GROUNDWATER IN THE CITY

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Prague -
the Growth Pole of the Czech Republic

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Photo on the title page

Old public wells in Prague (Kolejní Street)

In the 19th century, a network of several dozen public wells with hand pumps was built and used by Prague inhabitants for drinking water supply. They carried the pumped groundwater in containers to their households. It was a significant improvement in the sanitary quality of water in Prague.

Previously, since the 15th century, the majority of the population relied only on water from the Vltava River, which was distributed to Prague fountains from four water towers (Petržilkovská water tower for Lesser Town, Old Town water tower for Prague's Old Town, Šítkovská water tower supplying the upper New Town and Novomlýnská water tower for water supply to the lower Prague New Town). A special case was the fountain on Charles Square (until 1848 named Cattle Market, Viehmarkt), which had better quality water than the other fountains, because it was supplied with groundwater from a spring on what is today the Na Rybníčku Street, behind the Church of St. Štěpán, not by the Vltava water like the other fountains.

Further development of the city led to the fact that even these sources of shallow groundwater were gradually abandoned during the first half of the 20th century (partly due to the gradually increasing requirements for drinking water quality), as the development of the Prague water supply system continued using quality groundwater from the source in Káraný, north of Prague.

Author of photography: Ing. Anna Hrabánková

GROUNDWATER IN THE CITY

T. G. Masaryk Water Research Institute, Public Research Institution
Prague 2020

Dear readers,

groundwater is an integral part of the hydrosphere and the entire environment. Groundwater is a particularly important source of quality drinking water and valuable aquatic and water ecosystems also depend on it.

The quantity and quality of groundwater is currently impacted by changes in climatic conditions and various human interventions in the natural conditions of the region. One of the features of a healthy landscape is a well-functioning hydrological cycle, and resilience to various climatic extremes (droughts, floods). The ability of the landscape to infiltrate a significant portion of the precipitation into groundwater below the surface of the region reduces the risks and impacts of flood situations. Sufficient groundwater in the landscape significantly helps to bridge the drought periods.

Groundwater also occurs in the city. It is the urban development that has a negative impact on the quantity and quality of groundwater: Buildings and paved areas reduce the infiltration of precipitation below the ground level. Tunnels, deep foundations and underground utilities artificially drain the area and reduce groundwater table levels. In urban areas, there are many potential sources of pollution impacting the quality and purity of groundwater in cities. Gradually improving care for surface water in the city, i.e. streams and reservoirs (various revitalization and renaturation projects, reduction of pollutant releases) naturally also contributes to the improvement of the state of groundwater. In addition, however, attention must be paid to some special aspects, such as an increased support for the infiltration of precipitation in places where permeable rocks occur, or the care of springs and wells in the cities.

The aim of the publication *Groundwater in the City* is to acquaint the general non-professional public, including the young generation, with the basics of hydrogeology as a science dealing with groundwater. Urban, and especially Prague, environments reflect such topics, including water wells in Prague, rock environment of Prague, groundwater pollution in cities, sources of drinking water for Prague, specifics of water isotope composition in the city, springs in Prague, impacts of buildings and land use on precipitation infiltration and groundwater table level, etc.

The chapters contain illustrative graphics for an easier understanding of the individual phenomena. Finally, there are review questions to help you determine how well you have digested the new information. In addition to this book, an electronic learning module on the same topic was created. This publication is available free of charge in printed form at the T.G. Masaryk Water Research Institute, Public Research Institution, and also in an electronic format on the website heis.vuv.cz/projekty/praha-adaptacniopatreni. It is part of a 3-part series that includes the following titles: *City and Water, Groundwater in the City* and *Adaptation of the City to Floods and Droughts.*

I believe that all three of these publications will help you expand your knowledge of water and nature around us.

Josef Vojtěch Datel

ISBN 978-80-87402-87-0
ISBN 978-80-87402-86-3 (Czech version)

Our thanks:

The publication was co-financed by the European Union from the European Structural and Investment Funds.

Name of the program: Operational Program Prague – Pole of Growth of the Czech Republic

Project title: Analysis of adaptation measures to mitigate the effects of climate change and urbanization on water regime in the area of outer Prague

Project registration number: CZ.07.1.02/0.0/0.0/16_040/0000380

Project lead: T. G. Masaryk Water Research Institute, Public Research Institution

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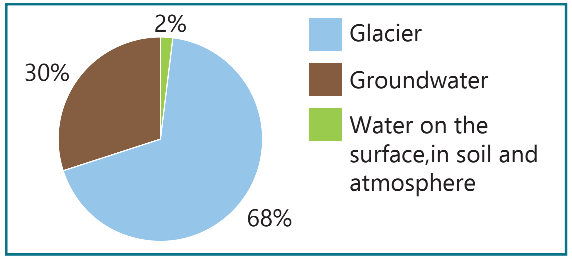
1. SUBSURFACE WATER

In the natural environment, we find water not only on the surface (in the form of streams, rivers, lakes and ponds) and in the atmosphere (rain and snowfall and less common forms such as hail, fog, dew or hoarfrost), but also below the surface. The water below the earth's surface is called subsurface water, and it is a very important form water. It consists of soil water and groundwater.

- SOIL WATER
  Occurs just below the surface in the soil to a depth of about 1 – 2 m and is important mainly for plants that uptake it with the help of roots. The scientific field of hydropedology deals with soil water.
- GROUNDWATER
  Is located at greater depths, where it fills various cracks, cavities, and pores in the rocks. The scientific field of hydrogeology deals with it. Groundwater makes up about 30% of all fresh water on Earth, so it is the main source of quality drinking water for humans (groundwater in wells).

Fresh water makes up only about 2.5% of all water, the rest is salt water. Most freshwater is bound in glaciers (about 68%) and therefore is mostly inaccessible. Water on the surface (in rivers and lakes) makes up only about 2%. Therefore, groundwater is extremely important, making up about 30% of the freshwater supplies on Earth.



Distribution of fresh water on Earth

Sometimes we can encounter the term undergroundwater instead of the correct term groundwater. But this is an unprofessional and incorrect term, and we should not use it.

Hydrological circulation

Groundwater is part of the water circulation in the landscape. It originates by infiltration of precipitation (rain or melting snow) below the surface of the area, and it is drained by springs into surface streams (streams, rivers). The quantity of soil and groundwater is constantly changing, depending on the quantity of rainwater that seeps in below the surface.

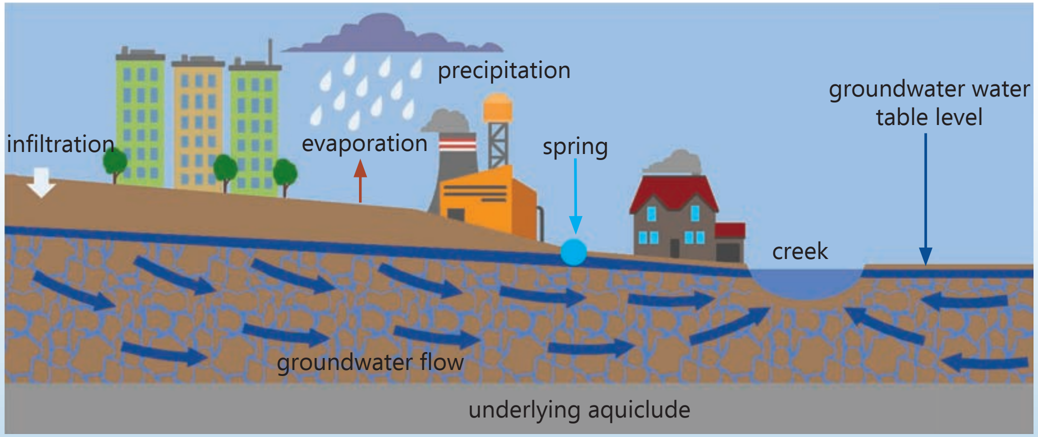
What determines what portion of the rain or melting snow seeps in? It depends on how well the soils and rocks are permeable (sandy soils and rocks are well permeable, clayey poorly permeable). The quantity of water that evaporates is also important - in the summer heat, most water usually evaporates, even in heavy rains. Torrential rains from storms quickly run off the surface and also do not seep in much. Snow and rainfall in the colder half of the year are therefore much more important for replenishing groundwater supplies. In our country, over the whole year, on the average two thirds to three quarters of water from precipitation evaporate.

The often mentioned so-called rule of thirds (a third of rainwater runs off the surface, a third evaporates, a third seeps in) usually does not apply. In our country, only about 10 – 15% of water can seep in under the surface. In cities, it is even less – in many areas, no water can seep in (where there are buildings, concrete, or asphalted areas). In the city, it is therefore necessary to protect open areas where water can seep in, to ensure seepage of water from roofs, etc.).

Hydrogeological structure

The rock environment, where there is a complete circulation of groundwater (from the site of infiltration to the site of drainage) is called the hydrogeological structure, and consists of three parts:

- Area of origin (infiltration) of groundwater, where precipitation seeps in below the surface.
- Accumulation space, where water flows from the point of infiltration to the point of drainage and where it creates groundwater reserves.
- Place of drainage, where groundwater returns to the surface, usually in valleys where it feeds watercourses, emerges in the form of springs or causes water logging of the terrain (not always – water logging is sometimes related only to surface water).



Ground water circulation in the landscape – typical shallow hydrogeological structure

The figure shows a location with a higher elevation over the sea level in the left part of the figure where the rainwater from rainfall seeps in, and arrows indicate the direction of the flow towards the valley to the place of drainage (water stream, spring). The arrows show that part of the water flows shallow below the surface (where it may be within reach of plant roots and trees), while another part of the water reaches greater depths. At the foot of the slope, shallow groundwater can flow out like a spring.

2. GROUNDWATER IN ROCKS

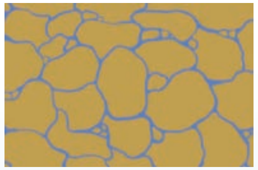
Rock porosity

Rocks contain various pores, cavities and fissures that may contain groundwater. Different rocks differ in size, shape, character and number of these cavities. To describe these cavities, we use the parameter called porosity. It is the ratio of rock volume to pore volume.

Experiment at home to determine porosity: Take a flowerpot, fill it with any dry soil or sand and calculate its volume V (according to the shape of the flowerpot as the volume of a cylinder or truncated cone). Then slowly pour water on the entire surface of the flowerpot evenly from a container of known volume. The moment the water starts to flow from the bottom of the pot, the water has filled all the pores. The porosity of the soil in percent is easily determined by dividing the volume of the soil in the pot by the volume of water used up and multiplying by 100. If we get, for example, 30%, it means that 30% of the soil volume was free space filled by water.

Depending on the shape of the cavities, there are three basic types of porosity:

- INTERGRANULAR POROSITY (PORE)
  In rocks it is formed by free space among individual grains (e.g. sand, gravel, sandstone). Soils (sandy or clayey loams) also have a pore porosity, but the individual grains are very small, so the spaces among the grains are also very small, but there are even more of them.



Pore porosity

- FISSURE POROSITY
  In hard rocks, such as granite, gneiss, basalt, etc., there are only smaller or larger cracks in which groundwater can move.

Fissure porosity

- KARST POROSITY
  Some rocks are well soluble in the water that flows through them, such as limestone. The original cracks gradually expand by dissolution, creating larger underground cavities.

Karst porosity

Rock permeability

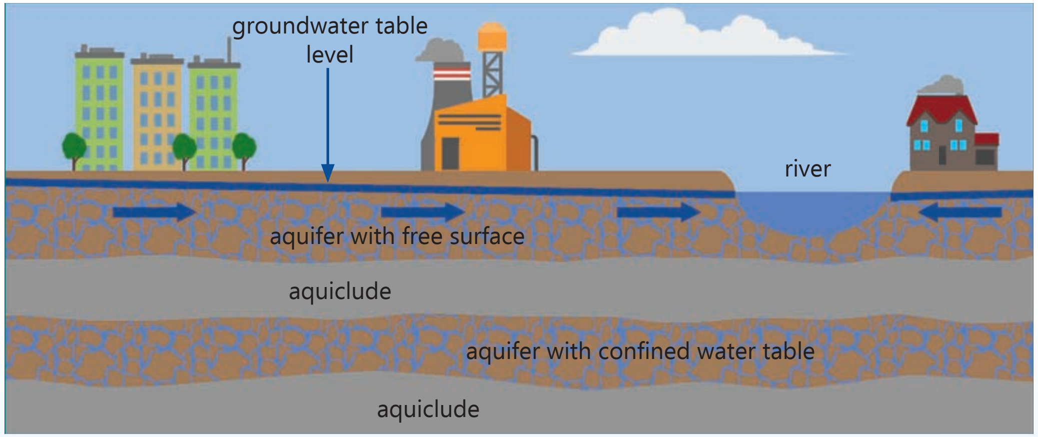
Rock permeability is important in the search for a source of groundwater. In order to find a sufficiently rich source of water, we need to find a rock that has high permeability, and in which more groundwater can flow than in low-permeability rock.

