Ground water plays an important role in Switzerland, both as a source of drinking water and as an integral component of the natural hydrologic cycle. Even though the original practices for protecting ground water have successfully overcome some of the more traditional problems, they must now be extended to include recharge zones in order to insure adequate protection from persistent chemical contamination. As illustrated by comparing water consumption to ground water regeneration in Switzerland’s most densely populated areas, a surplus of drinking water should not be taken for granted. The sustainable utilization of ground water must, therefore, be ensured by employing modern resource management practices.

About 80% of Switzerland’s drinking water comes from ground water (both pumped and spring water). Of this total, 48% can be used without any treatment, while 41% must be disinfected on a single-stage basis (UV irradiation or chlorination). This is fortunate since many smaller communities normally lack the know-how and financial resources to operate large water treatment plants. Only about 10% of the country’s ground water has to undergo multi-stage treatment in order to meet stringent Swiss drinking water quality criteria; this applies to karst water and anoxic ground water in particular.

Natural Ground Water Regeneration Processes

Until recently, ground water was regarded as an underground reservoir that is virtually sealed off at both the top and bottom; consequently, it was thought to be in only very limited contact with the aboveground environment. It was only after ground water contamination by anthropogenic chemicals was documented that this view changed. As a result of these discoveries, ground water is now acknowledged to be an integral part of natural water systems and a component of the hydrological cycle (Fig. 1).

Ground water is mainly formed by the infiltration of rain and river water. In the transition zones between surface water and ground water, numerous physical, biological and chemical processes take place which have a profound effect on ground water composition. The Swiss practices of ground water protection take into account all of these processes, including self-purification of the infiltrating water.

Ground Water Regeneration with and without Oxygen

As rain water infiltrates through unsaturated soils into the ground water, naturally occurring organic materials are oxidized by microorganisms (aerobic respiration). The carbonic acid formed during this oxidation process then reacts with limestone to cause ground water hardening (cf. paper by J. Zobrist, p.15). Exchange processes with the atmosphere usually guarantee the presence of sufficient oxygen, therefore, aerobic ground water regeneration is the norm in Switzerland.
In the infiltration zone between surface water and ground water, a wide variety of small animals live on the dissolved nutrients (cf. paper by T. Gonser, p. 6), whose concentrations and availability largely determine the numerous biogeochemical processes that occur. Similar processes occur during the exfiltration of ground water into surface water.

During the infiltration of river water, atmospheric oxygen is often excluded. With a high concentration of ammonium or dissolved organic substances, available oxygen is rapidly consumed, resulting in a sequence of reductive processes (cf. J. Zobrist, p. 15). This is known as anaerobic ground water regeneration.

Ground Water Protection
In densely populated areas, as is common in many parts of Switzerland, anthropogenic influences may be superimposed on these natural processes of ground water regeneration (Fig. 1). Undesirable substances may thus enter the ground water from agriculture, industry, commerce, construction, energy production, and transportation. Substances such as fertilizers and pesticides, seepage from landfills, runoff, and street drainage can infiltrate directly through unsaturated soil zones, while other contaminants such as sewage effluent infiltrate mainly via river water.

To minimize the negative effects of anthropogenic activities, a comprehensive ground water protection policy has been instituted in Switzerland. In ground water collection zones, the use of fertilizers and pesticides and the handling of chemicals, etc. are restricted or prohibited altogether in order to preserve the self-purification capacity of the aquifer. Water protection zone 2 is generally established so that infiltration through this regime takes at least 10 days, which is normally long enough for self-purification and decomposition of biologically degradable substances. If this is not enough to ensure high quality drinking water, further protection measures are taken.

In Switzerland, 80% of the drinking water is obtained from ground water (both pumped and spring water). Although Switzerland is often called the water tower of Europe, our ground water still has to be managed with care.

Fig. 2
a) Qualitative and b) quantitative aspects of ground water. A thorough knowledge of physical, chemical and biological processes at the microscopic level is essential for understanding the macroscopic system by which ground water becomes drinking water.

Fig. 3
Average ground water regeneration rates in Switzerland, Africa and global land masses compared with drainage and evaporation rates. Precipitation seepage into the ground water is clearly above average in Switzerland.
water, a number of drinking water treatment methods can then be employed. Drinking water protection in Switzerland is based on three main principles (Fig. 2a):

- Ground water protection
- Self-purification capacity of water resources
- Drinking water treatment

This macroscopic approach is based on microscopic processes, which must be examined in depth to allow a reliable assessment of how pollutants behave in the subsurface (cf. papers by S. Hug, p. 19, J.R. van der Meer, p. 24, S. Haderlein, p. 21).

While the original protection zone concept successfully overcame the traditional problems of hygiene and degradation of organic pollutants (e.g., mineral oils), it was soon found to be inadequate against persistent chemicals such as pesticides, chlorinated solvents, etc. The new ground water protection policy, therefore, extends existing practices to include catchment and infiltration zones, thereby accounting for 90% of permitted ground water utilization (cf. E. Hoehn, p. 27). In order to put this extended policy into practice, it will be necessary to prepare suitable legislation over the next few years.

**Ensuring Sustainable Ground Water Utilization**

The quantity of ground water available for utilization largely depends on seepage, infiltration and exfiltration rates (Fig. 2b). This macroscopic level comprises the interplay of microscopic interchange processes such as mixing, gas-water interchange, etc., which can be investigated using environmental tracers (cf. R. Kipfer, p. 12). For example, the age of ground water can be determined within a range of years or millions of years. From this information, the regeneration rate can be derived, and the maximum amount of sustainable ground water utilization may be calculated. Such methods are indispensable for modern ground water management, though they are not yet in widespread use.

Although Switzerland is often called the water tower of Europe, our ground water still has to be managed with care. About 30% of precipitation in Switzerland rapidly flows away; another 40% evapotranspires from the vegetation. The remaining 30% seeps slowly into the ground water (Fig. 3), a very high percentage by international comparison. The average in Africa is only 7%, while the global mean is around 10%. Depending on weather conditions, about 250 to 700 mm of annual precipitation in Switzerland seeps into the ground water (international average = 84 mm; Africa = 50 mm). On the other hand, average drinking water consumption in the heavily populated areas (i.e., 500 people per square kilometer) is around 125 mm of precipitation or 250 cubic meters per person per annum, which includes industry, commerce and services. In contrast to the widespread notion that Switzerland has unlimited drinking water supplies, consumption in the highly populated regions is about the same as that which is replaced by precipitation. In similarly populated areas with much lower ground water regeneration rates, ground water depletion is expected.

In order to ensure qualitatively and quantitatively sustainable utilization of our valuable ground water resources, modern assessment methods must be applied more systematically. The articles in this issue of EAWAG news give a good overview of the state-of-the-art.