To develop a selective procedure for a statewide monitoring network for springs in Bavaria, the springsystems for the public water supply of Rötz and Schönthal were choosen among others to represent the aquifers in the Northeastern crystalline area of Bavaria. The investigations were planed in co-operation of the Bavarian Water Authority (BayLfW) and the Institute for General and Applied Geology (IAAG) of the Ludwig-Maximilians-University of Munich. Already the first field-screening showed the variation of physicochemical parameters in the two springsystems of Rötz. The large variations of the specific electrical conductivity (eC) in the so called „Old Springsystem" of Rötz range from 65 to 450 µS/cm, where the higer values (<250 µS/cm) are atypical for the geogenic background of the local hardrock areas. Starting the project with the aim to investigate the sensitive parameters of the springs and to develop a selection matrix for further springs, the main goal changed in the ongoing investigations to the clarification of the hydrogeological and hydrochemical conditions in the springsystems of Rötz. As a reference the springsystem of Schönthal is used, because it represents a system without anthropogenic impacts due to the domination of forests in the catchment.

For the investigations the following milestones were set:

- the monitoring of the temporal and spatial variation of the physicochemical parameters
- the investigation of the influences of water-particle-interactions on the hydrochemistry
- the development of a thermodynamic model with phase-boundaries, between which natural chemical reactions are possible
- the calculation of theoretical mass transfers along flowpaths into and inside the springsystems based on inverse thermodynamic models
- the verification of the hydrochemical results with hydraulic models

The working area is located about 20 km to the NW of Cham and 15 km to the W of the German-Czech border in the southern Upper Palatinate Forest, NE-Bavaria (fig.1) and comprises approximately 40 km^2. The geology is divided into two parts, which are seperated through a big fault system. The Western part consists of migmatic gneisses and granitic intrusions of the Neunburger Massif. The Eastern part is characterized by three different, mainly dark, biotite bearing gneisses. Additionally, the weathered bedrocks are covered with tertiary and quarternary material, especially in the vallies and on both sides of the river Schwarzach. The main fault-system passes in N-S- and subordinate W-E-direction. In the region of the hill Birken-Berg it is noticeable, that the course of the fault-system changes from a N-S to a NE-SW-direction and the migmatic gneisses with granitic intrusions are separated from the massiger Gneis (massive gneisses) and Lagengneis (layered gneisses) (fig.3). Hydrogeologically, the base of the fissured aquifer is formed by of the massive, barely fissured gneisses and granites of the deeper basement. The fissured aquifer is in hydraulic contact to the overlaying intergranular aquifer of the weathered zone and the covering layers. The receiving channels of this area are the river Schwarzach in the North and the river Regen in the South. The landuse in this hilly region is characterized by spruce forest at the slopes of the hills and agriculture and grassland in the morphological lower areas. The climatic conditions are transitional ones between the relatively dry Naab-valley and the humid Upper Palatinate Forest. The annual mean precipitation is characterized by an even half year sum during the summer-, and winter-half-year (about 380 mm/ half year). In dependence of the landuse the value of the actual evapotranspiration (455-520 mm/a) ranges between the calculated potential evapotranspiration using the method of HAUDE (1955) and HÖLTING (1996). The most plausible results for most parts of the area could be received by the calculation-method of ELLING et al. (1996), since this method considers the influence of spruce forest on the evapotranspiration rates. As a result of the different calculations used, the recharge rates in the springsystem of Rötz vary between 1,6 and 2,5 l/(s*km^2) and 2,5-6,0 l/(s*km^2) in the whole working area.

Field measurements and samplings were done periodically between the 11.06.96 and 07.07.99. The hydrochemical data were regionalized using the geostatistical programms Geo-EAS and Surfer in order to get an overview of the spatial variability of the physical and hydrochemical parameters (chap.7). The indistinct conclusion of the geostatistical analysis for the parameters, except the pH-value and the dissolved contents of silica acid, bicarbonate, sulfate and potassium, indicates a heterogeinity of the data pool which impairs the regionalisation. The appearance of „hole-effects" indicates the influence of outer components (spatial outliers), i.e. the existence of different water-types, changing landuse in the catchments, water from different aquifers or the inflow of water into the catchment. Cross-validations of interpolated and measured data show significant differences as a result of the coexistance of low and high values especially in the „Old Springsystem" of Rötz. The extreme values were strongly falsified through smoothing effects as a result of the interpolation method. The hydrochemistry of the natural springwater of hardrock areas is generally characterized by a low mineralization. This type of water is located in a broad sector between the villages of Öd and Löwendorf and the area in the NW of the village of Marketsried (fig.58). Except for the higher mineralized water of the „Old Springsystem" of Rötz, all increased mineralizations indicate the influence of agricultural use, shown by increased nitrate-, chloride-, potassium- and calcium-concentrations. The high eC-values and chloride-concentrations around the hill Dachsbau can not be the result of anthropogenic impacts. Street salting, the influence of the covering layers and chloride-bearing minerals or fluid inclusion can be excluded as a result of the temporal variations and leaching experiments. Thus it is concluded that there has to be an inflow of higher mineralized chloridic or sulfatic water.