It is common that rocks with high porosity (sand, gravel, sandstone) also have high permeability, which means that water can flow through them easily. However, this is not always the case – for example, clayey rocks also have high porosity but low permeability. If the pores are too small or poorly interconnected, water cannot flow through them and the rock is poorly permeable.

Clay and sand may have the same magnitudeof total porosity (e.g. 25%) but their permeability is completely different. This is due to the fact that while in sand water can seep through most of the pores, in clay the pores are so small that water is trapped in them by capillary forces and cannot flow.

Hydrogeological aquifer and aquiclude

Different rocks and rock layers below the surface in the given area have different permeabilities. In permeable rocks, groundwater flows much more intensely than in less permeable rocks. The rock environment can therefore be divided into hydrogeological aquifers and aquitards.



Groundwater circulation in the landscape – typical shallow hydrogeological structure

- HYDROGEOLOGICAL AQUIFER
  Is a rock that may contain enough free-flowing groundwater that can be abstracted, e.g. by a well. The permeability is significantly higher than the rock permeability of the adjacent aquiclude. Depending on the geological structure of the region, there may be several aquifers on top of each other, separated by aquicludes. In deeper aquifers, the water is usually under higher pressure due to the overlying aquiclude (aquifer with a confinedwater table). The aquifer does not always have to contain groundwater, it can be partially or completely dry (e.g. due to drought, artificial drainage, etc.).
- HYDROGEOLOGICAL AQUICLUDE
  Is a rock significantly less permeable than the rock of the adjacent aquifer, and contains only small quantity of free water. Most of the water in an aquiclude is confined in small pores and is not free to move.

In cities, groundwater in the first aquifer near the surface is the most impacted by development, and is also threatened by pollution, such as from environmental accidents or sewage leaks. In the countryside, pollution from fertilizers and pesticides used in agriculture is common. It is therefore better to utilize a deeper aquifer for groundwater abstraction for drinking water purposes, which is better protected against pollution by impermeable rocks of the overlying aquiclude.

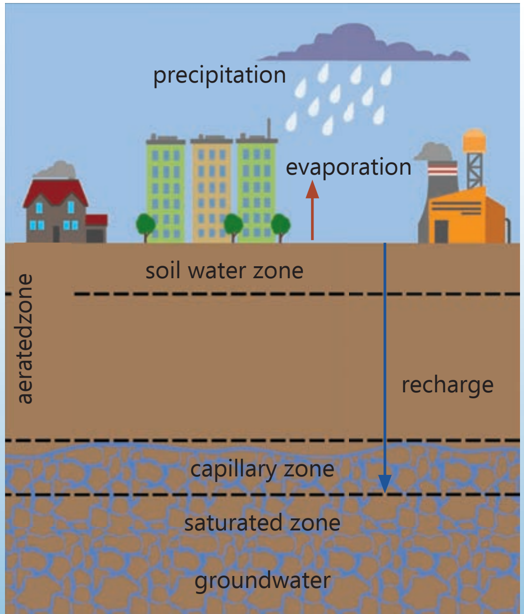
3. GROUNDWATER DEPTH

Aerated and saturated zone

When we start digging a well, we first penetrate through a layer of soil, then a layer of rock, which will be moist but will not release water, until we reach the groundwater table level at a certain depth, and directly in the well, water appears. According to the quantity of water in the rock pores (pores, fissures and karst cavities), we classify the rock environment of the first hydrogeological aquifer below the surface into two basic zones - aerated and saturated.

AERATED ZONE (unsaturated zone) is the space between the land surface and the groundwater table level and includes the zone of soil water. It is important for replenishing groundwater supplies - if rainwater seeps in below the surface, due to gravity it seeps further into the depth towards the groundwater table. It is characterized in that only part of the pores is filled with water. The quantity of water in the pores is not constant and changes over time, depending on whether a lot of water has seeped in (e.g. when it rains a lot, most of the pores in the aerated zone may be filled with water) or a small quantity of water (during a prolonged drought most pores in the aerated zone are without water).

SATURATED ZONE saturated zone is situated under the groundwater table and is characterized in that 100% of the pores of the rock are filled (saturated with) water. If we want to abstract the groundwater, e.g. by a pump, this is only possible from the saturated zone; the well then must extend to a certain depth below the water table.



Groundwater depth occurrence zones

Between the aerated and saturated zone is the so called capillary zone, which is generated by the capillary action of groundwater from the water table upwards, due to the capillary forces in small pores. The smaller the pores, the higher the water is able to rise – the highest capillary zone occurs in clayey soils (water can rise up to several meters from the water table), in gravel, where there are only large spaces between the grains, it is only a few centimeters high.

The depth of the upper edge of the capillary zone is important for built-up areas and buildings (especially if it reaches close to the ground surface), as it can cause water to rise into the foundations of the masonry, and their dampening. If the groundwater table is shallow below the ground surface (e.g. in a valley around streams), the capillary zone can be a source of water for waterlogged locations on the surface (wetlands, wet meadows), where there are numerous protected species of plants and animals.

When we are digging a well, it is important for us to know how deep the groundwater table is (i.e. the upper edge of the saturated zone). If we are building a house, it is important to know the depth of the capillary zone, which is closer to the surface than the water table, because it can damage foundations and walls by water capillary action.

The influence of the city and buildings on groundwater

The natural occurrence and flow of groundwater in the built-up area is influenced by many human interventions.

The aerated zone is often impacted by construction on the surface or the infiltration of rainwater is hampered by impermeable surfaces (asphalt, concrete). The result is a reduction in groundwater storage. In some places, on the other hand, artificial sources of infiltrated water appear, in the form of water leaks from water supply and sewerage lines. The result is greater quantity of water in the aerated zone and an increase in groundwater storage, but also a greater risk of waterlogging of buildings, the surface of the area, or possibly leakage of pollution into the environment.

The saturated zone can be affected by deep foundations of buildings, tunnels, underground utilities (sewers, water mains, various cables, etc.). They can cause drainage of the area (and thus a reduction in the quantity of groundwater, a drop in water table levels, the extinction of springs, etc.), or, conversely, a rise of the water table, if they represent an obstacle to natural flow. This is associated with the risks of waterlogging the foundations of buildings, land, origin of landslides, etc.

In the built-up area, groundwater is often artificially drained by various drainage systems to reduce the water table elevation and protect the foundations from moisture and sometimes aggressive effects of water. The result, however, is an overall reduction in the quantity of water in the urban landscape.

The result of building various structures and other human interventions is usually an accelerated run-off of water from the area, lowering the groundwater table and reducing groundwater quantity. It is therefore important to pay attention to the measures that can reduce these negative effects, even before the start of any construction activity. After damaging the water conditions, it is difficult, if not impossible, to restore them.

Not only do buildings have an impact on groundwater in the cities, but sometimes groundwater also has a negative effect on buildings. If the groundwater water table level (or the upper margin of the capillary zone) is within the reach of foundations and basements of buildings, it can cause dampening of building foundations, walls, basements, etc. Sometimes groundwater is also chemically aggressive and damages concrete or steel structures. Lowering the water table by artificial drainage (or by thoroughly insulating the underground parts of buildings to separate them from groundwater) is then a way to eliminate these negative effects and protect the buildings and equipment.

4. GROUNDWATER TABLE

Groundwater table and groundwater flow

The groundwater table forms the interface between the aerated and saturated zone in the rock environment. Above the water table are only some pores filled with water. Below the groundwater table, all pores are filled with water.

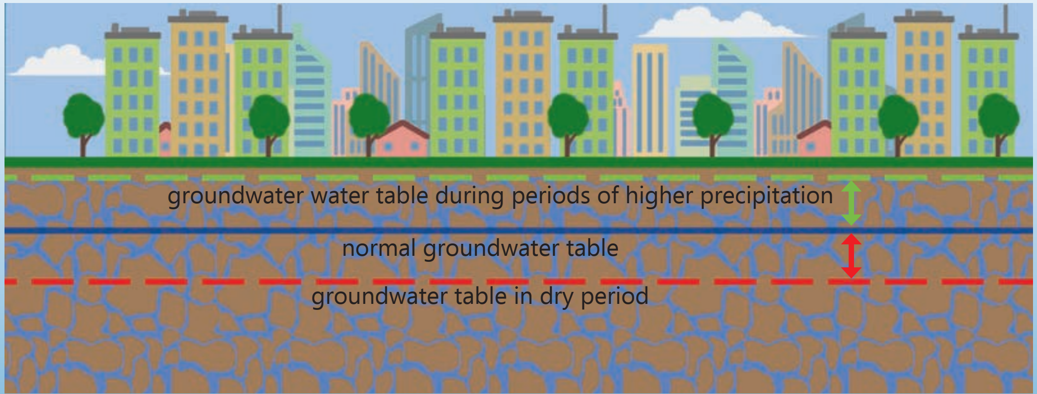
Like the water table in a river, we can schematically imagine the groundwater table as a plane – a flat surface (two-dimensional geometric shape), which has a gradient (slope) in the direction of the water flow. When we know the slope of the water table, we will then know in which direction the groundwater is flowing. The groundwater table usually has a small slope (e.g. 1 °), but this is enough to cause water to flow. The direction of the groundwater table slope usually corresponds to the direction of the slope of the ground surface of the area, so the groundwater flows in the direction of the ground slope down into the valley.

The more permeable the rock is and the greater the slope of the groundwater table, the higher the groundwater flow velocity. Average flow velocities are around one meter per day.

The maximum flow velocities attain over 10 meters per day (e.g. in coarse gravel), in clayey rocks the groundwater moves at a speed of only a few millimeters per day.

Groundwater table fluctuations

The depth of the groundwater table below the surface is not constant, but changes over time. When it rains a lot and when there is a lot of melting snow, more cavities in the rock are filled with water and the groundwater table rises closer to the surface. Conversely, when there is a long drought, the water table drops because groundwater still flows in the direction of the water table slope, but it is not recharged. Because it takes some time for the precipitation to seep into the groundwater through the rock environment, changes in the groundwater table level are delayed after precipitation. For shallow groundwater this usually represents several days to weeks, for deeper groundwater it can be months to years.



Elevation range of natural shallow groundwater table fluctuations

Changes in water table can vary at different speeds. An annual period is typical, reflecting the annual course of precipitation: in spring the groundwater table is at the highest level (groundwater is recharged from melting snow and spring rains) and in autumn at the lowest level (in summer, groundwater is practically not recharged, just runs off). This seasonal fluctuation can usually attain 1 – 2 m, sometimes more.

However, groundwater table may fluctuate even in shorter, e.g. weekly periods, when due to heavy rainfall or floods the level may temporarily increase or decrease due to intense drought. There are also long-term trends of changes in groundwater table, e.g. due to climate change, there is a long-term trend of a slight decrease in groundwater table levels.

Changes in groundwater table in the city

Fluctuations in the groundwater table in cities can have a negative effect, for example, greater dampening of the foundations of buildings, cellars, etc. in the spring, when the groundwater table level is at its annual maximum.

When assessing the impact of groundwater on structures, it is necessary to know the extent of fluctuations in groundwater table level in the given location, and not only consider its average level. It is important to know especially the maximum water table elevation (including the capillary zone) that groundwater can reach during the year.

In the cities, in addition to natural causes, there are also various human interventions that affect the change of groundwater table level. These changes usually cause a drop in water table and are more permanent:

- Drainage of building foundations and drainage effect of underground structures (tunnels, underground garages, deep basements of buildings, etc.).
- Reduction of rainwater seepage by continuous urban development, existence of underground utilities, creation of impermeable surfaces (asphalt, concrete) and drainage of rainwater through rainwater drainage sewers,
- Groundwater abstraction for various purposes (drinking water supply, irrigation water, process water for industry, etc.).

