Peter Huggenberger
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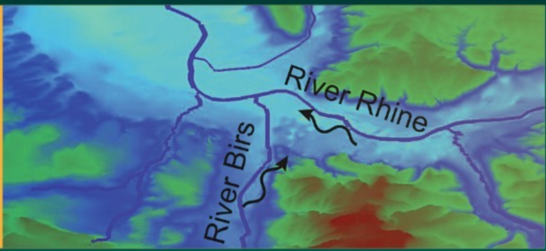
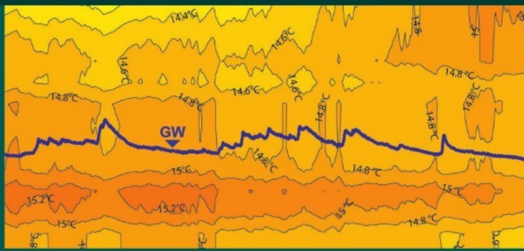
*Editors*




# Urban Geology

## Process-Oriented Concepts for Adaptive and Integrated Resource Management

Springer

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*Cover illustrations:* Top: Photograph of an excavation pit in the Novartis Campus area. Bottom left: Base of the unconsolidated rock of the Basel area (cf. Chapter 4.1). Bottom right: Groundwater head and temperature development observed in a riverine groundwater monitoring well (cf. Chapter 5.5)

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# Preface

This book reflects the experience of the authors, working in a multidisciplinary team of specialists and scientists on urban geosciences including geology, hydrogeology, hydrogeophysics, river-ecology, and on research projects at the Basel University. Besides the academic activities, the Applied and Environmental Geology (AUG) is in charge of the geological survey of the Cantons of Basel-Stadt and Basel-Landschaft.

Modern quantitative earth-sciences can contribute significantly to finding solutions concerning the sustainable use or subsurface resources in urban environments. The approaches we present in this book are mainly problem oriented. This includes the cooperation of specialists from several universities and institutions with different backgrounds worldwide to find solutions to specific problems related to urban environmental questions.

Urban subsurface resources and especially urban groundwater bodies are particularly vulnerable to environmental impacts, and their rational management is of major importance. Therefore, the development of optimization strategies is necessary. Such strategies should consider simultaneously the numerous impacts on urban subsurface resources, such as infrastructure development or groundwater and geothermal subsurface use.

Often, infrastructure development in urban environments and associated alterations in land use only consider the benefits for the improved infrastructure itself and planning largely takes the pragmatic form of engineering for short-term economic objectives. This often leads to adverse effects concerning quantitative and qualitative issues of subsurface resources including groundwater flow regimes, induced natural hazards, and use conflicts in general.

Although legal frameworks for protection of natural resources have continuously been adjusted in the last decades, damages still occur. Until now, the impacts on natural resources were mostly regarded as solitary limited impacts and examinations of the interactions between them, and other aspects such as possible interactions at a regional scale were not attempted. There are several reasons for this. More attention is paid to purely technological aspects concerning resource management during construction rather than to issues dealing with sustainable resource use as part of our ecosystems. In addition, some projects undertaken under outdated legal frameworks, i.e., some 30 years ago or even longer, would not be approved today because more restrictive laws pertaining to resource use, as well as changed perceptions and policy, now apply.

Currently, our knowledge on subsurface processes is incomplete as concepts for the sustainable use of the urban subsurface are rare. The present legislations and related regulations are confronted with many contradictions which would require a harmonization. These harmonization processes turn out to be very difficult. A discussion on future goals for quantitative and qualitative issues of subsurface resource has just begun. Such present initiatives also include future demands on subsurface resources.

In order to develop strategies for the sustainable use of subsurface resources in urban areas, environmental impact assessments have not only to incorporate aboveground vitiations like noise exposure and air pollution, but also to address the negative impacts on subsurface resources including groundwater flow regimes.

This book presents some alternative approaches for the implementation of adaptive management. Adaptive management schemes of environmental systems start with the definition of particular profiles of systems (i.e., water supply). Together with the identification of system profiles, specific targets are defined that lead to overall goals for particular subsurface resources, in the case of groundwater, i.e., the desired long-term development of urban groundwater resources. As the individual targets may interfere with each other and together not necessarily lead to the desired overall goal, techniques that facilitate the comparison of interference must be applied. This can be accomplished by the development of scenarios and the implementation of equivalence and acceptance criteria.

