02.14 Groundwater Temperature (Edition 1999)

Overview

The groundwater temperature in the agglomeration of Berlin is significantly influenced by man.

Temperatures measured, in the near surface groundwater of the city center, shows that the average temperature has increased more than 2°C over the thinly populated surroundings outside the city. The evidence also indicates that long term groundwater temperatures will continue to rise.

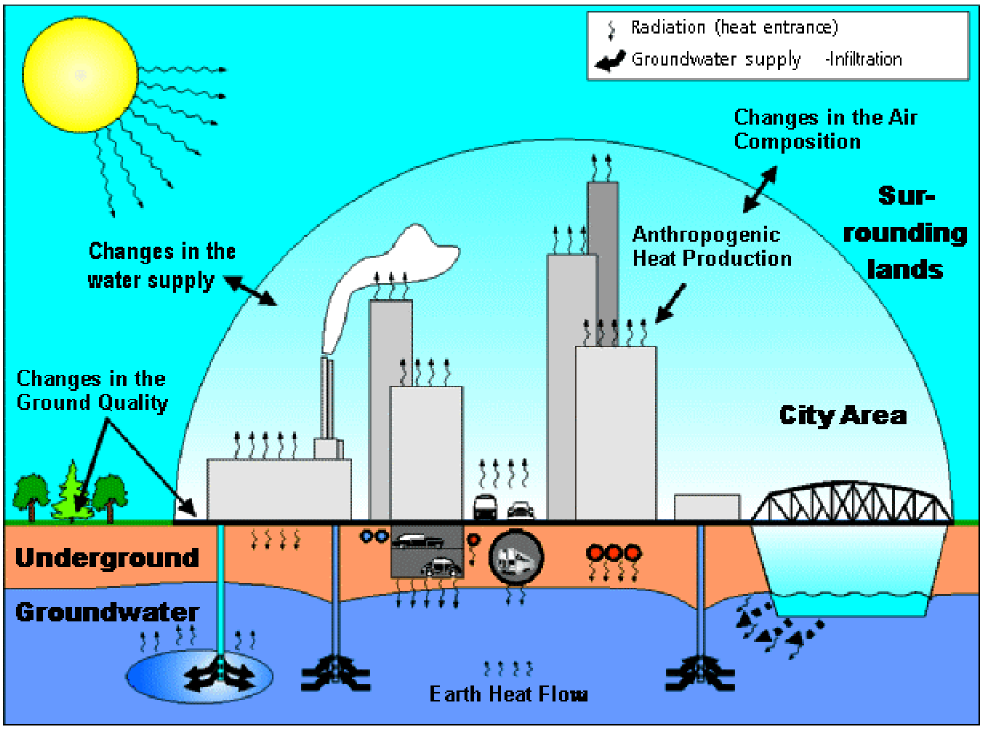

Fig. 1: Schematic Diagram of the Causes that Influence Groundwater Temperature

The causes for the rising temperature are varied and are directly connected with the increasing urbanization of the land. There are many influences from direct to indirect for the change in groundwater temperature (cf. Fig. 1):

- **Direct influences** to the groundwater temperature are caused from all of the heat produced by: the sewage network, hot-water-heating-pipes, electric lines and subterranean constructions like: auto and subway tunnels, underground garages etc.
- Groundwater heat-use and storage e.g. in connection with the use of heat pumps.
- **Indirect influences** to the groundwater temperature are caused by the course of urbanization, that originates with the change of heat regime in the lower atmosphere. By Gross (1991) important indicators are:
  - The disturbance of the water regime because of a high degree of surface sealing
  - The change of soil property caused by an accumulation of houses (differences in the near surface heat production and heat capacity)
  - The changes of radiation caused by changes in the atmosphere
  - The anthropogenic heat generation (domestic heating, industry and transportation)

In comparison to the surroundings a change of the heating regime has been caused by the above mentioned reasons. The city heats itself slowly, storing altogether more heat and gives this again slowly to the surroundings, that means it is being generally considered as a huge heat saver. In the long term this process increases the average of the air as well as soil temperature (cf. maps of the topic 04 climate).

