.ethbib.ethz.ch

Noack T, Fäh D, Kruspan P (1999) Erdbebenmikrozonierung für den Kanton Basel-Stadt. Geologischer Bericht Nr. 24, Landeshydrologie und -geologie, 83p

Prokop G (2003) Sustainable management of soil and groundwater resources in urban areas. In: Proceedings of the 2nd IMAGETRAIN cluster meeting, Krakow, Poland, 2–4 Oct 2002

http://www.springer.com/978-3-0348-0184-3

Urban Geology
Process-Oriented Concepts for Adaptive and Integrated Resource Management
Huggenberger, P.; Epting, J. (Eds.)
2011, XVI, 216 p., Hardcover
ISBN: 978-3-0348-0184-3
A product of Springer Basel