Although the covering layers over gneisses and granites have a similar variation of mineral composition, it is possible to detect differences in the leaching behaviour of cations by batch-experiments. Because the differences of both soil types (soil over gneisses and granites) are the C_{org}-contents only, the organic parts in the upper parts of the soils should be responsible for the different results of the leaching-experiments and the deficits in the analyzed charge balances. Furthermore, the batch-experiments show that sulfate is the dominating anion, which is also reflected in the column-experiments with granite-gruss. This dominance is however accompanied by low concentrations (mg SO_4^{2-}/kg) attributed to adsorption processes, the incorporation into organic material, dilution processes and precipitation of solid phases like aluminiumsulfate. According to the results of the sequential soil extraction and the column-experiments, calcium dominates the cationic water soluble and exchangeable parts in the gneiss-samples, while aluminium is most important in the extracts of granitic samples. The chloride content of the batched samples shows a broad concentration-spectrum (2,5-108 mg/kg), where the highest concentrations appear near the state road ST 2150, at the side of a forest path nearby and in the south of the hill Dachsbau. While the first two increased concentrations are related to thawing salt, this source can be excluded in the third location.

An influence of the precipitation on the water chemistry can not be observed in the automated measurements of the eC, water temperature, oxygen saturation and pH-value in the springsystem of Schönthal (chap.6.2.4). Possible reasons for this fact are the little eC-differences between the groundwater and the rainwater, the unfavourable mixing conditions or the choosen interval of the measurements. Even though no short term changes seem to exist, all springs have seasonal variations of the water temperature, which are controlled by the inflow of melted snow and the in time shifted influence of the air temperature. The hydrochemical parameters can be used to classify the springs. Beside the anthropogenic influenced water with nitrate contents above 10 mg/L, low-mineralized bicarbonatic water and high-mineralized chloridic or sulfatic water can be found. Using the temporal variations, the eC-values and the Cl^--, Ca^{2+}- und SO_4^{2-} -concentrations, it is possible to divide the springs in three water types with two subgroups (chap. 6.3.2):

group 1.: low mineralized water (eC <100 µS/cm), chloride- und calciumconcentration <8 mg/L, bicarbonate as dominating anion. [1a: sulfate <10 mg/L, 1b: sulfate >10 mg/L]

group 2.: anthropogenic influenced or chloridic water (eC: 100-225 µS/cm), increased nitrate and/or chlorid-concentrations (15-50 mg/L), irregular nitrate and chloride variations. [2a: sulfate <10 mg/L, 2b: sulfate >10 mg/L]

group 3.: higher mineralized water of granite areas (eC >225 µS/cm), chloride as dominating anion (>60 mg/L), strong eC-fluctuations.

Using the species distribution (alkaline-earth and sulfate species) calculated with the code PHREEQC we can classify five water types:

- ❍ type 1: alkaline-earth species: ([$MgSO_{4\,aq}$] and [$CaSO_{4\,aq}$]: 4,0-5,0%)
  sulfate species: ([$MgSO_{4\,aq}$]: 0,8-1,5%, [$NaSO_{4\,aq}$]: partly over 0,5%)

- ❍ type 2: alkaline-earth species: ([$MgSO_{4\,aq}$] and [$CaSO_{4\,aq}$]: 0,4-3,5%)
  sulfate species: ([$MgSO_{4\,aq}$]: <1,5%, [$CaSO_{4\,aq}$]: <2,5%)

- ❍ type 3: alkaline-earth-species: ([$MgSO_{4\,aq}$] and [$CaSO_{4\,aq}$]: 1,3-2,3%)
  sulfate species: ([$MgSO_{4\,aq}$]: 3,5-4,5%, [$CaSO_{4\,aq}$]: 7,3-9,1%)

- ❍ type 4: alkaline-earth species: ([$MgSO_{4\,aq}$] and [$CaSO_{4\,aq}$]: 5,2-6,5%)
  sulfate species: ([$MgSO_{4\,aq}$]: 0,9-2,1%, [$CaSO_{4\,aq}$]: 2,3-4,4%)

- ❍ type 5: alkaline-earth species: ([$MgSO_{4\,aq}$] and [$CaSO_{4\,aq}$]: 5,4-6,3%, Mg^{2+} und Ca^{2+}: <90%)
  sulfate species: ([$MgSO_{4\,aq}$] and [$CaSO_{4\,aq}$]: 7,0-8,0%)