This long term warming of the soil leads also to a warming of the groundwater. The temperature influences the physical characteristics such as the chemical and biological composition of the groundwater. It can also result in the deterioration of the groundwater quality.

One hundred percent of Berlin’s drinking water comes from groundwater, which is being extracted almost exclusively from the city area. The groundwater also supplies a large percentage of the needed water for industrial uses. Therefore, the protection of the groundwater from hard changes like the raising of the groundwater temperature, is of high importance- specifically in the context of sustainable water use.

Since 1978 the deep groundwater measurements points from the entire city have been processed and evaluated to strengthen received **temperature profiles** that include both a chronological and spacial depiction of the groundwater fields.

The presented map should be:

- the beginning of a documentation of the temporal changes of the groundwater temperature under the City
- and serve as permission basis for actions that would cause changes in the groundwater temperature

Additionally it can be combined with other map topics (for example: geological, hydrological) for decision making and preplanning of an energetic management of the groundwater.

With help from heat pumps or probes the surplus heat can be used. Fossil fuels are being saved in this way, as a contribution to progressive energy politics by the reduction of harmful climate gas emissions.

Groundwater Temperature and Annual Temperature Path

The substantial heat source for the earth is **Solar radiation,** which is responsible for the surface temperature. The radiated solar energy warms the near surface ground and this in turn warms the atmosphere and the underground. The regular energy from the sun on the surface of the earth amounts to an average of ca. 0,75 kW/m². Different surface types and elevations, as well as both seasonal and daily changes to the amount of sun exposure, lead to local and time deviations from the median value.

The surface temperature penetrates with decreasing intensity into the ground. The penetrated depth and the speed in which the heat is transported depends on the heat transfer ability of the ground.

The **heat transfer** in the ground can be distinguished between conductive and convective heat transfer.

During the convective heat transfer the heat movement occurs through the material (for example ground and seepage water), on the other hand the conductive transfer results from the transportation of energy through push ”processes” between molecules.

There is also another form of surface heating, that comes out of the earth and passes to the surface. It is called the **earth heat flow**. It originates in the production of heat from the decay of radioactive isotopes. However this form of heating is much weaker than the sun.

In the continental crust of the earth the heat flow density is defined as the heat flow per unit area perpendicular to the standard area, so there are regional differences (Hurtig & Oelsner, 1979). The heat flow density in the Berlin area amounts to ca. 80 mW/m².

The near surface groundwater temperature is therefore essentially caused by the exchange of heat between the sun, the earth’s surface and the atmosphere, with a much smaller amount from the earth heat flow directed at the surface.

The regional average annual temperature at the surface in Berlin, under anthropogenically unbiased conditions, is ca 8,5 to 9°C.

Daily fluctuation affect the ground only up to a depth of about 1,5 m, while seasonal fluctuations affect a depth of ca. 20-30 m. Below this depth the seasonal influence is no longer registered, This is the beginning of the so called neutral zone. At this point temperatures rise depending on the heat transfer ability of the rocks and the regional heat flow density (Fig. 2).

In the Berlin area the average rise in temperature in this region, until a depth of ca. 300m, is 3°C per 100m.