In some cases, however, the groundwater table level in the city may be higher than under the natural conditions. Underground structures positioned transversely to groundwater flow (e.g. some metro stations) can dam the flow and thus cause a permanent increase in the groundwater table. The temporary rise in water table levels may also be related to water leaks from damaged water and sewage pipes. The water table level is also higher in places where rainwater from the roofs seeps in, which is required for all new buildings today.

Monitoring of groundwater table levels

The Czech Hydrometeorological Institute (CHMI) deals with regular measurement of changes in groundwater table levels. Throughout the Czech Republic, it has a network of several hundred shallow and deep boreholes and springs, which it regularly measures and evaluates changes in the quantity of groundwater. Several of these monitoring points are also in the outskirts of Prague. Information about them can be obtained on the CHMI website (www.chmi.cz).

5. FISSURE GROUNDWATER

Geological conditions of Prague

The geological structure and rocks types present in a particular area determine what type of groundwater and where it occurs. In order to study groundwater, we must first know the geological settings of the area.

On most of the territory of Prague, Paleozoic and Proterozoic shales occur. Within the shales we can find minor occurrence of other rocks - siltstones, sandstones, quartzites. The rocks are permeable only through the fissures, which are mostly present in layers of quartzites and sandstone, and least in shales. In the southwest, from Radotín and Slivenec to Hlubočepy and Prokopské valley, extend the Proterozoic limestones from the Silurian and Devonian periods. The flow of water dissolves the limestone and causes karst phenomena, the rocks have karst porosity and therefore significant karst permeability.

From the north, the edge of the Bohemian Cretaceous Basin of Mesozoic age (Upper Cretaceous) extends into Prague. Sandstones and siltstones (marls) constitute a layer that covers older rocks. We can find them in the highest places in Prague, especially in the north and west (Letňany, Prosek, Ruzyně, Bílá hora). Sandstones have a significant pore porosity and thus very good permeability.

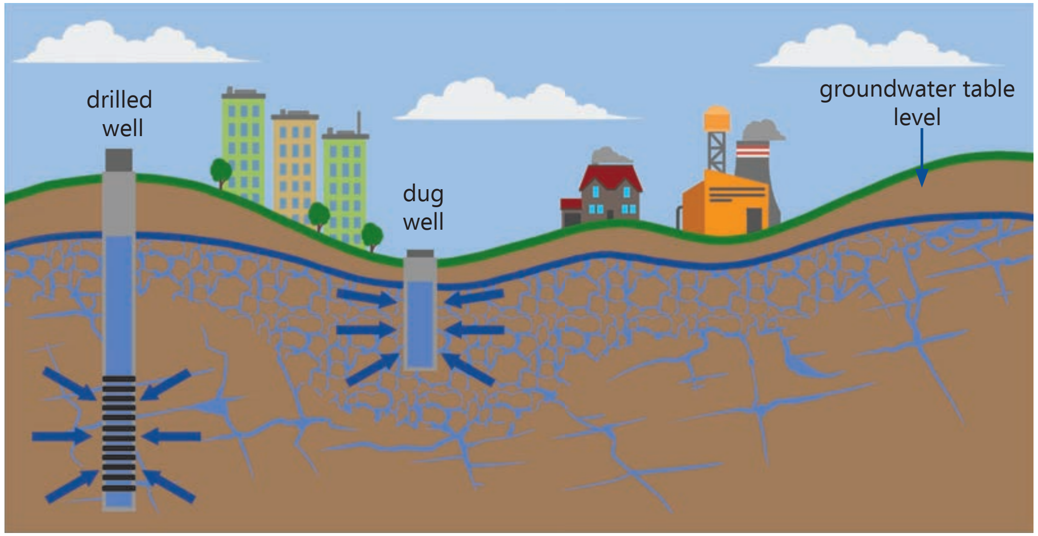
Around the Vltava River and smaller streams, the youngest sediments transported and deposited by the river occur. These are mostly various gravel sands forming several meters thick layers covering older bedrock. It is a very well permeable environment. Man-made sediments are also typical of cities – various earth fills, embankments, etc. They usually have a large pore porosity and thus very good permeability.

On the territory of Prague, we can encounter all three main types of porosity of rocks – pore, fissure, and karst. Cretaceous sandstones and gravel sands around watercourses have the highest permeability.

Rocks with fissure permeability

Hard rocks (granites, gneisses, shales) have negligible pore size, so their permeability depends on the existence of various fissures through which groundwater can seep. At the surface of the territory, these rocks are affected by weathering processes (on an average to a depth of 10 – 20 m), which cause their greater cracking and disintegration into smaller fragments. Therefore, their permeability tends to be greater at the surface, and decreases with depth as the fissuring decreases. The depth range of more frequent occurrence of fissures is up to about 50 – 100 m, deeper fissures permeable to groundwater occur very rarely.

The fissures are not evenly distributed in the rock, in some places more fissures occur, and in some less. Likewise, groundwater, which is associated with the existence of fissures, occurs differently in different places – sometimes more and sometimes less. If we are looking for a source of groundwater in such an area, it is important to find locations with more intensively weathered and decayed rock (shallow well in the picture), or an environment where there are more larger and deeper fissures (deeper drilled well in the picture).



Fissure permeability environment with upper weathered zone

Shallow groundwater carries a greater risk of contamination from the surface. It is difficult to position a deeper borehole in the right place so that the borehole penetrates well-permeable fissures and has sufficient water yield. Various geophysical methods are used for this. E.g. geoelectric measurements can find a crack filled with groundwater, because it is much more conductive than the surrounding dry rock.

Occasionally, people using a diving rod can be encountered who are looking for a place for a well. However, their activities are not based on expertise and border on charlatanism. It is therefore better to rely on real university-educated experts – hydrogeologists, who can invite geophysicists. If a person using a divining rod works successfully, this can be attributed to his/her practical experience and knowledge of the area, not his/her extraordinary abilities.

In fissure-permeable rocks, shallow groundwater in weathered zone a few meters below the surface can be utilized, or deeper fissure water can be exploitedby a borehole several tens of meters deep.

There are not many permeable fissures in the shales that occur on the territory of Prague, and they contain little groundwater. More fissures and thus groundwater tend to be in the quartzites and sandstone formations. In order to successfully find a source of water, it is therefore necessary to first find these rocks in the predominant shale environment according to the geological maps. Groundwater from these shales is not of the best quality or taste, it usually has high contents of sulphates and iron.

Fissures can also be found in rocks with other major types of porosity. E.g. sandstones have a predominant pore porosity, but if they are hard enough, they can also be fissured. Also, the limestones with predominantly karst porosity, have also fissures. The fissures thus contribute to increasing the porosity and permeability of these rocks. We say that such rocks have double (dual) porosity.

6. PORE GROUNDWATER

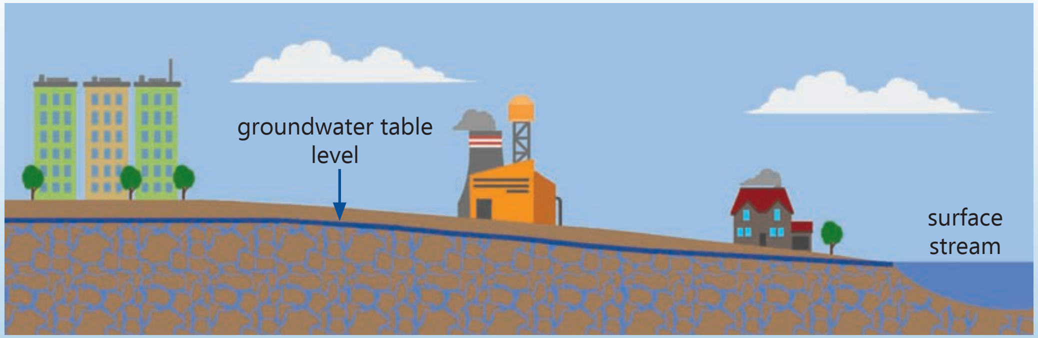
Rocks with intergranular porosity

Rocks consisting of grains of different sizes have the so-called intergranular porosity. These are, for example, sand, gravel, gravel sand (mixture of sand and gravel), but also sandstone. The grains of these rocks are large, visible to the naked eye, and therefore the gaps between the grains are large, the permeability is also very good, these are typical rocks of hydrogeological aquifers. Rocks with finer grains (e.g. clay, loam, loamy sand) also have pore permeability, but the pores are small, so the permeability of these rocks is not high. These are typical rocks of hydrogeological aquicludes.

Unlike fissure-permeable rocks, where water is concentrated only in the fissures, the pores are evenly distributed throughout the rock and thus groundwater is also evenly distributed throughout the rock environment. Finding a suitable place for a well is therefore much easier.

Groundwater in a river alluvium

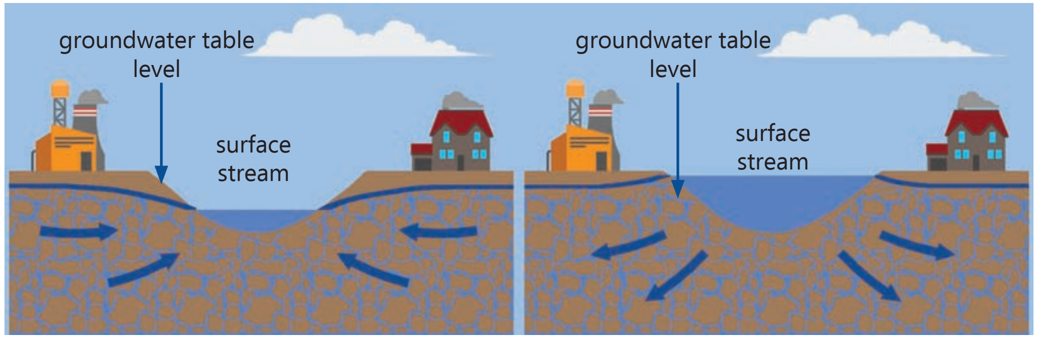
In the valleys around rivers and streams, there are several meters thick layers of alluvial sediments (in the case of the Vltava River in Prgaue, on the average 10 – 12 m). For large streams, very permeable coarse-grained rocks (gravel, gravel sands, coarse sands, etc.) predominate. Smaller streams (Botič, Rokytka, Prokopský Creek, Šárecký Creek, etc.) have lower sediment carrying capacity, the alluvial sediments arelimited, they are finer-grained and less permeable (sands, loamy sands, loamy gravels, etc.).



Shallow groundwater in a river alluvium

The shallow groundwater in the river alluvium is called the riverain water. Its water table is shallow just below the surface of the area and is in close relationship with the surface water with which it mutually interacts.

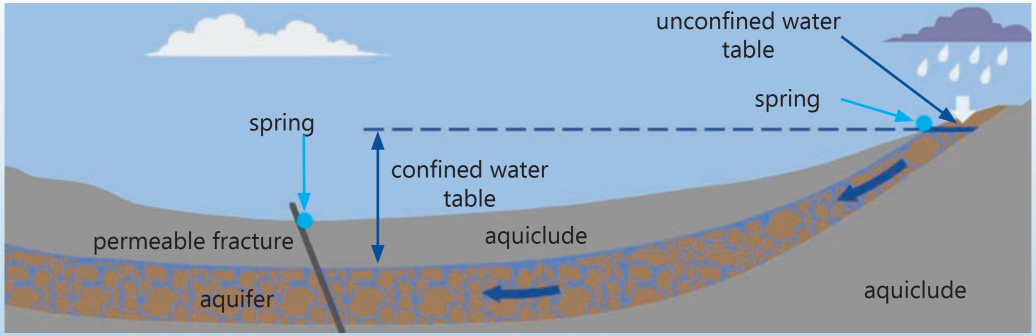
Riverain water can drain into a river or stream, or surface water can seep in and feed shallow groundwater around it. If the groundwater table elevation is higher than the water elevation of a nearby stream, groundwater is drained into the stream (normal state, picture on the left). If the water level in the stream is higher than the groundwater table around it, water from the stream may seep into the groundwater (picture on the right). This occurs, for example, during a flood, at locations where the river or stream are dammed (weir, reservoir, drive), or vice versa, when the groundwater table level is reduced (by pumping water, drainage effect of buildings, etc.).



