Polish Geological Institute Special Papers, 18 (2005): 33–38
Proceedings of the Conference "Hydrogeological transboundary problems. West and East European Bridge"

GROUNDWATER BODIES IN TRANSBOUNDARY ZONES. THE COMMON GERMAN-AUSTRIAN THERMAL TRANSBOUNDARY GROUNDWATER BODY

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Abstract. In the large transboundary Bavarian-Austrian molasse basin, a deep thermal groundwater body of about 6,000 km^2 is intensively used for spa purposes and also to gain geothermal energy in Germany and in Austria. The decreasing closing pressure of the thermal water wells in one spa in Bavaria was a sign that this groundwater body might be "at risk" in the sense of the Water Framework Directive due to the overuse of the thermal water. The Permanent Water Commission Germany-Austria decided for a hydrological and mathematical model to elaborate on these problems. The models and their commonly achieved results, the coordination benefits of further thermal water uses and the relation to the European Water Framework Directive are presented. They allow to make up the balance of the groundwater resources in the basin, to quantify sufficiently the groundwater recharge, and to quantify possible effects on existing neighbouring wells. A further use of the thermal water resources will be only possible if the thermal water is used rationally and the existing hydrostatic conditions will in general be preserved by reinjecting geothermally used thermal water.

Key words: thermal water, transboundary groundwater, groundwater body, groundwater reinjection, geothermal energy, hydrological model.

Abstrakt. W wielkim transgranicznym bawarsko-austriackim basenie molasowym na obszarze 6000 km^2 występuje zbiornik wysokotermalnych wód podziemnych. Wody te są intensywnie wykorzystywane w Bawarii i w Austrii dla potrzeb uzdrowiskowych oraz grzewczych. Na ujęciach w jednym z uzdrowisk bawarskich zaobserwowano jednak zmniejszające się ciśnienie tych wód, będące sygnałem potencjalnego zagrożenia dla całego zbiornika, przez nadmierną eksploatację. W celu zbadania tego problemu Stała Niemiecko-Austriacka Komisja Wodna postanowiła opracować model hydrogeologiczny i matematyczny. W artykule przedstawiono wspomniane modele i uzyskane dzięki nim wyniki. Omówiono także potencjalne korzyści płynące z koordynacji dalszego wykorzystywania wód termalnych oraz relację tych działań do zaleceń Ramowej Dyrektywy Wodnej. Koordynacja eksploatacji wód pozwoli na utrzymanie równowagi zasobów basenu, na właściwe ilościowe określenie zasilania wód podziemnych oraz na wyliczenie potencjalnego wpływu eksploatacji na sąsiednie otwory. Dalsze wykorzystanie zasobów wód termalnych będzie możliwe wyłącznie wtedy, gdy wody będą wykorzystywane racjonalnie, a obecne warunki hydrodynamiczne będą zachowywane przez ponowne zatłaczanie wykorzystanych wód.

Słowa kluczowe: wody termalne, transgraniczne wody podziemne, zbiornik wód podziemnych, zatłaczanie wód podziemnych, energia geotermalna, model hydrogeologiczny.

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INTRODUCTION

In the transboundary Lower Bavarian–Upper Austrian molasse basin, thermal water is already intensively used for spa purposes and also to obtain geothermal energy. The molasse basin as a whole unit forms a large aquifer for thermal groundwater resources, and is rather independent of the upper groundwater layer. Therefore, Bavaria and Austria decided jointly to identify this groundwater resource as a separate groundwater body. To ensure a sustainable use of these important groundwater resources, both states opted for a joint approach to protect the deep groundwater aquifer. As a first step, characterisation of the groundwater body with the help of a numeric groundwater model was prepared.

The thermal water resource is located in the Malm (Upper Jurassic) karst, in the Lower Bavarian and Upper Austrian Molasse Basin. Use of the thermal water in Bad Füssing, Bad Birnbach, and Bad Griesbach, in the German region, and Geinberg and others in the neighbouring Austrian region, is of increasing economic importance today. This can be seen from a high increase of overnight stays number during the last years.

The main uses may be compiled as follows:

- Spa use in Bavaria — $1.4 \cdot 10^6$ m^3/a, equivalent of 46 l/s.
- Spa use in Upper Austria — $2.1 \cdot 10^6$ m^3/a, equivalent of 66 l/s.
- Geothermal use in Bavaria — $2.4 \cdot 10^6$ m^3/a, equivalent of 76 l/s.
- Geothermal use in Upper Austria — $3.6 \cdot 10^6$ m^3/a, equivalent of 115 l/s.