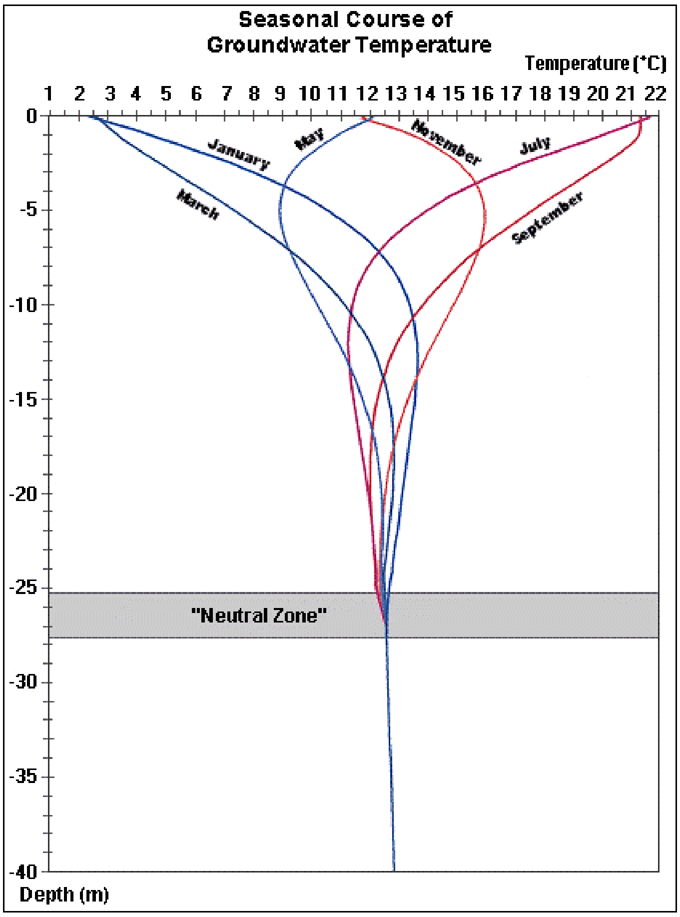

Fig. 2: Seasonal Course of Groundwater Temperature

Surface Form and Groundwater Situation

In the nearly east-west direction runs the Warschau-Berlin glacial valley separating the Barnim-Plateau in the north of the city from the Teltow-Plateau and the Nauener Plateau in the south (Fig 3). The terrain elevations of the glacial valleys accounts for 30 to 40 m above sea level, while the plateaus lie an average of 40-60 m above sea level. Singular hills rise over 100 meters above sea level (cf. map 01.08, SenStadtUmTech 1998).

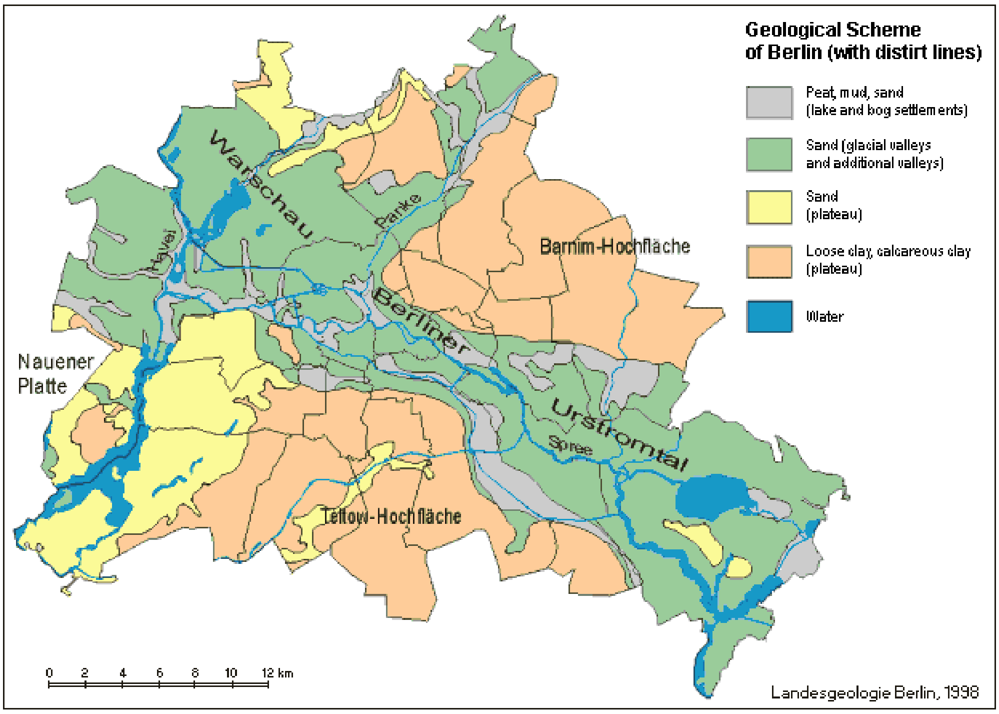

Fig. 3: Geological Scheme of Berlin

In Berlin the pore space of the predominantly sand and gravel sediments are, over 150-200 meters, completely filled with groundwater until just below the surface. This is used as the drinking water supply for the city. The distance from the groundwater to the surface fluctuates depending on the morphology and geology between 0 m and a few meters in the glacial valley as well as five to over 30 meters on the plateaus (cf. map 02.07, SenStadtUmTech 1997).