Relationship between riverain water of a valley alluvium and surface stream: on the left drainage of groundwater into the stream, on the right a state allowing surface water seepage into groundwater

Groundwater of basin structures

A hydrogeological basin is a structure where the positions of more and less permeable rocks alternate. Rainwater is infiltrated at the edges of the basin, where there are permeable rocks at the surface, flows into the center of the basin, where the pressure gradually increases due to the elevation of the infiltration site, and is drained to the surface at a suitable location (e.g. on a permeable fracture). These structures contain the largest resources of groundwater in the Czech Republic (e.g. the Czech Cretaceous basin); they are widely used for drinking water supply.



Scheme of a hydrogeological basin with the alternation of aquifers and aquicludes and groundwater flow from the point of infiltration at the edge of the basin to the location of drainage in the center of the basin

Strata of Cretaceous sandstones and siltstones (marl) can be found in the highest places in Prague (Letňany, Prosek, Ruzyně). Sandstones are well permeable, but their extent is not large enough to contain as significant quantity of groundwater as the large accumulation in the several hundred meters thick formations in northern and eastern Bohemia.

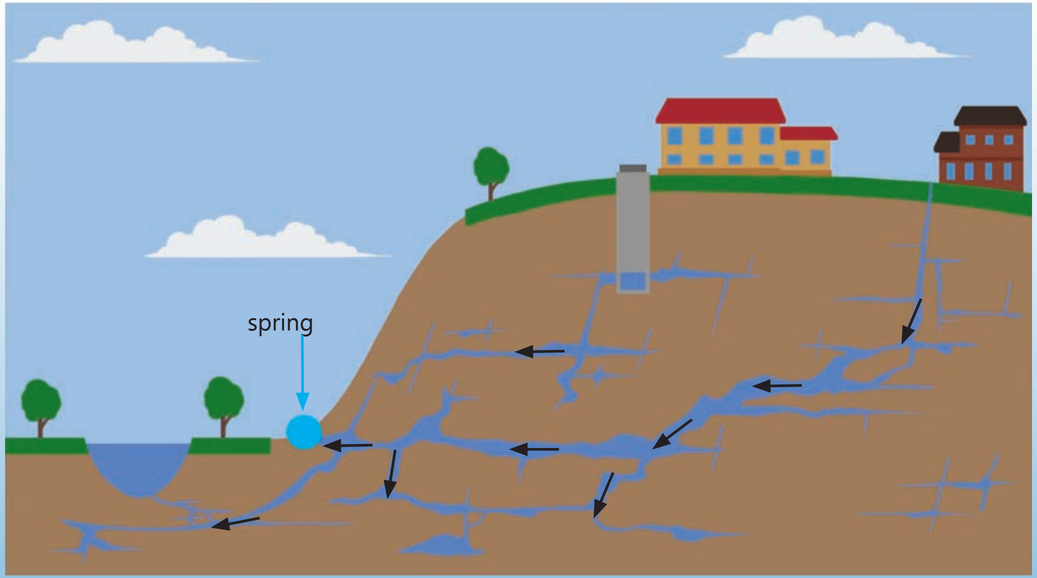
7. KARST GROUNDWATER

Karst phenomena

Groundwater can dissolve some rocks (most often limestone, but also dolomites, calcareous sandstones, etc.). Water seeping from the surface into the ground expands the original cracks and creates larger cavities. Karst porosity is created from the original fissure porosity. It is a gradual and long-term process lasting millions of years. Various karst phenomena and shapes arise in the landscape, such as grikes, sinkholes, water sinks and springs, caves, abysses, underground streams, and lakes. Cave systems are often very large, even several kilometers long. Dissolved limestone in water elsewhere creates new shapes - stalactites in caves, travertine dams on streams, travertine sediments at karst springs, etc. Important karst areas in the Czech Republic are the Moravian Karst near Brno and the Bohemian Karst between Prague and Beroun.

Limestone and karst phenomena of the Czech Karst can be found directly on the territory of Prague, for example in the Prokopské Valley and its surroundings. The center of the karst area is between Karlštejn and Beroun.

The the Bohemian Karst is a very valuable natural area. Many karst phenomena can be found in the area formed by Paleozoic limestones. The Koněprusy Caves are the largest cave system in Bohemia. Limestone rocks extend to the northeast up to the territory of Prague (Radotín, Slivenec, Hlubočepy) and rock exposures of limestone can be admired in the Prokopské Valley or on the Barrandov Rock by the Vltava River, or in some old limestone quarries (e.g. Požáry near Řeporyje or Cikánka near Radotín) .



Groundwater flow scheme in karst limestones with karst porosity

Hydrogeological regime of karst areas

Groundwater flow in karst areas is very different from areas with other rock types. Groundwater is gradually concentrated in several main and largest channels, which are gradually formed in the limestone by its dissolution. The mechanical erosion of the rock caused by the rapid flow of large quantity of water in these channels is also important.

The connection of the surface of the area with the underground channels and cave systems (through widened cracks, sinkholes, abysses) causes rapid recharge of water from the surface to the underground, sometimes entire streams disappear below ground. The result is negligible presence of water on the surface of karst areas, which together with the alkaline pH suits the specific arid and lime-loving vegetation that we will not find anywhere else.

Another consequence of the existence of karst phenomena is the deepposition of the groundwater table, which descends down to the level of the main channels and cave systems, which thus have a significant drainage effect on their entire overburden.

The flow of groundwater through karst rocks is usually very fast, much faster than in other rocks, where we encounter maximum speeds of several meters per day. In karst rocks, the velocities of groundwater flow are in the tens and hundreds of meters per day, in the main channels even more, and thus approach the flow velocities in surface streams.

Because the groundwater flow is concentrated in several channels, drainage is also concentrated: karst areas are characterized by springs with high yield (even in tens and hundreds of liters per second), draining large areas.

Flow velocity and close interconnection of groundwater with the surface results in much higher vulnerability of groundwater in karst areas. An accidental release of any pollutant means that the pollution penetrates underground very quickly (in hours to days). This is completely different situation from other areas, where it usually takes days to weeks for the substance to seep into groundwater, well protected by overlying rock layers. The protection of groundwater in the karst areas must be approached in the same way as the protection of surface water, its vulnerability is very high.

It is necessary to take into account the specific quality of karst waters – these are waters of good taste (chemical type $Ca-HCO_3$ to $Ca-Mg-HCO_3$), but very hard (high transient hardness) and alkaline (high pH). High vulnerability results in frequent pollution (from agricultural activities, wastewater, etc.).

Building a well in karst rocks is challenging. It must be dug in hard limestones to a greater depth than elsewhere, and the well must penetrate flow channels with flowing groundwater, otherwise it may be completely dry. It is therefore safer to choose shallower wells in the alluvium of local streams, it is also practical to use the water of a karst spring, if it is nearby.

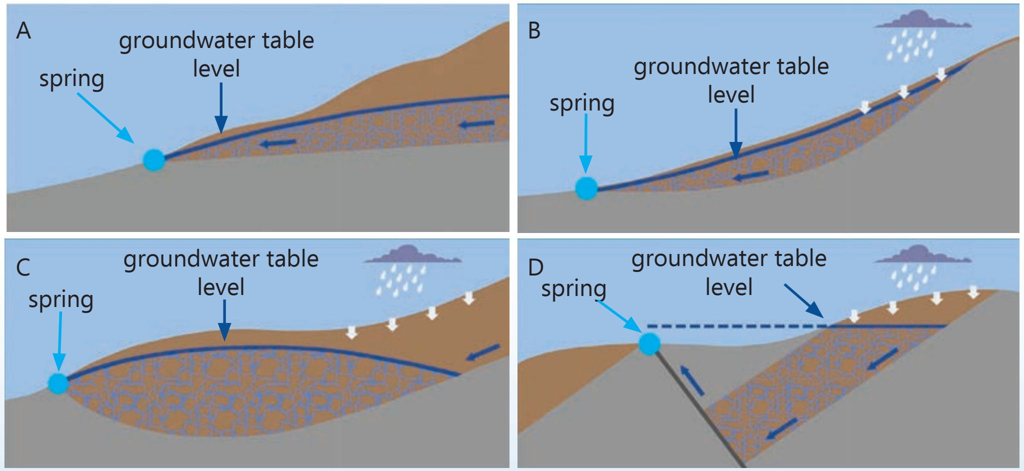
The karst landscape is very valuable for nature protection, which is why the Protected Landscape Area of the Bohemian Karst was pronounced, extending to the territory of Prague near Radotín. The most valuable parts are protected by small, protected nature areas (reservations, natural monuments). Similarly, there is the Moravian Karst Protected Landscape Area near Brno.

8. GROUNDWATER DRAINAGE AND SPRINGS

Each hydrogeological structure is completed by a drainage area. It is the lowest point of the hydrogeological structure or its part. These are usually valleys of watercourses draining the territory of the adjacent river basin. The drainage area is the location where groundwater leaves the hydrogeological structure and becomes surface water. Drainage can be visible (e.g. spring) or hidden.

Springs

A spring is a concentrated and visible natural outflow of groundwater on the earth's surface. Every watercourse begins with a spring. There are thousands of springs in the Czech Republic, many of them can be found in Prague. The springs are divided into several types according to the outflow type and the type of hydrogeological structure. If there are several springs of the same origin in one place, the place is called a spring area.



Types of springs according to the type of outflow (a – descending contact spring, b – descending talus spring, c – depression spring, d – fissureascending spring)

A fundamental property of a spring is its yield. It is given in liters per second. The yield of springs is usually different, karst springs are high yield (e.g. the spring in Svatý Jan pod Skalou in the Bohemian Karst has a yield of over 20 L/s). Common spring yields are in tenths to units of liters per second.

The stability of the spring is also important. The yield of a spring in a shallow hydrogeological structure (e.g. the talus spring in the picture) varies greatly according to precipitation. A short period without precipitation (e.g. one month) is sufficient to dry such a spring, because the water seeping through the rubble and clay along the slope needs to be constantly recharged. A spring draining a deeper and larger hydrogeological structure (e.g. the ascending or contact spring in the picture) has a more stable yield and is maintained even in a longer period of drought. It reacts to larger fluctuations in precipitation with a delay of months to years.

The temperature of the spring water behaves similarly – water of a shallow structure copies the course of the annual air temperature (i.e. higher water temperature in summer and lower in winter), and the deeper and larger the structure drained, the more stable temperature the spring water has throughout the year, close to the annual average air temperature at the given place.

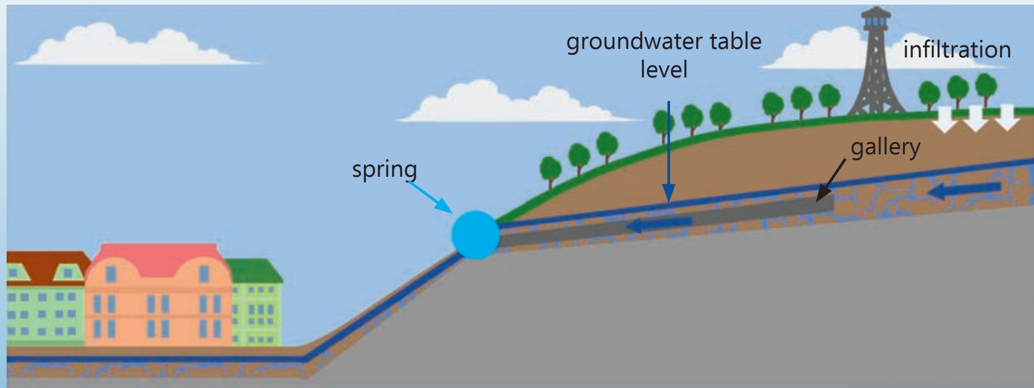
The yield of the spring, its stability, temperature, and composition of the spring water are important data for determining the origin and age of the spring water for its possible use and for ensuring the protection of the spring.

Sometimes groundwater is drained in a hidden way below the surface of the area. If there are permeable rocks (e.g. rubble or river gravel) at the outflow of the spring, the spring water will flow into them and nothing will be visible on the surface. Another example of a hidden spring is a situation where groundwater flows directly into the surface stream, through the bottom or sides of the riverbed.

