To protect the potability of ground water supplies, the revised Water Protection Act in Switzerland now divides inflow into subsurface \((Z_U)\) and surface \((Z_O)\) zones. In many cases, rough estimates are adequate for dimensioning \(Z_U\) zones. With regard to the infiltration of river water and subsurface flow from valley slopes into ground water, however, such estimates are inadequate.

**Extension of the Protection Concept**

Since January 1999, the new Water Protection Act (GSchV) has been in force in Switzerland. Amongst other aspects of the law, it prescribes the protective zoning of intakes to ground water for drinking purposes. The critical intake zones are divided into three categories:

- Subterranean \((A_U)\) and surface \((A_O)\) water protection areas,
- Subsurface \((Z_U)\) and surface \((Z_O)\) inflow zones,
- Ground water protection zones I–III.

The water protection categories and zones are virtually unchanged from the existing regulations, while inflow zones \(Z_U\) and \(Z_O\) are new elements in the protection legislation. These zones serve for the protection of water quality in existing and planned ground water wells in the public interest, if the water is contaminated by pollutants which cannot be adequately decomposed or excluded, or if there is any significant risk of pollution”.

Dimensioning of the \(Z_U\) zone is based on well known, simplified assumptions, as follows:

- A homogeneous isotropic aquifer of infinite length,
- Stable ground water flow in the horizontal direction.

The \(Z_U\) zone can thus be represented in parabolic form (Fig. 1).

**Problems with Inflow Zoning**

In the perialpine valleys with glaciofluvial gravel aquifers, there are at least two problematic cases where this simplified approach is inadequate:

- Infiltration of polluted river water into the ground water, e.g., below sewage treatment plant outlets,
- In flow of subsurface waters from valley slopes, polluted, e.g., with fertilizers.

In both of these cases, more detailed investigations are needed. Apart from conventional boring, hydrochemical and geophysical methods, modern techniques such as tracer investigations and computer simulation are now available. Examples are given here of how these two cases can be examined.

**a) Infiltration Flow in the Töss Valley**

Situated in the gravel of the central Töss valley south of Winterthur (Linsental region) are several large drinking water wells belonging to Winterthur water works (including the Sennschür and upper Au wells). In the 1950s, ground water conditions were investigated in this area. Based on numerous piezometer measurements, isohypsic ground water contour lines were plotted both with and without pumping. These results were interpolated manually and recorded on maps. It is not clear from the drawings whether or not inflow during pumping is exclusively from the Töss. The assumption that exclusively fresh water infiltrates into the well is probably an erro-
neous impression given by the horizontal two-dimensional representation. It is much more likely that ground water also flows in from a deeper level below the river Töss. This inflow either originates from further upstream in the Töss valley or comprises of “genuine” ground water fed by rainwater or tributaries. Ground water dating by tracers (e.g., inert gases; Hofer et al., 1998; Beyerle et al., 1999) supports this assumption. A two-dimensional vertical representation of hydraulic conditions would partially correct this illusion, but the oblique flow paths (from a direction oblique to the vertical plane) would still be shown incorrectly. For a correct representation of the mixing ratios and residence times of the various ground water types, a three-dimensional model is required.

During the course of a dissertation at the ETHZ and the University of Berne (Mattle, 1999), a mathematical model with five layers was compiled. Apart from the ground water contour and flow data acquired earlier, the above-mentioned dating methods were used for the first time to calibrate this model. Figure 2 shows the Töss underflow and mixing of various ground water types. One drawback of the 3-D representation is that the position of the individual streamlines is only valid to a limited extent. It is better to check the average residence time of the ground water against tracer measured data, since the position of the streamlines greatly depends on the aquifer permeability and its spatial distribution.

b) Lateral Ground Water Inflow in the Klettgau Region

The Klettgau region in the canton Schaffhausen is likewise a gravel plain, but without significant surface water flow in the valley. The ground water originates almost exclusively from rainfall seepage and lateral inflow. Drinking water in the wells, in particular the wells Chrummenlanden near Neunkirch and Trasadingen, is contaminated by anthropogenic nitrate, and in Trasadingen by geogenic sulfate. For this region, a 2-D model of ground water flow was compiled and calibrated using ground water level and permeability measurement data (Oekogeo, 1999; Bühl and Tietje, 1999). Comparison of hydrochemical data and ground water levels revealed significant lateral inflow to both wells from karstic zones on the edge of the valley. In the case of Chrummenlanden well, mathematical modeling showed residence times of part of the ground water in the valley floor of only about five months. The model did not enable an assessment of:
- the proportion of lateral inflow in the pumped ground water,
- the depth of surface inflow from valley slopes,
- the outer limit of the well catchment zone ZU.

As with infiltration flow, therefore, lateral inflow problems can be better solved with a 3-D presentation.

Cost Relevance of the Outer ZU Limit

For an accurate estimation of the outer ZU limit, a detailed knowledge of the flow system is required. In cases such as the two examples described here, mathematical simulation by stochastic methods compensates to some extent for the inaccuracy of the modelled ZU limit (e.g., Vassolo et al., 1997). The accuracy of the calculated ZU limit increases according to the amount of data available. If twice as much data is available, the probability area of the ZU limit location is reduced by about half.

Fig. 2
Plan and cross-sectional views of stationary flow conditions during pumping at Linsental, Winterthur. The two different grey shadings indicate various streamlines (third and fifth layers of the Töss model). (Graphic: Mattle, 1999)
In other words, the outlay involved in estimating the outer $Z_U$ limit is highly cost-relevant. The overall costs of protection measures in the $Z_U$ zone are made up of survey costs together with actual protection costs such as in the form of direct payments to farming operations. These two cost elements are interrelated. The additional outlay required for enhanced data and greater accuracy in determining the outer $Z_U$ limit must be compared with the expenditure incurred by a lack of detailed knowledge (Fig. 3). By balancing these two cost elements – survey costs and outlay for protection measures – overall costs can be optimized.

**Better Survey Methods and Implementation Support Required**

The EAWAG sees a need for greater accuracy in delineating the well catchment zone, $Z_U$, in cases of infiltration or lateral inflow. More detailed studies are required in such cases to ensure the well-integrated quality assurance of water resources. This involves:

- the determination of measuring methods, e.g., for the main parameters of residence time distribution and mixing ratios,
- implementation support for $Z_U$ and $Z_O$ zoning in these two problem cases.

**Fig. 3**
Overall cost estimate for $Z_U$ zone delineation: Relationship between data acquisition costs for more detailed survey (upward sloping grey zone) and resultant savings in water protection costs, e.g., for direct payments (downward sloping dashed zone).

The Töss ground water in the Linsental ensures the drinking water supply for Winterthur.