The geothermally used water is wholly reinjected into the same aquifer.

Figure 1 presents a survey on the thermal water area indicating the groundwater body with the main thermal water use in this area. An extensive extraction of thermal groundwater over the years led to a decreasing closing pressure in several balneological installations, as shown on Figure 2 for the Bavarian spa Bad Füssing. The decreasing closing pressure of the thermal water wells in Bad Füssing was a sign that something was going wrong with this groundwater body.

Fear that there was an overuse caused by the extraction of thermal water out of the karst malm limestones was confirmed already by a previous research project Hydrogeothermal Energy Balance and Groundwater Resources of the Malmkarst in the large South German Molasse Basin (1984–1989). The result of this research project was that the natural discharge of thermal water should be 1.5 m^3/s in the whole area, only.

Due to the increasing thermal water extractions in Bavaria and Austria, a new more detailed groundwater balance was necessary for the German-Austrian part of the whole large South German Molasse Basin. This has been done with the help of a sophisticated groundwater model.

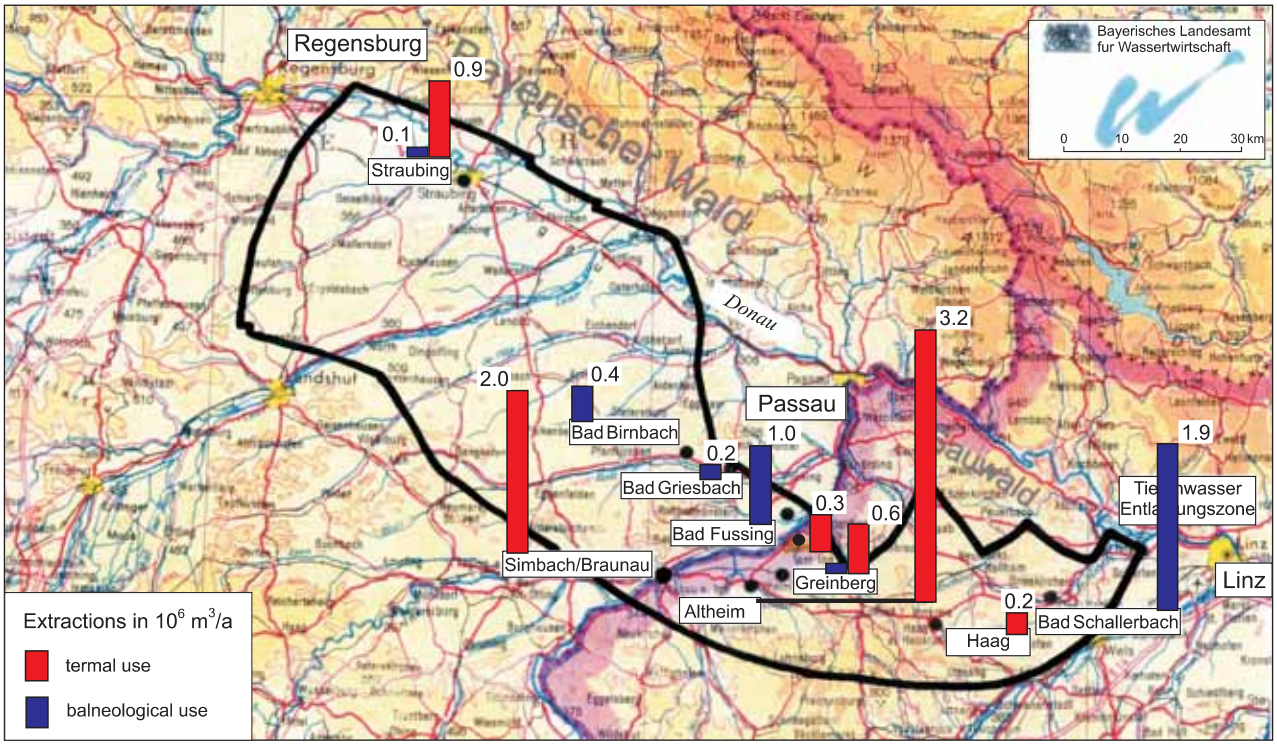

Fig. 1. Survey of the termal groundwater area with importent uses

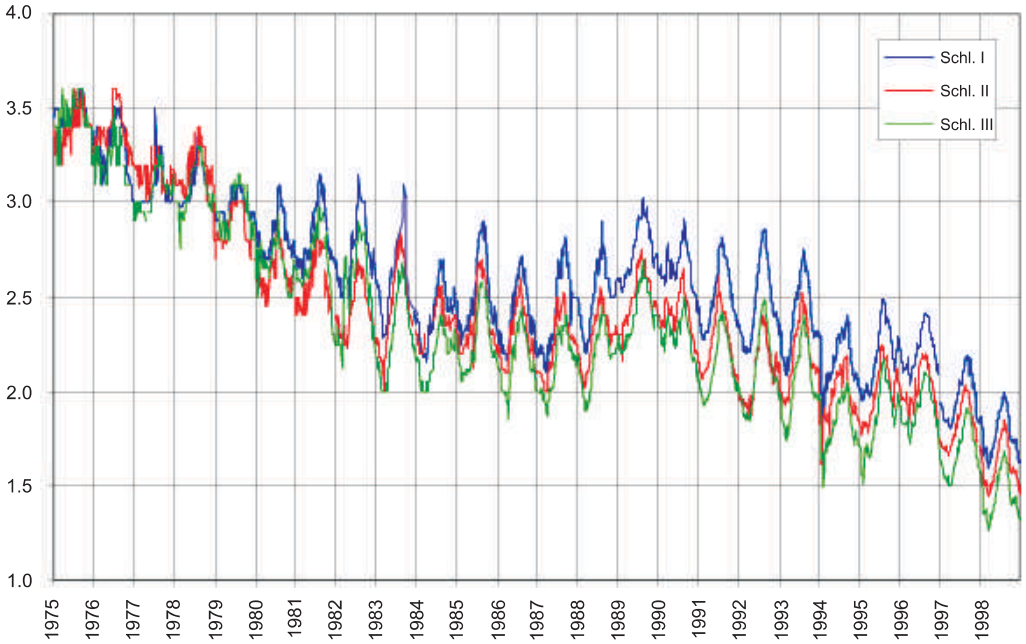

Fig. 2. Decreasing closing pressure in Bad Füssing

BILATERAL AGREEMENT GERMANY-AUSTRIA ON WATER MANAGEMENT

Since 1987, there exists a bilateral agreement called "Regensburg Treaty" for the transboundary water management questions between Germany and Austria. The Regensburg Treaty rules the water management cooperation in the Danube river catchment area, which is taken care of by the Permanent Water Commission. This Commission have installed, between others, an expert group "Tiefenwasser" (deep groundwater) to handle mutual questions of deep aquifers. This group was chosen to solve problems concerning the transboundary thermal groundwater body.