The conceptual approach we propose includes the combination of instruments that allow to adequately identifying influences of the various single impacts on the complete environmental system. Both impacts that only affect the system in its immediate vicinity and impacts with influence on the system on a regional scale are considered. There are four main elements which are important for a successful management of urban subsurface resources: (1) Efficient management of subsurface data and data mining to provide geological data in 3D; data should be organized in such a way that fast data access is provided; (2) Specific field investigations and experiments to study the relevant processes in urban environments and to provide adequate boundaries for modeling approaches; (3) Development of tools for intelligent analysis of subsurface monitoring data and the setup of geological, hydrogeological, or geotechnical models; and (4) The development and implementation of adaptive management concepts at different scales as a base for the setup of scenario techniques in decision processes. Based on these elements, comparative studies as well as scenario development are focused on predefined development goals.

An important aspect of resource management in urban areas is the availability of geological and hydrological information. Generally, large amounts of data are available that are spread at different institutions. The availability of these data often is difficult and its preparation for specific questions time consuming. This was the main reason to setup a geological database for northwestern Switzerland, consisting of a systematic data collection, an analysis of drill-core data, including the administration of metadata from geological and hydrological reports. The database can be connected to a Geographical Information System (GIS) for 3D structural analysis. Together with further hydrological data, the database represents a unique data source that is suitable for empirical studies and hypothesis testing in the domain of quantitative information fusion of urban geological or hydrological questions.

The book chapters integrate existing and new scientific knowledge, methods, and tools into these new concepts. Such an approach facilitates the implementation of the Water Framework (WFD) and Habitats Directives (HD) as well as a better management of subsurface resources. Main target groups addressed include professional hydrogeologists and geologists, urban planners and water supply engineers, environmental agencies, universities, as well as students in hydrogeology, planning, water supply, and environmental sciences.

The topics illustrated in this book have their origin in projects in the urban region of Basel, northwestern Switzerland. The examples deal with questions which have practical as well as research character. Almost all topics are also relevant for other urban areas and the sustainable use of subsurface resources in general.

Basel, Switzerland

Peter Huggenberger
Jannis Epting

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# Chapter 1
# Content

**Peter Huggenberger and Jannis Epting**

The various research topics that are illustrated in this book have their origin in projects in the region of Basel, Northwestern Switzerland. They deal with questions which have practical as well as research character in the domain of "urban geology." In the following, a brief overview of the contents in the various book chapters is given.

## 1.1 Chapter 2: Settings in Urban Environments

This chapter summarizes the common settings in urban environments, including a general description of the value, functions and characteristics of urban resources (water, energy, materials, etc.) as well as a statement about the challenges for environmental sciences.

The chapter also includes an asset of present protection and management strategies. The necessity to provide decision support for questions arising in the context of "urban geology" as a service for the public domain will be highlighted.

## 1.2 Chapter 3: Hypotheses and Concepts

This chapter introduces some of the main hypotheses and presents several concepts for adaptive and integrated resource management in urban areas. The methods are discussed together with the basic principles for the sustainable use of urban resources.

As urban environments are continuously changing and settings are spatiotemporal highly heterogeneous, such approaches allow to plan and control sustainable infrastructure development with respect to natural resources. Prerequisites are analyses of resource systems and an inventory of current and future profiles of

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such systems together with the definition of targets and goals for specific urban regions (Sect. 3.1).

We focus on how to advance an understanding of some of the relevant process in urban environments and on developing methods for testing hypotheses. In a next step, we outline risk profiles for subsurface resources, which comprise the determination of principal hazards or risk patterns for subareas and different resource users. This also includes the identification, localization, and capture of the relevant processes that lead to specific risk situations (i.e., conflicts and hazards from geothermal energy use, diffuse and point source pollution, microbial pollution through river–groundwater interaction, etc.). Thereby, the detection of risk situations is the basis for differentiated subsurface resource protection measures (Sect. 3.1).

The management of resources in urban areas requires a definition of manageable units of the subsurface. The delineation of such units not only is relevant for the exploitation of subsurface resources, but also allows to define boundaries and to derive fluxes of heat and mass including water compounds across these boundaries (Sect. 3.2).

We present a sustainable regional planning concept for the use and protection of water resources that allows us to address both spatial and temporal aspects of groundwater vulnerability. Furthermore, we discuss the role of quality control systems, which include the monitoring of physical, chemical and microbiological parameters, the definition of Critical Control Points (CCPs) as well as flux calculations, which can be derived from groundwater modeling (Sect. 3.3).

In the context of the ongoing debates on the impact of anthropogenic and climate change to quantitative and qualitative aspects of groundwater resources, we evaluated and summarized the present state of the groundwater temperatures in the city Basel. In three parts, we discuss (1) several positive and negative feedback mechanisms concerning water and thermal budgets and the impacts of climate change in urban environments; (2) the effects of predicted climate change on groundwater vulnerability in urban environments; and (3) analyses of historical groundwater temperature data to delineate different zones of urban groundwater bodies (GWB) and to optimize future observation networks (Sect. 3.4).