The **groundwater removal** of drinking and industrial water extraction has led to the formation of wide funnels in the surface of groundwater. This changes the natural depth and flow velocity of the groundwater, as well as the natural flow direction of the groundwater. For that reason in the areas with well galleries near the rivers and lakes there are influent conditions, that means the near surface water infiltrates as bank filtrate in the groundwater. Additionally the groundwater is warmed throughout the year (for example in the area of the Spree) by the cooling of heating power stations.

Population structure and climatic relationships

The city of Berlin has a polycentral settlement structure that is characterized by the existence of two main centers, smaller city centers and dense areas of living, green, trade and industry areas. Larger business and industrial areas normally lie on settlement and development axes directed by the city radials from the center to the outskirts as well as on canalized surface waters.

Here is a largely simplified look at the city (Fig. 4):

Areas

- without settlement, primarily vegetation
- with low to medium settlement density
- with high settlement density, city center and industrial areas

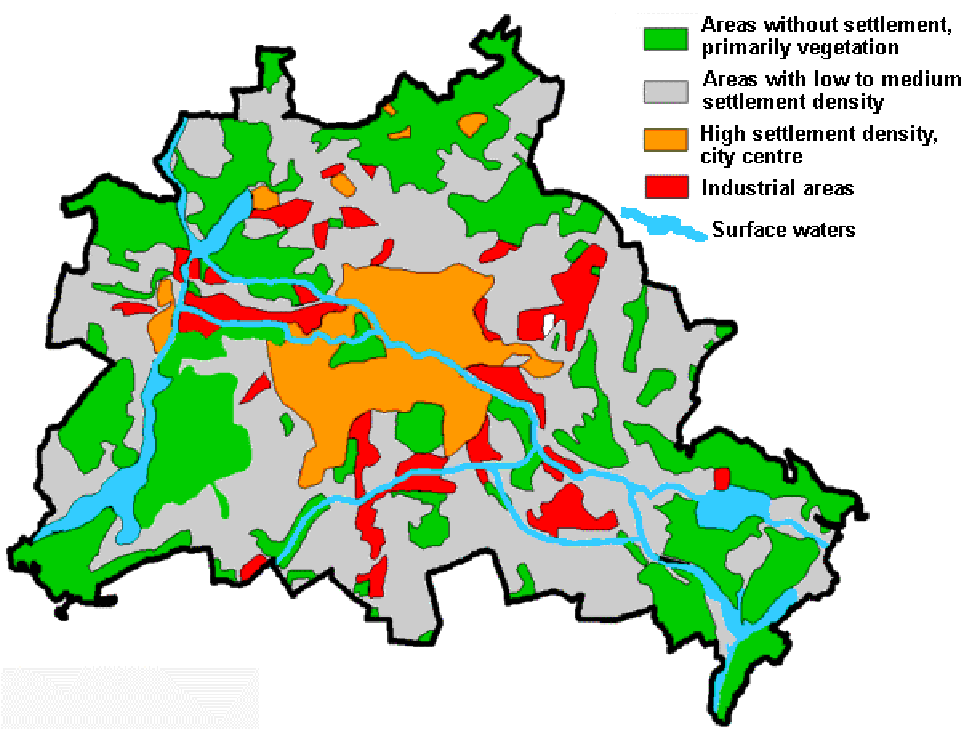

Fig. 4: Simple Diagram of the Urban Structure of Berlin

The local climatic situation in Berlin shows above all that the structurally high-condensed city center has profound changes in the heat regime compared to the surroundings. By anthropogeneous activities, energy passes as heat into the city-atmosphere. So the middle year air temperature in the outskirts (Dahlem) amounts to 8,9 °C. In comparison the average temperature in the city center is over 10 °C (cf. map 04.02, SenStadtUm 1993b).

Statistical Base

The following map of the groundwater temperature distribution is based upon 433 **measurement points** that were gathered between 1978 to 1998. In areas with earlier measurement periods **1997-1998** temperature dispersions were repeatedly included. For a time from January to October 1991 measurements were reported every two months. Generally the temperature profiles were gathered from the near surface water to the expansion depth. The measurement point distance normally was 1 m. For the measurement a resistance dependent on temperature was used. The accuracy of the measurements was within ± 0,1 °C.

