5.2 Groundwater Yields

Germany has considerably more groundwater than some of the other European countries. This groundwater can usually be used for drinking water supplies, owing to its good quality and because it is less vulnerable to pollution than surface water supplies. Only in those parts of the country with a high demand and conditions that are unfavorable for groundwater production do surface water supplies prevail (Atlas Map 7.2 "Water Supply"). The considerable importance of groundwater occurrences for the water supply plays a large role in regional planning, e. g. when there are conflicts of interest about the use of natural resources. The importance of a groundwater occurrence is determined by its natural (i. e. geological, hydrological, and chemical) properties and demand (amounts and location). One of the properties of a groundwater occurrence is its potential yield, i. e. the amount of groundwater that can be economically obtained from a well over a long period of time.

High-yield groundwater occurrences are due to the following factors:

- sufficient precipitation evenly distributed over the year,
- a thick aquifer in sandy, gravelly unconsolidated rock, fractured consolidated rock, or karst,
- favorable relief (neither extremely steep nor very flat areas) and surface water conditions.

The effects of these regional conditions lead to a large difference in potential groundwater yield. The regional differences in the climate (Atlas Map 2.14 "Climatic Water Balance") have relatively little effect on the potential yield: The mountainous regions with high precipitation rates very often consist of rocks that are unsuitable for aquifers. A high relief normally increases fast runoff components at the expense of infiltration; a very flat relief with little runoff leads to a high groundwater table and a relatively high percentage of evapotranspiration.

The most influence on the potential yield of groundwater occurrences in Germany is the composition of the aquifer rocks. The geologically young deposits of sand and gravel are the most important for the water supply.

The regional distribution of potential groundwater yields can be plotted from the long-term performance data for wells and waterworks. The data for hydrogeologically well-known areas can be extrapolated to other, similar areas (HÖLTING 1992). The map provides an overview of the groundwater occurrences in Germany and permits an estimate of their regional significance in terms of their potential yield. In the relatively large areas in which no significant groundwater occurrences are shown, groundwater can be obtained in many places for the local water supply.

Methodology

The map is based on studies made by the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR, Federal Institute for Geosciences and Natural Resources) in 1977/78 and extended to the new Federal States in 1992/1993.
The map of the potential yields of groundwater occurrences was prepared at a scale of 1 : 1 000 000 in cooperation with the state Geological Surveys, the Senator für Bau- und Wohnungswesen Berlin (West Berlin Senator for Building Construction and Housing) and the Bayerisches Landesamt für Wasserwirtschaft (Bavarian Water Management Office) (VIERHUFF, WAGNER & AUST 1981). The maps evaluated for the 1 : 1 000 000 map were at scales of 1 : 200 000 to 1 : 500 000.

The extensive hydrogeological and statistical studies of BAMBERG, GABRIEL, GARLING & ZIEGLER conducted in the 1970s, as well as the 1 : 500 000 map of types of groundwater occurrences ("Karte der Grundwasserlagerstättentypen", 1983) derived from their studies, were used to prepare the potential groundwater yield map of the new Federal States.

The potential groundwater yield was assessed quite differently in the various sources of data. Usually, the values were given as the mean of measured or expected well yields (in L/s or m^3/d), as the mean of the annual production of existing or possible waterworks (in hm^3/a or $10^6 m^3/a$), or as yield classes.
The different types of data were harmonised regionally and a common legend was prepared. In this process, it was taken into consideration that waterworks in areas with high-yield or very high-yield aquifers in unconsolidated rock usually have many wells and a correspondingly large catchment area, waterworks in areas of high-yield consolidated rock are smaller, averaging three wells, and in areas with less significant groundwater occurrences or none at all, single wells are the rule. The boundaries of the legend units were drawn along the boundaries of the aquifers. In contrast to Map 1.6 "Hydrogeology" and Map 5.1 "Hydrogeological Regions", the map was not derived from the geological map, which shows the distribution of near-surface rock units, and is thus more generalised.

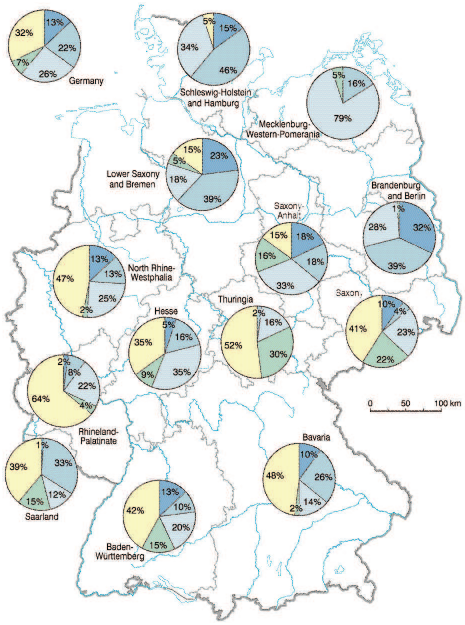

Fig. 1 Distribution of the five classes of groundwater yields shown in Map 5.2 in Germany and in the individual Federal States

Map Structures

The map shows a generalised representation of the distribution of groundwater resources in Germany based on the yields of existing waterworks or potential yields derived from this data. The importance of the groundwater occurrences for the water supply can be read from their classification in five yield classes, which range from significant and less significant occurrences to areas with no or regionally insignificant groundwater resources. The regionally significant occurrences are subdivided into subclasses of roughly quantified yields.