## 1.3 Chapter 4: Methods

A unique urban system is presented where geological, hydrogeological and hydrological data are systematically collected, verified and integrated into a comprehensive database and Geographic Information Systems (GIS) and from there into geological and hydrogeological models. This basis of information also allows us to develop tools for seismological prediction of subsurface behavior during major earthquakes. The provision of tailored database and GIS applications, including preliminary data analysis, 2D and 3D data as well as geostatistical analysis will be highlighted. In this chapter, we also address general statements regarding the role of data for urban geological and hydrogeological issues (Sect. 4.1).

In a next step, we present some basic elements for adaptive resource management, which include (1) the setup of adequate observation networks for monitoring; (2) selection of appropriate modeling tools; and (3) the definition and realization of specific field measurements to close existing knowledge gaps. We discuss some general thoughts concerning the optimal design of observation networks and the appropriate selection of measurement parameters. Further, we illustrate the choice of some available geological and hydrogeological modeling approaches for different environmental questions (Sect. 4.2).

As an example for comprehensive field investigations we present some hydrogeophysical research methods, including their applicability in urban environments. We show that the application of such methods allows a spatial continuous characterization of the subsurface and can be used for a nondestructive mapping and monitoring (Sect. 4.3).

Most urban aquifers are characterized by a high natural and anthropogenic heterogeneity of the subsurface as well as a large spatial variability of hydraulic parameters. Therefore, detailed knowledge of subsurface structures is an important prerequisite for the understanding and solution of specific problems related to adaptive resource management. We present some of the existing concepts and methods for the assessment and description of subsurface heterogeneity. Emphasis is placed on structure analyses using geostatistical approaches (Sect. 4.4).

When studying geological and hydrogeological processes a huge amount of spatiotemporal data accumulate, which have to be analyzed and interpreted. In this chapter, we present methods such as nonlinear statistics that allow the extraction of relevant information by hiding unnecessary information of complex datasets (Sect. 4.5).

## 1.4 Chapter 5: Examples and Case Studies

In this chapter, we illustrate results of case studies from the region of Basel, Northwestern Switzerland.

In a first set of case studies we address protection issues of groundwater production and river restoration in urban areas, with a focus on drinking water supply aspects. We present protection schemes for several major drinking water supplies in the region of Basel. We focus on hydrogeoecological issues in the context of river restoration projects in urban environments. Urbanization in the last century created a series of environmental problems such as flooding, groundwater pollution and ecological changes, including a decrease of characteristic habitats of riverine landscapes together with a drastic reduction of species. With three examples, we illustrate strategies to integrate hydrogeoecological aspects in an early planning process of engineering projects as drinking water and flood protection measures or river restoration in urban areas. Further we focus on the setup of monitoring networks and modeling tools, river–groundwater interaction, aquifer heterogeneity, and the reconciliation of water engineering measures along rivers.

In a second set of case studies, we address engineering and hydrogeological questions that emerged during the development of urban infrastructure projects in the region of Basel. Here, we focus on groundwater management and protection issues during and after completion of two infrastructure development and upgrading projects.

In a third set of case studies, we encompass management concepts as well as monitoring, modeling and remediation strategies for contaminated sites in trans-boundary settings. In a first case study, we discuss strategies to understand and predict the cumulative effects of the numerous single impacts on groundwater resources during a major suburban development project. In a second case study, we illustrate the development of groundwater pollution in a heavily industrialized groundwater protection area during the last decades.

In the fourth set of case studies, we address karst in urban environments. Groundwater circulation in evaporate-bearing horizons and the resulting evolution of karst frequently causes geotechnical problems such as land-subsidence or collapses. Such processes are of particular concern in urban areas where soluble geological formations coincide with vulnerable infrastructures as transportation systems. In this chapter, we focus on two case studies where subrosion, land-subsidence, and impacts on infrastructures have been observed. The case studies allow the illustration of the complex interrelations between natural phenomena and processes that are induced by present-day engineering and subsurface activities in the region of Basel.

In the fifth set of case studies, we address the use of shallow geothermal energy in urban environments. Increasing geothermal energy use can exceed the subsurface potential for different heating and cooling systems and effect groundwater quality. Currently, in most urban areas, regulations for water resource management and geothermal energy use are sparse and limited to the rule “first come, first served.” In this chapter, we focus on concepts for monitoring and modeling the influence of geothermal systems as well as on the provision of suitability maps for site evaluation. In the first case study, we present a concept that allows to rapidly evaluate proposed drilling sites that are suitable for geothermal use. In the second case, we present a thermal groundwater management concept on the basis of developed monitoring and modeling tools.

In a sixth set of case studies we deal with natural hazards in a regional context, including earthquakes and earthquake risk reduction, major flood events, and flood protection measures.

# 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

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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.