Methodology

In order to get an spatial statement over the groundwater temperature distribution, a **Kriging-Interpolation** based on a Variogram analysis was calculated. Prerequisite for the execution of a Variogram analysis is that the groundwater temperature is regionalized that can be regarded as the realization of a coincidence-function. A regionalized variable distinguishes itself through its relationship to its neighboring points.(Akim & Siemes, 1988). With a **Variogram analysis** it is tried to characterize these structure-characteristics and to use them mathematically. The results are integrated as input-parameters into the Kriging-Interpolation. The interpolation delivers a freely selectable grid, whose junction points return the calculated groundwater-temperatures.

Map Description

The penetration of the seasonal temperature fluctuation and therefore the depth of the neutral zone is determined by geological factors like the distance from the surface to the groundwater, the heat transfer ability of the rocks, the groundwater formation and from the anthropogenic factors. In Berlin the **neutral zone** is dependent on the above named relationships at a depth of between 15 - 25 m (Henning & Limberg 1995).

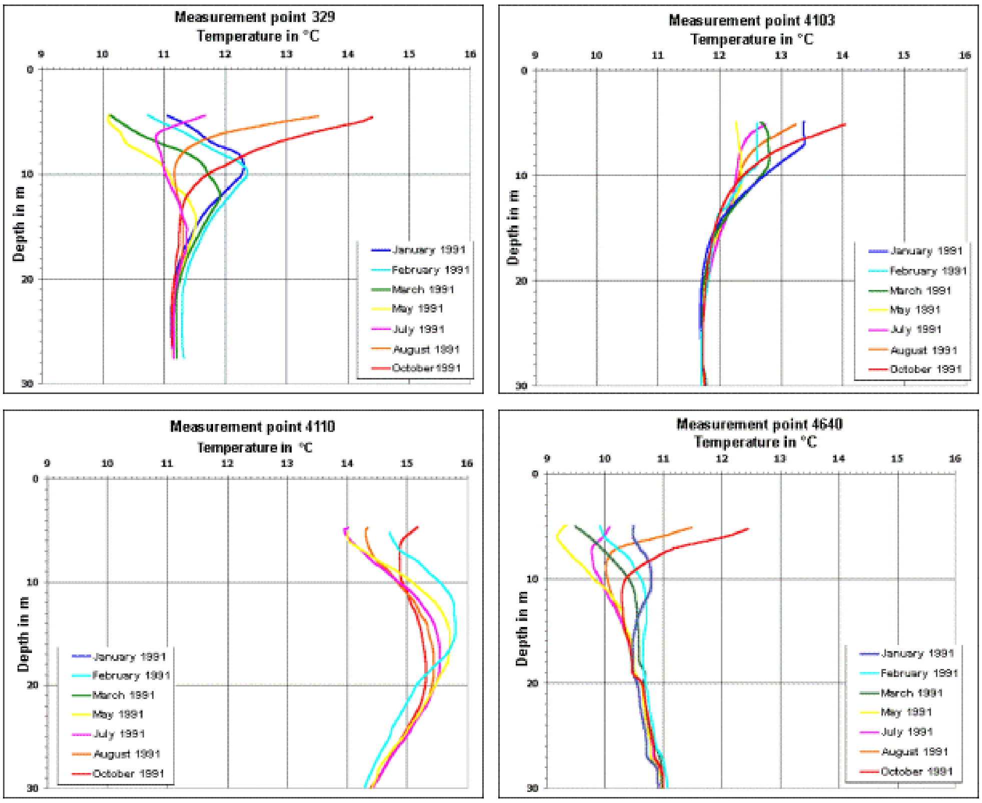

Fig. 5: Seasonal Change of Groundwater Temperature

In Fig. 5 the four groundwater measurement points are compiled from about the same geological position but in different settlement areas. The time variation of the temperature dispersion is in the first 30 meters under ground. The groundwater measurement points are in about the same average depth from ca. 5 m. The first ten meters under ground are characterized as a change from fine sand to middle sand.