GROUNDWATER MODEL AND RESULTS

The above mentioned expert group decided to answer the questions with the help of a hydrological groundwater model. Besides the characterisation of the groundwater body and presentation of the flowing and discharge conditions in the body, this model should also be a relevant and useful instrument for the German and Austrian authorities to evaluate the required water extractions and the potential yield, under the consideration of other existing wells, on a reliable basis when licensing thermal water extractions. Taking particularly into account the required groundwater extractions in this area, forecasts were necessary for the future thermal groundwater management as well as an exact identification and description of the existing thermal water use.

The groundwater model area is presented on Figure 1, and extends from Regensburg and Landshut in the north, to Linz in the south. It is only a part of the South German Molasse Basin. The Danube river accompanies the eastern border for long distances. With a total area of 5,900 km^2, the groundwater body is 150 km long and 55 km wide.

The thermal water flows within the carbonatic Malm aquifer. The Malm (Upper Jurassic) crops up near Regensburg and dips towards the south. Near the Inn river, the top of the Malm rocks reaches a depth of about 2,000 m below sea level. From the Inn river to the east, they are ascending to Danube river, west of Linz, and are cut by important tectonic structures. A general flow direction of the thermal groundwater is from north-west to south-east. This result shows that the formerly assumed direction was wrong.

A data analysis shows also that the thermal water resources have different temperatures and different grades of mineralisation. The following balance elements had to be considered in the model:

— afflux (infiltration) from vertical groundwater recharge,
— afflux from lateral marginal inward flows,
— discharge from vertical exfiltration,
— extraction by wells,
— effusion (exfiltration) of groundwater into the Danube river.