Springs in Prague

Even on the territory of Prague, dozens of springs have been preserved so far, especially in the less built-up and more peripheral parts of the city. But the springs used to be also in the center of Prague, and in the Middle Ages they were important sources of drinking water. E.g. in Na Rybníčku Street near Štěpánská Street, there was a spring feeding a small pond. A spring also supplied the fountain on Charles Square until the 19th century, which had much better water than other fountains in Prague supplied with water from Vltava. The springs are vanishing due to the development and drainage of the area, disappearing due to landscaping, excavations and underground structures, and the current climate change is not benefiting them either.

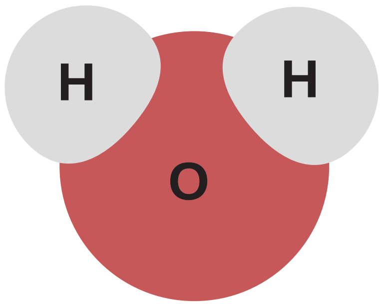
The most famous are the Petřín springs, springing on the slope of hill Petřín. Originally, these were contact springs, where at the level of their contact with the underlying shales, groundwater flowed from the Cretaceous sandstones forming the top parts of the Petřín and Strahov areas. Today, however, these are artificial springs originating in the old galleries from the Middle Ages, crisscrossing the Petřín hill. The outflows from these galleries are conveyed to suitable locations on the Petřín slope and aesthetically modified to resemble springs. Due to the development above them (Petřín, Strahov), the water has deteriorated in quality and is not suitable for drinking.



Scheme of groundwater springs on slope of Petřín (with indicated drainage gallery)

9. WATER MOLECULE H_2O

Chemically pure water



Water molecule consisting of two hydrogen atoms and one oxygen atom

Chemically pure water is a chemical compound consisting of two hydrogen atoms and one oxygen atom. Chemically pure water has the formula H_2O and does not contain any other substances. However, water in nature (water in rivers, streams, ponds, groundwater, rainwater, water in the form of snow and ice) is not chemically pure, it contains a lot of dissolved and undissolved substances, is populated by various organisms, etc. Distilled water manufactured for various technical purposes and containing only a minimum quantity of solutes (less than 10 mg/L) approaches the characteristic of a chemically pure water.

Isotopic composition of water

However, the oxygen and hydrogen atoms in the water molecule are not all the same, we say that they are formed by different isotopes.

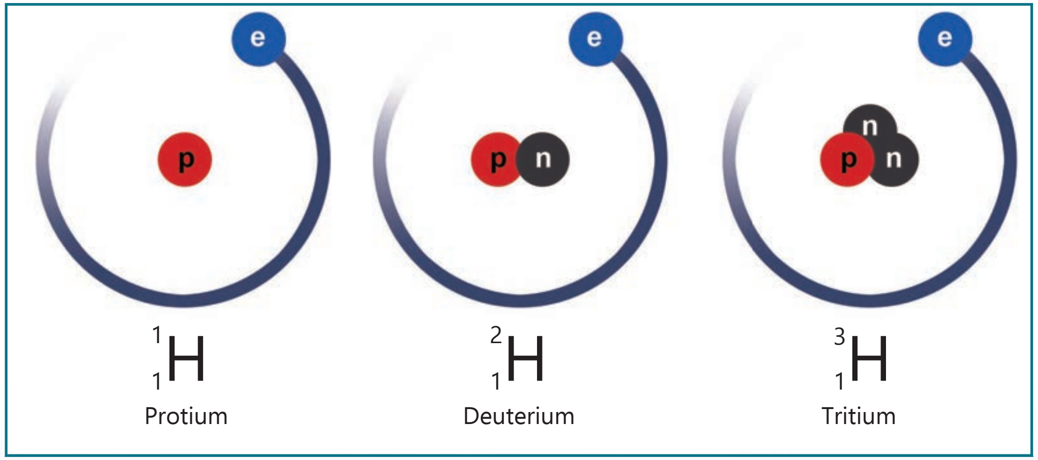
Isotopes are atoms of the same element that have the same number of protons in the nucleus but can have different numbers of neutrons. Isotopes can be stable – not changing over time, and unstable – undergoing radioactive decay.

Hydrogen has two stable isotopes, ^{1}H and ^{2}H – also referred to as deuterium D. These isotopes occur in a ratio of 5,000: 1. Oxygen has three stable isotopes ^{16}O, ^{17}O and ^{18}O, occurring in a ratio of 3,150: 5: 1. This means that for 5,000 molecules of water with the common isotope ^{1}H, there is one molecule of water with the isotope 2H. Similarly, for 3,150 molecules of water with the most common oxygen isotope ^{16}O, there are five molecules of water with the oxygen isotope ^{17}O, and one molecule with the oxygen isotope ^{18}O. These stable isotope ratios express average values valid for the Earth as a whole.

At a particular location, water may have a ratio of stable isotopes of hydrogen and oxygen slightly different from the average values. This is used by scientists to study the origin of the water and the processes taking place in it.

The reason for these differences is the different physical properties of the individual isotopes, e.g. in melting and boiling points. H_2O water has a boiling point of 100 °C at normal pressure, while D_2O water has a boiling point of 101.42 °C under the same conditions due to the heavier molecule, and a melting point of 3.82 °C (instead of the usual 100 °C and 0 °C for H_2O). Thus, if the water evaporates intensively, the H_2O molecules change to the gaseous state a little faster, and the concentration of heavier D_2O molecules in the remaining liquid water relatively increases. Similarly, D_2O molecules concentrate in the melting snow because they melt at a higher temperature. In the urban environment of Prague, average air temperatures (over 10 °C) is higher than, for example, in the colder foothills of the Krkonoše Mountains (around 7 °C), so due to more intense evaporation, the water of Prague streams, ponds and reservoirs has a slightly increased share of D_2O (and this also applies to oxygen isotopes).

Tritium



Three isotopes of hydrogen occurring in natural waters, differing in the number of neutrons in their atom (e – electron, p – proton, n – neutron)

There is a third isotope of hydrogen - tritium ^{3}H (sometimes referred to as T). This isotope is not stable, it is subject to radioactive decay, it is a so-called radioisotope. Its half-life is 12.32 years. The half-life is a physical constant indicating the time needed for half of the tritium atoms in the sample to decay. Thus, in 24.64 years only a quarter of tritium atoms remain, in 36.96 years an eighth, etc. When it decays, it produces beta radiation and changes into a stable helium atom ^{3}He.

Tritium is formed in nature by cosmic radiation, but partly by human action (residues of nuclear weapons tests, banned in the atmosphere in 1963; tritium water is also a by-product of nuclear power plant operation). Today, tritium concentrations are constantly decreasing and approaching the natural background (slightly disturbed by man by the operation of nuclear power plants) which is not dangerous to human health. The concentration of tritium is used to determine the so-called age of groundwater, i.e. the time that has elapsed since the rainwater seeped into the ground.

Tritium can be used to determine the age of groundwater on the order of decades, up to a maximum of 100 years. If the groundwater is older, e.g. from deeper basin structures, other naturally occurring radioisotopes with a longer half-life are used, e.g. the carbon radioisotope ^{14}C with a half-life of 5,730 years. Using ^{14}C present in groundwater in HCO_3 bicarbonates, we can determine the age of groundwater up to tens of thousands of years.

10. GROUNDWATER COMPOSITION

Natural water as a mixture

Water in nature is not chemically pure (i.e. only H_2O), it is a complicated physical/chemical mixture of many substances, the occurrence, form and ratio of which change in place and time. The knowledge of water composition is important both for humans (use of water for drinking or as utility water) and for various organisms that depend on water. In a man-made urban environment, natural water is usually negatively impacted by humans (water pollution by various substances), which can limit its use.

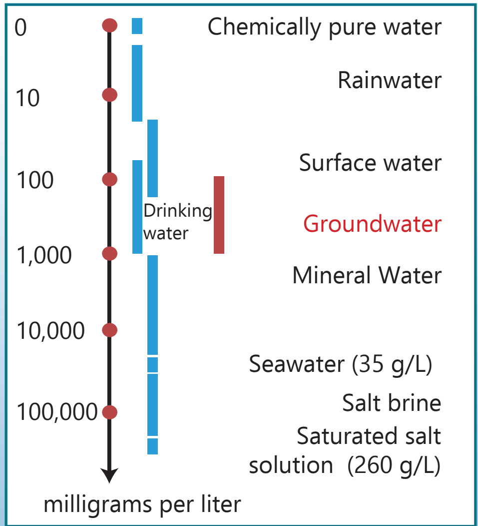
In natural waters, we can find three groups of different substances:

- Dissolved substances forming a homogeneous mixture (solution) with water, which cannot be visually distinguished, only at the molecular level. Groundwater usually has more dissolved substances than surface water.
- Undissolved substances form an inhomogeneous mixture with water and cause water turbidity. They are composed of clay particles, dust, sand, organic matter. They occur mainly in surface waters (dust and dirt washed away by rain from the surface, soil erosion during rains). Quality groundwater has very few undissolved substances.
- Living organisms (cyanobacteria, algae, bacteria, viruses, higher organisms, etc.) are typical for surface waters. In quality groundwater that is not polluted from the surface, foreign living organisms do not occur. They are visible under a microscope.

Dissolved substances in water

Dissolved substances can be divided into dissociated, where the molecule (e.g. NaCl – salt) splits into positive and negative ions (Na^+ and Cl^-), and undissociated, when the molecule remains together even in a dissolved state, e.g. silicon dioxide – SiO_2.

Different types of natural waters also differ according to the total mineralization, i.e. according to the concentration of dissolved substances, which is usually given in milligrams per liter (mg/L). Clean healthy drinking water should have mineralization in the range of about 80 – 1,000 mg/L. Ordinary groundwater tends to have total dissolved solids of several hundred milligrams per liter. And what is the mineralization of other types of water you can find in graph on this page.



Total mineralization of various types of natural waters and requirements for drinking water

The main anions in groundwater and other natural waters are the bicarbonates HCO_3^-, sulphates SO_4^{2-} and chlorides Cl^-. The main cations are calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^+). These six ions usually make up over 90% of the composition of natural water.

- Using the predominant main ions, we characterize the chemical type of water, such as Ca-HCO_3, Ca-Na-SO_4-Cl, etc.
- The remaining part of the composition of natural waters consists of secondary components, such as cations of potassium K or various metals, especially in groundwater (Fe, Mn, Al, Cu, As, Zn, Se, Cr, Ni, Co, B...), or some organic substances.
- For waters polluted by municipal wastewater or from agriculture, the occurrence of various nitrogen compounds is typical (nitrates NO_3^-, nitrites NO_2^-, ammonium ions NH_4^+).
- Gases, e.g. from the atmosphere (carbon dioxide CO_2, oxygen, nitrogen, etc.) are also dissolved in natural waters. In groundwater, we can sometimes encounter gases originating from various biochemical and geochemical processes in the earth's crust (sulfaneH_2S, radioactive gas radon Rn, methane CH_4, etc.).

Water hardness and aggressiveness

Water hardness is a natural property of water and depends mainly on the quantity of calcium and magnesium compounds dissolved in water. Two types of water hardness exist: transient and permanent.

The transient hardness is caused by calcium and magnesium bicarbonate, $Ca(HCO_3)_2$ and Mg $(HCO_3)_2$. It can be removed by boiling water, but insoluble compounds in the form of so-called limescale (mainly calcium and magnesium carbonate $CaCO_3$ and $MgCO_3$) fall out of the water, encrusting and damaging water heaters, washing machines, dishwashers, kettles.

Other Mg and Ca compounds, mainly sulphates, cause permanent hardness. They cannot be easily removed from water by boiling, therefore the permanent hardness of the water does not damage the heating devices.

A smaller part of Prague is supplied with drinking water from the underground sources in Káraný, north of Prague. It is known that this water when used in home has higher transient hardness than water from the surface water source from the Želivka River, which is the main source of drinking water for Prague.

Water aggressiveness is the ability of water to disrupt concrete, steel, and other materials. It is usually caused by the presence of a larger quantity of some dissolved substances: carbon dioxide CO_2, sulphates SO_4^{2-} and magnesium Mg^{2+}. Acidic waters with low pH and slightly mineralized waters with very low hardness also have an aggressive effect. On the territory of Prague, sulphate aggressiveness is mainly encountered - groundwater from shales usually has high concentration of dissolved sulphates.