The observed groundwater temperature as well as the wider temperature dispersion depends on the specific position of the point of measurement.

The **lowest temperatures** of the near surface groundwater are generally early in the year (February to May), the **highest** in late summer (September to October). An exception occurs at measurement site 4110. Here the highest temperature is in winter (January) and the lowest point is in summer (July). This measuring site is an extreme case because it is next to an industrial area with a large amount of warm water waste production close to the near surface water. Since the surface-water is warmed up strongly by cooling water discharge, especially during the winter-months, and influent situations predominate through the proximity to a waterworks, an increase of the groundwater-temperature occurs all-year. Over the whole year a temperature abnormality including year long fluctuations is observed to only differ by approximately 1 °C.

The shape of the temperature dispersion of measurement sites 329 and 4103 below the neutral zone is a further hint to transient temperature relationships. This means that a **long-term rise** in the **groundwater temperature,** also at large depths, can be expected.

Table 1 contrasts different settlement areas with selected temperatures.

Measuring points with settlement types	**Depth of groundwater [m]**	**Minimum-temperature [°C]**	**Maximum-temperature [°C]**	**Temperature of the neutral Zone [°C]**	**Depth of the neutral Zone [m]**
4640 Predominately vegetation	ca. 5	ca. 9	ca. 13	ca. 10	ca. 20
329 Medium settlement density	ca. 5	ca. 10	ca. 14	ca. 11	ca. 20
4103 High settlement density	ca. 5	ca. 12	ca. 14	ca. 12	ca. 20
4110 Industrial areas	ca. 5	ca. 13	ca. 15	ca. 14	ca. 35

Tab. 1: Scheme of Selected Temperature Characteristics in Different Urban Areas

From Table 1 it can be gathered that, in general, with increasing settlement density an **increase in the groundwater temperature** (cf. fig. 5) can be registered.

The following table distinguishes the temperature of the neutral zone in the different settlement areas.

Areas	Temperature in the neutral zone
without settlement, primarily vegetation	< 10 °C
with low to medium settlement density	10 - 11 °C
with high settlement density, city center and industrial areas	> 11 °C

This map presents the groundwater temperature distribution in the city area of Berlin with the reference horizon at sea level. The corresponding dependence of the position in the glacial valleys or the plateaus is 30 - 60 m.(cf. fig. 3). In this depth there are no daily and yearly influence of temperature fluctuation.

The distance between the individual isolines is 0,5°C. The groundwater temperature fluctuates between 8,0°C in the outskirts of the city and 13,5°C in industrial areas. It has been generally observed that the **groundwater temperature rises from the outskirts to the city center**. The temperature dispersion in the northeast shows a continual rise to the city center, while the remaining city areas have more distinct positive and negative temperature anomalies.

The heavily built on and sealed city center is surrounded by the 11,5°C isoline. Inside this area are (known from local investigations) points that exceed 12°C. The highest measured temperatures are near the cooling water discharge of the heat power station. Outside of the city center there is a correlation between high temperature and high soil sealing (cf. map 01.02, SenStadUm, 1993a) for example near the center and industrial areas.

The observed temperature anomalies in the southwest of the city is also striking. They may be a result of the closed down **Wannsee landfill** that produces heat through decomposition.

Below the extended forest-areas in the outskirts-area of southeast, west and northwest, the temperatures are <10 °C. Furthermore, negative temperature-anomalies of under 10 °C exist within this area, characterized by a high degree of vegetation. So, two large green areas are noticeable to the south of the city center.

Densely settled areas have a groundwater temperature that is more than 2°C higher than areas free from settlement.

Among other things, the near surface groundwater-temperature-distribution in the city area shows a connection with the distribution of industry-settlements, waste heat production, surface sealing, free areas and the entry of heated surface water through influent situations. Under consideration of the groundwater flow field, one can assume that these factors have an essential influence on the change of the groundwater temperature (Blobelt, 1999). Since an accumulation of these factors occurs normally in the city, the factors of influence mutually overlap.

Altogether the results of the temperature measurements show that the groundwater has clearly warmed in the city of Berlin especially in the central area. The long-term cause of this is the onward urbanization, with its profound heating of the near surface ground and consequently of the groundwater.

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Maps

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