The groundwater recharge is composed mainly of subterranean inward flow from the adjacent Bohemian Massif (530 l/s) — the deep groundwater in the crystalline of the Bavarian Wood (part of the Bohemian Massif) is under high pressure there — and from infiltration of precipitation in the northern part of the groundwater body area (260 l/s). In some areas, a certain vertical exfiltration into the overlying strata (confined

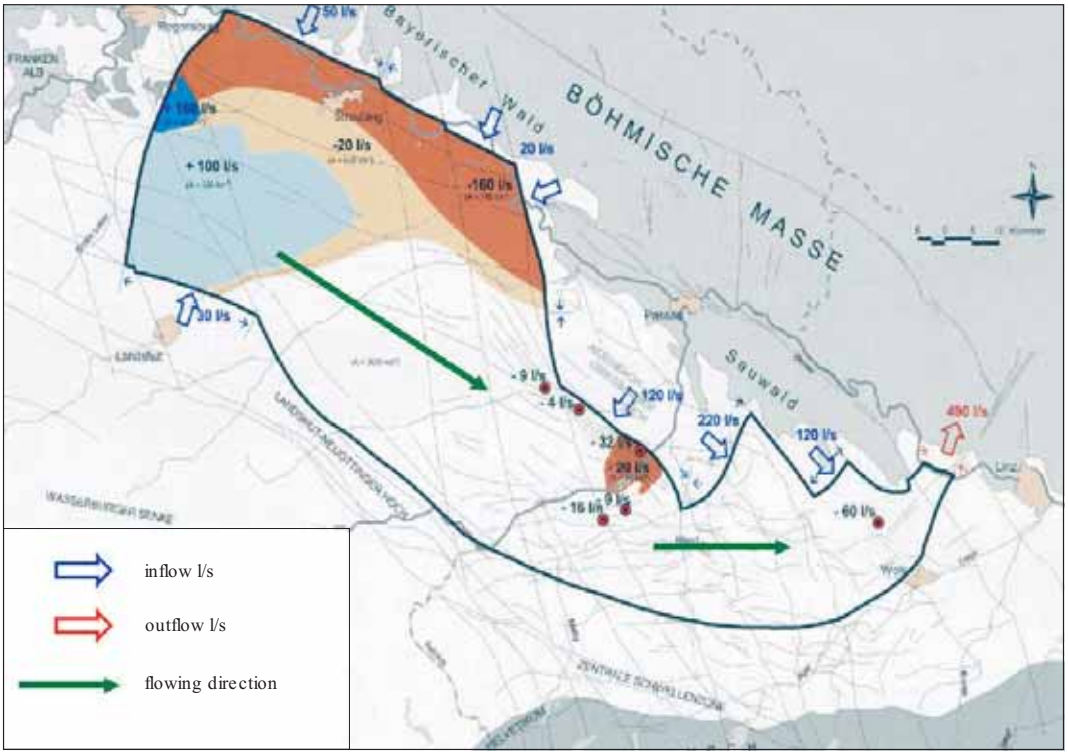

Fig. 3. Survey of water balances of the model area

groundwater!) is found (in total *c.*160 l/s). A considerable quantity of water leaks from the groundwater horizon into the Danube river, close to the city of Linz (490 l/s). The individual inputs and discharges are shown on Figure 3. All flows are given in this figure as the long-time average values.

THERMAL WATER FLOW MODEL

Based on the hydrological model and its results, a mathematical flow model was developed by German-Austrian cooperation with the help of a consultant. This model should have had the following abilities:

— simulate the natural flow conditions;
— improve the knowledge of deep groundwater systems;
— check the hydrological model on plausibility;
— make forecasts possible;
— assess the mutual influence of existing or future thermal water uses.

In order to describe the groundwater flow under the existing heterogeneous conditions, an adaptable two-dimensional final element calculation model was chosen using a programme developed by Kiraly, Centre d'Hydrogeologie, Université de Neuchatel (CH). The model contained 3,190 elements and 5,989 intersections. In the neighbourhood of spas and wells, the net was condensed diminishing its basic units from 15 km^2 in the border area to 0.04 km^2. Due to this, the model allowed for an excellent simulation of different water extraction and, if necessary, for configurations of reinjection.