Both the amount of groundwater and type of aquifer rock are important for the decision to develop a groundwater occurrence for the drinking water supply. Exploration costs are usually less for areas of unconsolidated rock than for areas of fractured consolidated rock, whereas the cost of well construction and water treatment is usually higher. Aquifers in karst areas are vulnerable to pollution. For this reason, groundwater occurrences are classified according to these three types. Other characteristics that govern the cost of groundwater production, e. g. the depth of the aquifer and of the groundwater table or potentiometric surface, are less important in Germany and were thus not taken into consideration.

Waterworks with high production rates, in addition to the natural groundwater flow, take advantage of the infiltration of surface water resulting from the gradient artificially produced by the groundwater abstraction. These amounts are not well known and vary with time. Valleys in which the water supply can be economically augmented in this way owing to the hydrogeological conditions are marked on the map. These are areas in which the streams with sufficient water quality flow over thick gravelly, sandy sediments and there are nearby areas with a high water demand.

In some parts of Germany, the possibility of developing groundwater occurrences for the water supply has been detrimentally affected by mining measures, e. g. removal of the cover rock, mine drainage. The pumping of water from the mine affects the groundwater table over a wide area. When the mine is abandoned, the quality of the groundwater that refills the aquifer may be impaired. Such areas are marked on the map.

Fig. 2 Testing the yield of an artesian flowing well

Areal distribution of the varying groundwater yields in Germany

The largest area of high-yield groundwater occurrences is the Norddeutsches Tiefland (North German Lowlands). This area, especially outside the deposition areas of the most recent glaciation period, consists of thick layers of unconsolidated Quaternary and Tertiary sand and gravel. Especially occurrences in near-surface sediments in urstromtals and in deeper aquifers in Quaternary erosion channels are important. The corresponding groundwater-rich area in southern Germany is the forelands of the Alps, which also consists mainly of unconsolidated Quaternary and Tertiary (Molasse) rocks. Other areas with very high-yield aquifers are the entire Oberrheingraben (Upper Rhine Valley) and the Kölner Bucht (Cologne bight) of the Lower Rhine region, owing to the very permeable river gravels.

Aquifers with a lower yield are found in areas with unconsolidated rock where fine-grained loamy deposits predominate, e. g. till and basin sediments, or on the whole few glacial sediments were deposited, e. g. in northern and eastern Schleswig-Holstein and Mecklenburg. In the central mountain regions, the Keuper sandstones are an example of such aquifers.

In the central upland area of Germany, there are regionally important groundwater occurrences in the limestone formations of the Schwäbischer and Fränkischer Jura (Swabian and Franconian Jura) and Thuringia, of the Muschelkalk between the River Main and the Schwarzwald (Black Forest), and of the Cretaceous in eastern Westphalia; in the thick sandstone formations in the Pfälzer Wald (Palatinate Forest), the Black Forest, the Spessart and Solling regions; and, last but not least, in the basalt of the Vogelsberg region.

Fractured and porous consolidated rocks in general have a relatively low potential yield. When the aquifers are not very thick and their properties change over relatively short distances, the groundwater can serve local water supplies but will have no regional significance.

Large parts of Germany, totaling more than a third of the country, have no groundwater occurrences of significance. Examples of such areas are in the central uplands where the rocks are shale, schist, and crystalline rocks: the Rheinisches Schiefergebirge (Rhenish Slate Mountains), the Harz Mountains, the Thuringian and Bavarian Forests, the Erzgebirge (Ore Mountains), the upper Black Forest. The locally usable groundwater occurrences are almost only in the valley sediments where sandy, gravelly deposits are found. Of special significance are the local limestones and dolomites in the Slate Mountains, which can be karstified and can contain limited, but valuable amounts of groundwater.
Such regions, however, have considerable surface water resources and, owing to the rock properties and the topographic relief, dams can be built so that drinking water can be supplied to the large cities (Atlas Map 7.2 "Water Supply"). Figure 1 shows the relative areal distribution of the five classes of groundwater occurrences, according to their potential yield, in Germany and in the individual Federal States.

Practical Information

The production figures on the map are not related to a specific area size or a specific location within the area. Thus, a specific value for the amount of water that can be produced from an aquifer or the best location for a waterworks cannot be derived from the area boundaries shown. Moreover, the problem of overdraft from a high-yield aquifer with a low storage volume or the risk to the environment depend on the location of the waterworks and its construction. Such problems were not considered in this study and in any case have to be investigated in special site studies.