11. GROUNDWATER POLLUTION

Surface and groundwater have a crucial position in protecting the entire environment. Clean water is an indicator of the good quality of the entire environment. Groundwater is much better protected from pollution than surface water because there is a layer of rock between the surface and the groundwater table that protects the groundwater, especially when the rock is poorly permeable.

What is water pollution?

At first glance, a simple question may not have an entirely simple answer.

Water pollution (contamination) is any change in the original natural composition or properties of water caused by man.

Sometimes, however, only such state of water is referred to as pollution, when the change in composition or properties will cause limits of valid legal regulations to be exceeded. Groundwater is often assessed according to the requirements for drinking water (Decree No.252/2004 Coll.).

Example: The natural concentration of nitrates in groundwater is around 4 – 5 milligrams per liter. Groundwater, which has nitrate concentration, for example 15 – 20 mg/L, is polluted by humans, but it is still drinking water, because the limit for drinking water is 50 mg/L. Therefore, waterworks can sometimes consider water that has nitrate concentration e.g. 60 or 70 mg/L, to be contaminated, as it should no longer be used for drinking.

Moreover, not every above-limit value is pollution. Elevated values of some substances can be caused by natural influences. E.g. an increased iron content in groundwater is usually not caused by man but is related to the natural presence of iron minerals in some rocks, such as FeS_2 pyrite.

Types of pollution

From a chemical point of view, there is pollution by inorganic substances and organic substances. The most common inorganic pollutants are nitrates NO_3^- and other forms of nitrogen occurrence – nitrites NO_2^- and ammonium nitrogen NH_4^+, originating from municipal sewage and also from agriculture. However, pollutants also include other substances, such as heavy metals from industrial production - the most harmful are mercury Hg, lead Pb, cadmium Cd, arsenic As. The most common organic pollutants are the various substances produced from petroleum (fuels, oils, solvents such as benzene and toluene, etc.). Industrial solvents based on chlorinated hydrocarbons (perchloroethylene, trichlorethylene) are also common. Residues of pharmaceuticals, pesticides and other dangerous substances endangering human health and other living organisms are today increasingly appearing in the waters.

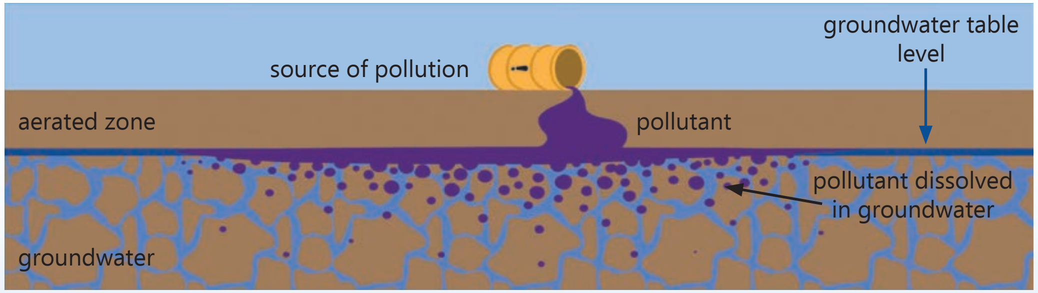
The biological quality of water is also important especially for drinking purposes, i.e. the presence of bacteria, viruses, and other organisms. Some of them can be a source of serious diseases. Uncontaminated groundwater is usually of good biological quality, but surface sources of drinking water always require disinfection.

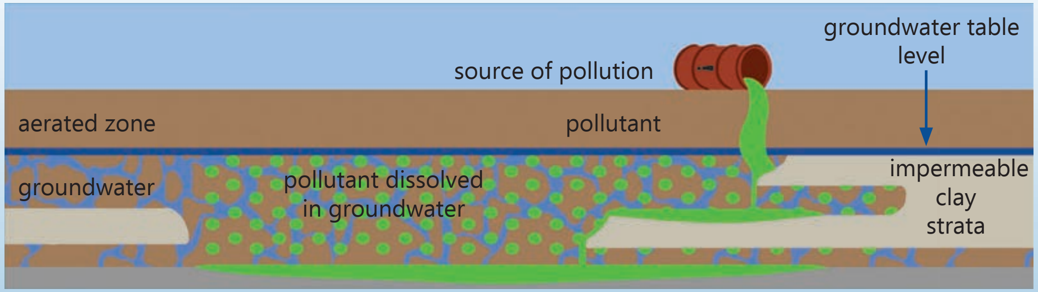
Pollutant behavior in the rock environment

To be able to correctly identify the hazards resulting from a particular pollution and the associated risks, it is necessary to understand the behavior of the released chemicals in the rock environment. The contaminant may be dissolved in water or may seep through the rock as a separate liquid (e.g. diesel, oil). In the dissolved form, the substance spreads together with groundwater, i.e. at the same speed and direction as the groundwater flows.

Substances lighter than water are technically referred to as LNAPL (abbreviation from the English designation Light Non-Aqueous Phase Liquid), and substances heavier than water by the abbreviation DNAPL (Dense Non-Aqueous Phase Liquid).

For a separately migrating liquid, it is important whether the liquid is lighter or heavier than water, i.e. whether it has a lower or higher density than water, because their behavior in groundwater is completely different. One liter of water weighs about one kilogram. Some liquids, such as petroleum substances, are lighter than water (one liter weighs 0.8 – 0.9 kg), and when they reach the water table, they float on it (e.g. an oil film on watertable). On the other hand, some liquids, such as chlorinated solvents, are heavier than water (one liter weighs, for example, 1.1 – 1.2 kg). When they come in contact with water, they sink to the bottom. Substances lighter than water are therefore found near the groundwater table level, while substances heavier than water pass through the entire aquifer and are concentrated at its bottom.





Different behavior of substances lighter than water (LNAPL, above) and heavier than water (DNAPL, bottom) in the rock environment and in groundwater

Both types of liquids also dissolve in water and additionally at the same time move. LNAPL substances in a dissolved form pollute the groundwater in the aquifer only close to the groundwater table, while DNAPL substances pollute the entire volume of groundwater in the hydrogeological aquifer, from the surface to the bottom, so the extent and severity of the pollution is much greater.

12. GROUNDWATER QUANTITY

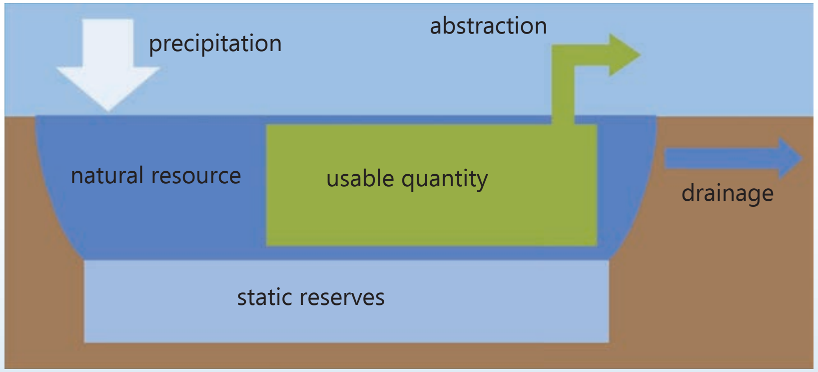
Groundwater balancing

Groundwater is part of the hydrological cycle, so its quantity is constantly changing. By infiltration of precipitation, groundwater is recharged, and at the same time it continuously discharges into the surface waters. When it rains a lot and more water seeps in than runs off, the groundwater quantity in the hydrogeological structure increases. When it rains a little or not at all, less water seeps in than it drains, and the quantity of groundwater decreases.

There is only a limited quantity of groundwater. It is therefore important to know how much groundwater we have in the different regions in the Czech Republic, so that we can determine what quantity we may abstract (for drinking water supply, for irrigation, etc.). The determination of the groundwater quantity is calculated in the hydrological balance (see the publication City and Water).

Static reserves and natural groundwater resources

Static reserves are the volume of groundwater that fills all cavities in a rock below the groundwater table level. Natural resources represent the quantity of groundwater per unit of time, by which the hydrogeological structure is continuously recharged by precipitation infiltration.



Static reserves, natural resources, and usable quantity of groundwater

The difference between static reserves and natural groundwater resources can be imagined using the example of a pond. The water in the pond represents static reserves. The water that flows into the pond through the stream are natural resources. If we abstract water from the pond, we can only capture quantity that is less than the inflow. However, if we abstract more water than the inflow, the stream flowing out of the pond will disappear and the water level in the pond will start to fall – static reserves will begin to decrease. Such abstraction is not sustainable in the long run, because one day it will result in drying out of the pond.

Only natural groundwater resources ensure long-term sustainable groundwater abstraction.

If water abstraction takes place at the expense of static reserves for a long time, the hydrogeological structure is overloaded, static reserves decrease. Short-term use of static reserves is possible, for example, to bridge summer drought, because we know that this reduction will be compensated by melting snow and higher precipitation in the spring.

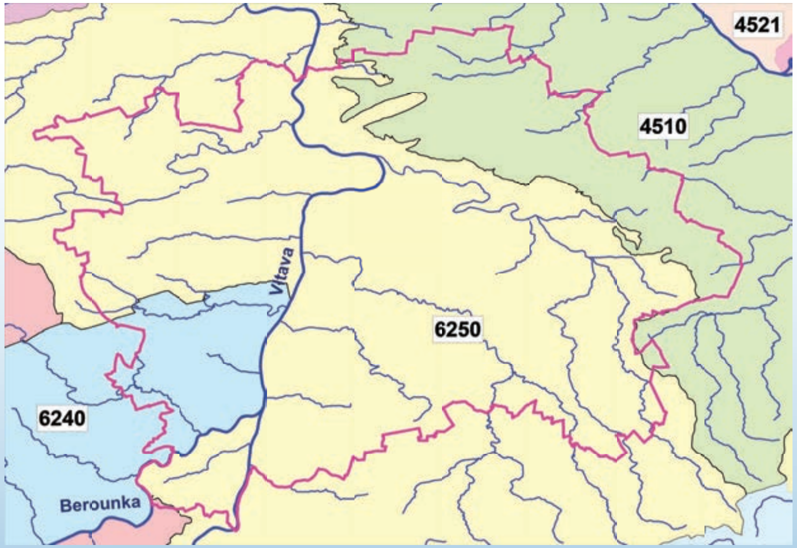
Natural resources of groundwater appear in the hydrological balance as the so-called groundwater (also basic) run-off from the territory and are given in liters per second per square kilometer. Areas rich in groundwater have these values of 5 – 10 L/s/km^2 (mountain areas, Bohemian Cretaceous Basin, etc.). In most areas of Prague, these values are in the long-term averages only around 1 L/s/km^2, due to lower precipitation, higher evaporation, and low permeability rocks. However, the ongoing development on the outskirts of the city further reduces precipitation and reduces the small natural resources of groundwater in Prague.

It is not possible to use all natural resources for groundwater abstraction. The usable quantity of groundwater is part of the natural resources that we can abstract in the long run, without compromising other groundwater functions in the area.

If we pump more groundwater, we could cause drying of streams, extinction of springs, endanger wetlands with protected plants and animals, etc.

Hydrogeological zones

Natural groundwater resources are best determined for an area that includes both recharge and drainage, i.e. the entire hydrogeological structure. In order to develop the balance of groundwater, the Czech Republic was divided into 152 areas, which are called hydrogeological zones. In such an area, the hydrological balance can be well calculated and natural groundwater resources determined.



Map of hydrogeological zones on the territory of Prague

A total of three hydrogeological zones cover the territory of Prague. Hydrogeological zone 6250 covers most of the area of Prague with low-permeable shales and has the smallest natural sources of groundwater. The 4510 zone extends in the northeast, consisting of sandstones and siltstones of the Bohemian Cretaceous Basin margin. In the southwest is the zone 6240 with limestones, which has the largest natural resources of groundwater in Prague (2 – 3 L/s/km^2).