Calculated master species (PHREEQC) in the water are Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, NO_3^-, SO_4^{2-}, $Si(OH)_4$, $[Fe(OH)_2]^+$ and H_2CO_3. Similar saturation conditions were found between the samples of Schönthal and the „New Springsystem" of Rötz, except for illite and between the surface waters and the waters of the springs of the „Old Springsystem" of Rötz, where water is undersaturated concerning adular, albite and $Al(OH)_{3(a)}$. The dominance of kaolinite in the covering layers (chap.5.4) is included as a main phase boundary in the thermodynamic model. As a result of the forced saturation conditions the water is supersaturated concerning gibbsite and the clay-minerals. The calculated thermodynamic data describes only a minor impact of CO_2 on the system, where in almost all samples a CO_2-decrease is accompanied by an O_2-increase and a decrease of the pH-value. Regarding the saturation conditions of the carbonate species, which are undersaturated in almost all water types, only small alterations were calculated. The low-mineralized waters show modeled water contents that fit to the natural local hydrochemical conditions, except for nitrate, whereas the results of the higher mineralized waters are to low for the sodium-, nitrate- and sulfat-concentrations. This leads to two different genetic models, where the phase boundaries for the waters of the „Old Springsystem" of Rötz must be modified in regard of the above mentioned parameters. This different behaviour points to a different origin and genetic development of the waters, which is also treflected in the distribution variation of the sulphate and alkaline-earth species (chap.8.1.3).

To check the possibilty of a connection between deep cycling water and the springsystems of Rötz, several higher mineralized water types were chosen (Diepold-spring, spring Glauber IV, spring Kostelní pramen and springs from the catchment of the Waldnaab (fig.85)). Thermodynamic calculations of three modell types were done to determine possible mass transfers on fictive flowpathes. A flowpath between the higher mineralized deep groundwater or the water types of the catchment of the Waldnaab and the „New Springsystem" of Rötz seems to be unrealistic, because the results of the three inverse thermodynamic models (NETPATH) calculate unfavourable mixing conditions. Since the mixing reactions need only a few parts of high-mineralized water, the water quality is primary controlled by the impact of shallow groundwater or evaporation processes. Calculations using model type III (chap.8.2.3) demonstrate the possibility to mix the low-mineralized waters of Rötz under thermodynamic plausible conditions using a combination of rainwater, surface waters and shallow groundwater. Main problems for all three types of models are the chloride and nitrate contents, since chloride is used to calculate the mixing rates or the evaporation/dilution-factor and nitrogen transfers can only be calculated using the species NH_3. The calculated mass transfers in the direction to the „Old Springsystem" of Rötz and the mixing conditions show the possibility of an inflow of deep groundwater. While the inflow of the extremely high-mineralized water of the type Glauber IV can be excluded, there is the possibility of an evaporation controlled impact of different water types. High evaporation rates favour the water type of spring Brunn, whereas low rates tend to a water type of the Sauerbrunnen or Kostelní pramen. Regarding the good relations between the Diepold-spring and spring Rötz-6A combined with exclusion of the flowpath to spring Rötz-5A, the hydrogeologcial conditions in both springsystems of Rötz show similar mixing effects of different waters, with an increased influence of rainwater in the „New Springsystem".

Using the programme FLOWNET the hydraulic conditions were calculated in dependance on the impact of covering layers (chap.8.3). The results of both models, which consisted of 800 cells, demonstrate the possibility for upwelling deep groundwater and the importance of the covering layers or the grusszone to the water storage. The main water flow takes place in the intergranular aqufier and only small parts belong to the fissured aquifer. In combination with the results of the inverse modellings the author expect eC-values of the deep water between 0,5 and 1,5 mS/cm, whereas the lower mineralization seems to be more realistic.

The following hydrogeological conditions can be concluded for the whole working area (fig.102): Springs in the agriculturally used areas get their water from the weathered zone or alluvial deposits and percolating surface waters. In the forest regions the groundwater originate from shallow groundwater of the weathered zone, too. On account of the strong inclination of the slopes the interflow and the surface run-off show a stronger influence, but without recognizeable changings of the water quality. This effect can be observed in the „Old Springsystem" of Rötz, where after a long lasting rainfall or the thaw the main part of the surface run-off flows into single morphological depressions and floods one of the shafts. In the lower part of the „Old Springsystem" we observe additionally the influence of upwelling, higher mineralized deep groundwater, which rises preferably in the higher permeable contact zone between the gneisses and the granites. The mixing of these different water types results in a broad variation of the groundwater chemistry, which can be observed in the working area.