13. GROUNDWATER USE

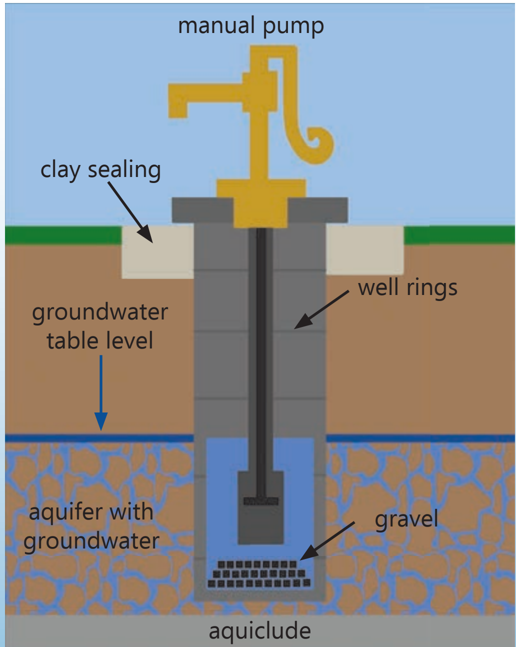
Wells

Groundwater resources are preferentially reserved for supplying the population with drinking water.
(Water Act No. 254/2001 Coll., Article 29, paragraph 1)

Groundwater is a very suitable source of drinking water for residents. Groundwater is mostly a resource of quality and safe water, well protected from pollution from the surface by a layer of soil and rock. Man has found in ancient history that the best water in the landscape is groundwater flowing from springs or captured by shallow pits (dug wells).

A WELL is a vertical structure used for groundwater abstraction. Excavated wells are usually about 10 – 20 m deep. Today - due to pollution and drought - drilled wells, which have an average depth of 30 – 50 m, sometimes even more, predominate. Wells can be used for individual needs or for waterworks supply. Waterworks wells have a much higher yield. In order for a well to provide quality water sufficiently over a long period of time, it must be properly positioned, properly constructed and quality implemented, well maintained and regularly cleaned. A pump, sometimes a hand pump, is usually used to abstract water. Wells are constructed structures (in the sense of the Building and Water Acts).

In some cases, groundwater may be abstracted by otherways, such as shallow collecting drainage, galleries, or a suitable spring may be contained by a spring sump.



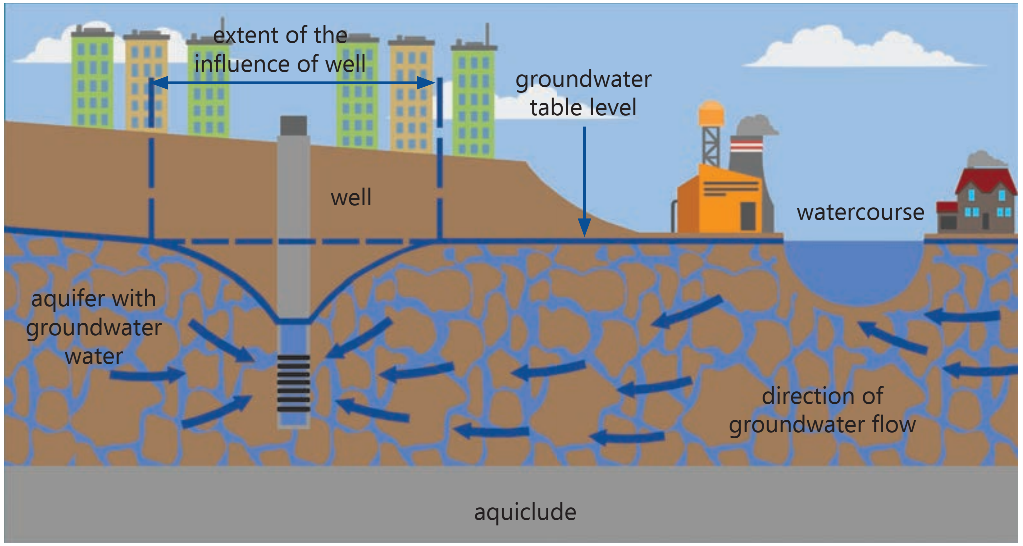
Typical design of a ring segment well with a manual pump

Protection of groundwater resources

Each source of drinking water must be protected from contamination and damage. Protection must be provided not only for the well, but also for its surroundings. To protect the well, the correct technical construction of the well is important, especially a good seal around the well on the surface and its good covering (e.g. with a lid) so that polluted water does not flow into the well from the surface.

To protect wells for public drinking water supply, protection zones are declared. The 1st degree protection zone protects the well and its surroundings to a distance of several meters from pollution and damage and is usually fenced. The protection zone of the 2nd degree protects the larger surroundings of the well from where the abstracted water flows into the well.

Water abstraction decreases the water table also around the well to a certain distance (this range of influence of the well is technically called the cone of depression). In some cases, the well can also draw water from a nearby stream or a reservoir (see figure). Various restrictions are necessary in the 2nd protection zone to prevent water pollution (landfill ban, stricter measures regulating wastewater, fuel and chemical storage management, restrictions on fertilization, use of pesticides, etc.).



Changes in flow and water table due to abstraction of groundwater from a well

For individual wells the protection zones are usually not declared, the owner, though, should ensure that potential sources of pollution (sewers, cesspools, stored chemicals, workshops, etc.) were as far away from the well as possible. In the dense development of towns and villages, it is problematic to ensure full protection of these small sources of water, which therefore often do not meet the requirements for drinking water quality.

Use of groundwater in Prague

Still in the middle of the 19th century, the inhabitants were dependent on water supply from fountains fed from the Vltava River. However, some fountains had better quality of water, such as the fountain on Charles Square, fed by groundwater from the spring on what is today the Na Rybníčku Street. Having your own well was an expensive thing until the 18th century. Gradually, however, a network of dozens of municipal wells was built throughout Prague in the 19th century, some of which can still be found (e.g. the well in the Kolejní Street on the cover of this publication, etc.). The wells provided the inhabitants of Prague with slightly better quality water, but as the requirements for the quality of drinking water gradually increased, they also ceased to meet the requirements.

In 1914, the modern era of the Prague water works began, when the growing population of Prague welcomed safe drinking water from groundwater sources from Káraný, north of Prague.

Today, Prague is completely supplied with drinking water from the Želivka River dam (75%) and from the underground source at Káraný (about 25%). Especially in the outskirts of Prague, however, there is a number of private wells that the inhabitants of Prague use as an additional source of water (most often for watering gardens).

Review questions

You can test your level of knowledge with the help of the following review questions. Of the four answers offered, always one answer is correct, one answer is partially correct, and two answers are incorrect. If you are unsure of the answer, you can find the appropriate chapter and subchapter according to the subject of the question and there you will find the correct answer. At the end of the review questions the correct answers and partially correct answers are provided with comments.

1. What is the term for water below the surface of the terrain?
   A. Groundwater
   B. Subsurface water
   C. Groundwater and soil water
   D. Undergroundwater

2. Why is precipitation in the colder half of the year important for groundwater recharge?
   A. It is more plentiful than in summer
   B. It is in the form of snow
   C. Smaller portion evaporates than in summer
   D. Soil is more permeable in winter

3. How can groundwater infiltration be supported in cities?
   A. By planting trees with deep roots
   B. Restoring watercourse beds to their natural state
   C. By supporting the infiltration of rainwater from the roofs of buildings
   D. By spraying water in the streets in the summer

4. How do we identify the place of groundwater drainage?
   A. Usually it is a valley where there is a stream.
   B. These locations are marked and fenced for human safety.
   C. Areas on the surface are waterlogged.
   D. A place where groundwater is pumped.

5. What kind of porosity does ordinary loam have in a flowerbed, for example somewhere in the park?
   A. Porosity is given by small pores among the loam particles
   B. Loam has no porosity, only rocks have porosity
   C. Fissure porosity
   D. Pore porosity (intergranular)

6. Why is it important in determining rock permeability to know not only porosity but also the pore size and their character?
   A. Only the largest pores determine the permeability of the rock.
   B. Very small pores do not determine the permeability.
   C. Only interconnected pores of such a size that water can flow freely through them are essential for permeability.
   D. Only permeable fissures determine the permeability of the rock.

7. What is a hydrogeological aquifer?
   A. It is a rock with high permeability.
   B. It is a rock with high porosity.
   C. It is a rock whose permeability is significantly affected by the location of underground engineering utility networks, usually sewers or water mains.
   D. It is a rock with significantly higher permeability than the rock of the overlying or underlying aquiclude.

8. Why is it important to know how high the water rises in the capillary zone?
   A. Capillary water can cause the foundations and walls of buildings to become damp.
   B. We can determine the required depth of the well accordingly.
   C. Capillary water impacts chemically and aggressively concrete foundations and damages them.
   D. Capillary water penetrates water mains and endangers the quality of drinking water.

9. What effect can sewerage lines have on groundwater?
   A. The effect can be positive, water escaping from leaks in the sewer line increases the quantity of groundwater in the area.
   B. Sewerage systems are always built above the groundwater table, so they have no effect.
   C. The effect can be negative, there can be an accelerated outflow of water along the sewer line and thus drainage of the area.
   D. The effect can be negative, the sewer increases the height of the capillary zone, and increases the risk of dampening the foundations of buildings.

10. What do we need to know to determine the direction and speed of groundwater flow?
    A. Depth of groundwater table and slope of the land surface in the area
    B. Slope of groundwater table, direction of the slope and permeability of the rock
    C. Slope of groundwater table and porosity of the rock
    D. Slope of groundwater table and permeability of the rock

11. Why is the spring season essential for recharging groundwater reserves?

A. Before the start of the growing season, trees and plants need less water, so more water remains to seep in below the surface of the area.

B. Freshly cultivated agricultural land in the spring allows for better water infiltration.

C. There is plenty of water from melting snow and spring rains, and there is also low evaporation.

D. It usually rains the most in the spring, therefore most water seeps in.

12. Why is knowledge of groundwater table fluctuations important for building design?

A. The foundations of buildings should always be above the average groundwater table in order to avoid negative impacts of groundwater on foundations.

B. If the foundations of buildings are within the maximum groundwater table level range (including the height of the capillary zone), the foundations of the building must be protected from the negative effects of groundwater by appropriate measures.

C. If the foundations of buildings are within the range of the average groundwater table level, the foundations of the building must be protected from the negative effects of groundwater by appropriate measures.

D. If the foundations of buildings are within the range of the maximum groundwater table level, the foundations of the building must be protected from the negative effects of groundwater by appropriate measures.

13. Who monitors groundwater table levels in Prague?

A. City of Prague

B. Prague Water Supply and Sewerage Utility

C. Czech Hydrometeorological Institute

D. Water levels are measured by automatic equipment

14. Which rocks in the territory of Prague have pore permeability?

A. Gravel around the Vltava and sandstones

B. Sandstones and slate

C. Paleozoic limestone and slate

D. Gravel around watercourses and sandstone

15. Which expert will you first contact if you plan to build a well on your land?

A. Waterworks worker

B. Geophysicist

C. Divining rod operator

D. Hydrogeologist

16. Are all rocks with pore porosity well permeable?

A. Yes, they are typical rocks of hydrogeological aquifers.

B. No, it depends on the size of the pores; if they are too small, the rock is poorly permeable.

C. Yes, because only coarser-grained rocks have pore porosity; fine-grained rocks have capillary porosity.

D. No, it depends on the size of the pores; if they are too small, the rock is impermeable.

17. What is the relationship of riverine water to the watercourse during a flood?

A. Flood water will seep into the shallow groundwater of valley alluvium.

B. The flood has no effect on the drainage of groundwater into the watercourse.

C. Flood water will seep into the shallow groundwater of valley alluvium, especially when water flows out of the riverbed.

D. Drainage of groundwater into a watercourse is one of the main reasons for floods.

18. The sandstones of the Bohemian Cretaceous Basin have the largest reserves of groundwater in the Czech Republic. Are these reserves also on the territory of Prague?

A. Yes, the Bohemian Cretaceous Basin extends with its edge into the northern and western part of Prague.

B. No, in the territory of Prague, the rocks of the Bohemian Cretaceous Basin are mainly less permeable siltstones.

C. Yes, the Bohemian Cretaceous Basin forms the bedrock of most of Prague.

D. No, only small occurrences of sandstones in the territory of Prague do not allow for larger groundwater reserves.

19. How does karst porosity originate?

A. Karst porosity has nothing to do with gap or fissure porosity.

B. It originates from pore or fissure porosity in rocks that are soluble in water.

C. It originates in various rocks, which the seeping water can dissolve and thus expand the original fissures.

D. It originates in limestones, where the seeping water dissolves the rock and expands the original fissures.

20. How does groundwater flow in karst rocks differ from groundwater flow in fissure or pore-permeable rocks?

A. Water flows much faster in karst rocks.

B. Water flows much deeper in karst rocks.

C. Water often has much higher mineralization and hardness in karst rocks.

D. Water flows much slower in karst rocks.

21. Why is information about the stability of spring yield important?

A. Karst springs have a constant yield.

B. A constant yield spring drains larger and deeper hydrogeological structure.

C. Constant yield usually means better quality of spring water.

D. Constant yield spring contains water from a nearby surface stream.

22. What is the character of the springs on the Petřín slope?

A. These are contact springs in which the sandstones located on Petřín and Strahov are drained.

B. These are descending springs in which shallow water seeping through the Petřín slope loams is drained.

C. These are not springs, but outflows from medieval galleries.

D. These are ascending springs through which water flows out of the underlying shales along the fissures.

23. What is chemically pure water?

A. A chemical compound consisting of two hydrogen atoms and one oxygen atom.

B. Unlike ordinary H_2O water, chemically pure water has the chemical formula D_2O.

C. Chemically pure water is distilled water.

D. Chemically pure water is obtained by boiling of drinking water.

24. What is the composition of stable isotopes of hydrogen and oxygen in the water of the Hostivař reservoir in Prague in comparison with the Lipno dam reservoir in the Šumava Mountains?

A. The composition corresponds to the average ratio of stable isotopes of hydrogen and oxygen on Earth, as elsewhere.

B. Water has a higher proportion of lighter isotopes of hydrogen ^{1}H and oxygen ^{16}O than in Šumava, due to high temperatures in Prague.

C. Water has a higher proportion of the heavier isotope hydrogen ^{2}H, due to the higher evaporation.

D. Water has a higher proportion of heavier isotopes of hydrogen ^{2}H, oxygen ^{17}O and oxygen ^{18}O, due to higher evaporation.

25. What are the sources of tritium in the Vltava water in Prague?

A. The water in the Vltava is not radioactive, it does not contain any tritium.

B. Tritium in the Vltava comes from the Temelín nuclear power plant.

C. Tritium in the Vltava has three sources – natural background concentration, residual concentrations from nuclear weapons tests in the atmosphere, and the Temelín power plant.

D. Tritium in Vltava water originates at the Dukovany nuclear power plant.

26. What kind of natural waters can satisfy the drinking water requirements in terms of total mineralization?

A. Groundwater only

B. Groundwater and partly surface water

C. Groundwater, surface water and mineral water

D. Surface water and groundwater

27. Choose the correct chemical notation of magnesium-calcium-sodium-bicarbonate-sulphate water:

A. Ca-Mg-Na-HCO_3-SO_4

B. Mg-Ca-K-HCO_3-SO_4

C. Mg-Ca-Na-HCO_3-SO_4

D. HCO_3-SO_4-Mg-Ca-Na

28. What causes the transient hardness of water?

A. Cations Ca^{2+} and Mg^{2+}

B. Calcium carbonate $CaCO_3$ and magnesium carbonate $MgCO_3$

C. Calcium bicarbonate Ca $(HCO_3)_2$, and magnesium bicarbonate Mg $(HCO_3)_2$

D. Calcium sulphate $CaSO_4$ and magnesium sulphate $MgSO_4$

29. Chlorides area common constituent of groundwater, their limit in drinking water is 100 mg/L. Which cases do not represent pollution?

A. Groundwater with 150 mg/L of chlorides in a well on the Mediterranean coast of Italy as seawater seeps into it.

B. Groundwater with 150 mg/L of chlorides in a well near a class 1 road in the Vysočina(Highlands) region, where salt is intensively applied in winter.

C. Groundwater with 150 mg/L of chlorides in a well near Hamburg, Germany, near the sea, as precipitation from the sea with a higher chloride content seeps in.

D. Groundwater with 150 mg/L of chlorides in a well in a village without wastewater treatment where it seeps into the ground.

30. What chemical organic substances are found in urban groundwater as common contaminants?

A. Fertilizers and sewage water

B. Petroleum substances, fuels, oils, benzene, toluene, etc.

C. Nitrates and pharmaceutical residues

D. Petroleum substances, chlorinated solvents, pharmaceutical residues, and pesticide residues

31. When chlorinated solvents leak and seep in below the surface, in which part of the hydrogeological aquiferdo we find them?

A. At the bottom of the aquifer as they sink to the bottom.

B. At the top of the aquifer as they float on the surface.

C. Throughout the aquifer profile from the surface to the bottom because they are continuously dissolved in the water.

D. These substances do not penetrate the groundwater at all, because they are trapped by capillary forces in the rock pores still above the water table.

32. What is groundwater balancing?

A. Determination of the dependence between precipitation infiltration and groundwater run-off.

B. Determination of the quantity of groundwater that is abstracted for drinking purposes in a specific area.

C. Determination of usable quantity of groundwater.

D. Determination of natural groundwater resources by calculating the hydrological balance.

33. How extensivecan a long-term exploitable quantity of water be?

A. It is the quantity of groundwater that is less than or equal to the specified natural resources.

B. It is the quantity of water that depends on the technical construction of the well or borehole.

C. It is the quantity of water that is always significantly less than the specified natural resources.

D. It is the quantity of water that includes natural resources and a small portion of static groundwater resources.

34. What is the purpose of hydrogeological zones?

A. To determine the magnitude of natural groundwater resources.

B. To determine infiltration sites and groundwater drainage sites.

C. To determine the size of static groundwater reserves.

D. To determine the quantity of groundwater.

35. What is a well?

A. Vertical structure used for groundwater abstraction.

B. Vertical structure used only for individual groundwater abstraction.

C. Dug vertical structure used for groundwater abstraction.

D. Vertical structure for the abstraction of groundwater; wells also include collecting cuts, galleries and spring sumps.

36. How is the protection of an individual well against pollution provided?

A. Protection zone 1 and 2 level will be declared.

B. The well is well sealed from the surface and the owner keeps a sufficient distance from possible sources of pollution.

C. The sewer and sump must be at least 12 m from the well in low-permeable rocks, and up to 30 m in well-permeable rocks.

D. The well must be cleaned regularly.

37. Have wells ever served in Prague as a source of drinking water?

A. No, until the 19th century, water from the Vltava was used, and then the water supply system was built from groundwater sources outside of Prague near Káraný.

B. Yes, in the 19th century a network of public wells was built, which served as a source of drinking water, until a water supply system was built throughout Prague during the 20th century.

C. Yes, even today the outskirts of Prague use wells as a source of drinking water.

D. Yes, there have been private wells in Prague since the Middle Ages, but a network of public wells for most Prague inhabitants was not built until the 19th century, and the wells were used until a water supply system was built throughout Prague during the 20th century.

Answers to questions

1. B correct, C partially correct – these are the waters that make up groundwater.

C correct, B partially correct – it does not have to be just snowfall, low temperatures are more important.

3. C correct, B partially correct – this can partly enhance groundwater only near the stream.

4. A correct, C partially correct – waterlogging can also be caused by surface water.

5. D correct, A partially correct – it is a description of the pore porosity, not the name.

6. C correct, B partially correct – the pores must also be interconnected.

7. D correct, A partially correct – the relationship to the aquiclude is important. Even a rock with lower permeability can be an aquifer if it is bounded by rocks with even lower permeability.

8. A correct, C partially correct – not every capillary water has an aggressive effect on the foundations.

9. C correct, A partially correct – this is true, but it must be added that groundwater is being polluted at the same time, so leaks from sewers cannot be understood positively.

10. B correct, D partially correct – thus we determine the velocity, but not the direction of flow.

11. C correct, A partially correct – it is a true partial aspect, but the essential is in point C.

12. B correct, D partially correct – it is important to think of capillary action, which can get groundwater a few meters above the water table in fine–grained rocks.

13. C correct, D partially correct – this is true, but it is not the answer to the question asked.

14. D correct, A partially correct – river gravels occur not only along the Vltava, but also along smaller streams (Botič, Rokytka, etc.).

15. C correct, B partially correct – a geophysicist can help in finding the source, but the main one is the hydrogeologist.

16. B correct, D partially correct – a rock is never completely impermeable.

17. A correct, C partially correct – water seeps mainly into the sides of the riverbed, where there are often low–permeable clays on the surface, preventing greater vertical infiltration from the surface.

18. D correct, B partially correct – it is true that there are mostly siltstones at the surface, but the sandstones are below them. The correct answer is therefore related to the small thickness and small area of these rocks in Prague.

19. C correct, D partially correct – karst phenomena occur most often in limestones, but not only in them, but also in dolomites, calcareous sandstones, gypsum, etc.

20. A correct, C partially correct – the statement is correct, but it is not the answer to the question.

21. B correct, C partially correct – this is usually true in the case of surface pollution, because a more stable spring contains water from a greater depth. However, the water may be of poorer quality for natural reasons (e.g. deeper waters in Prague from shale environments have high contents of sulphates and iron).

22. C correct, A partially correct – originally there were certainly contact springs, but in the Middle Ages the hill was penetrated by various galleries, and the current springs are discharges from the galleries, only modified as springs.

23. A correct, C partially correct – distilled water is close to chemically pure water, but still has a small quantity of dissolved substances (up to 10 mg/L).

24. D correct, C partially correct – the correct answer contains heavier isotopes of both atoms.

25. C correct, B partially correct – Temelín is the main source, but we cannot forget the background values and residual values from nuclear weapons tests in the atmosphere before they were banned in 1963.

26. B correct, D partially correct – sometimes surface water has small (if it consists predominantly of rainwater) mineralization. The minimum concentration of dissolved substances in drinking water should be at the level of 70 – 80 mg/L, optimally 200 – 400 mg/L, maximum 1,000 mg/L (rainwater has only 10 – 20 mg/L).

27. C correct, D partially correct – it is customary to write cations first and then anions.

28. C correct, A partially correct – the hardness is caused by Ca^{2+} and Mg^{2+} cations, but the question was about the temporary hardness, and it is important to state that these are bicarbonates.

29. C correct, A partially correct, higher chloride concentration may have been caused by seawater introduction by pumping on a nearby well, but it can also be a natural process where seawater can penetrate further into land, e.g. due to decreasing supplies of fresh groundwater due to drought.

30. D correct, B partially correct – oil hydrocarbons is the collective designation for further mentioned substances, so that it is a matter of their duplication, and no other common substances under D) are mentioned.

31. C correct, A partially correct – this is true for the liquid phase of these substances. During their vertical movement, however, they dissolve in water, so they contaminate (the part that is dissolved in water) gradually the entire depth profile of the aquifer.

32. D correct, C partially correct – the usable quantity of water is important, but determined only subsequently, natural resources are balanced.

33. C correct, A partially correct – theoretically the usable quantity can be up to 100% of natural resources, but in that case we have to reckon with fatal impacts on the water regime in the landscape (drying of streams, extinction of springs and wetlands extinction of water and water–related ecosystems).

34. A correct, D partially correct – the quantity of groundwater is a term that includes both natural resources and static reserves. Hydrogeological regions are primarily intended for the calculation of natural resources.

35. A correct, C partially correct – wells are not only dug, but also drilled.

36. B correct, C partially correct – it is correct information about sewers and cesspools, but there are more possible sources of pollution, therefore B is the more general formulation.

37. D correct, B partially correct – most wells were started in the 19th century, but even before that private wells at the houses of rich nobles, burghers, or monasteries were present in Prague.

Notes

Groundwater in the City

Published by T. G. Masaryk Water Research Institute,
Public Research Institution, Prague 2020

Author: RNDr. Josef Vojtěch Datel , Ph.D.

Graphic design and illustration: Jan Vohlídal

Printing: Repro Fetterle, s.r.o.

Number of pages: 44

First edition

Print run: 100 copies

ISBN 978-80-87402-87-0
ISBN 978-80-87402-86-3 (Czech version)

WWW.VUV.CZ

EUROPEAN UNION
European Structural and Investment Funds
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