The main results of the mathematic simulation are as follows:

— up to now, the overuse of the thermal water aquifer cannot be observed but further extractions for spa purposes are possible on a very small scale, only;
— effects of future uses can be forecasted with sufficient reliabilityt;
— the deep water with high salinity in the southern boundary area of the model can be mobilised;
— a total reinjection of hydrogeothermally used deep water is mandatory;
— the pressure conditions should be held stable as much as possible.

The groundwater model is a reliable instrument for the German and Austrian authorities to judge the required water extractions. It allows:

— to make up the balance of the groundwater resources in the Lower Bavarian–Upper Austrian Molasse Basin,
— to sufficiently quantify the groundwater recharge,
— to quantify possible effects on existing neighbouring wells.

The results of the carried out studies show clearly that further use of the thermal water resources will only be possible if the thermal water is used rationally, and the existing hydrostatic conditions will generally be preserved.

KEYNOTE PAPERS ON THE PRINCIPLES OF THE USE OF THERMAL WATERS IN THE BAVARIAN-AUSTRIAN MOLASSE BASIN

Taking into account the results of the thermal water flow model, a joint experts group worked out keynote papers, where joint protection and utilisation strategies were laid down in order to be able to manage the thermal water resources in both countries in a sustainable way and according to the best available technology. By this, an uniform transboundary approach will be assured.

The Permanent German-Austrian Water Commission, in accordance with the Regensburg Treaty, adopted the jointly elaborated keynote papers covering the following issues:

1. Thermal Water Management principles concerning thermal water use in quantitative and qualitative aspects.
   - The documented evidence of conformity in the thermal water demand to be used for spa or geothermal energy purposes is essential, as the proven demand is the basis of the authorised extraction. No surplus nor reserve quantities will be authorised.
   - A comprehensive protection of the thermal water resource is given top priority. Balneological use is preferred to the geothermal one. Balneologically used thermal water should, therefore, be used also for heating purposes.
2. Quantitative and qualitative capacities of the thermal water resources
   - In 1966, the degree of utilisation of thermal water with ca. 70 l/s, equivalent to 25% of the groundwater recharge, was already very high in the Western region balance. This led to the proven decreasing pressure in the spa Bad Füssing wells of about 30 m. It has been realised that reinjection of geothermally used water could reduced extractions to about 40 l/s and that pressure conditions could have been improved.
   - From this, it was concluded that the capacity limits were around 20 to 25% of the natural recharge for the whole survey area.
3. Dimensions of installations for thermal water use in spas and for thermal purposes.
   - Detailed information on construction and operating methods of the installations are given.
   - The determined limitations of water abstractions are obligatory for both sides (Austria and Germany) in order to protect the thermal water resources against overuse in a sustainable way.
4. Principles concerning the application, maintenance, and further development of the mathematical thermal water flow model.
5. Standardised application forms for groundwater extraction licences.
   - To ensure for both countries a homogenous uniform procedure.
6. Catalogue of requirements.
   - In order to ensure that uniform principles are applied when constructing and operating the installations and, in particular, when collecting and documenting data.
7. Exchange of relevant information and data as an efficient management of the thermal groundwater resources is possible only when both sides have the same status and level of information at any given time.

THE EUROPEAN WATER FRAMEWORK DIRECTIVE AND THE GERMAN-AUSTRIAN TRANSBOUNDARY GROUNDWATER BODY

The European Water Framework Directive (WFD) requires in annex II, 2.1 an initial characterisation of all groundwater bodies in the Member States of the European Union, to assess the degree to which they are at risk of failing to meet the objectives for each groundwater body under Article 4 WFD. For those groundwater bodies which have been identified as being at risk, a further characterisation is necessary. For those groundwater bodies which cross the boundaries between Member States, a review of the human activity impact on groundwater is required in annex II, 2.3. The risk assessment of this transboundary groundwater body can thus be resumed as follows:

Quantity. Within the framework of the Regensburg Treaty, hydrogeological and mathematical models for the groundwater recharge determination were established. It could be shown that there is no overuse any more. A common expert group worked out guidelines where joint protection and utilisation strategies were laid down. Thus, a sustainable use is assured. A good quantitative status will be maintained in 2015.

Quality. A good status is still existing because the confined deep groundwater is well protected by thick overlying layers (several hundred meters up to 1,000 m thick Tertiary and Cretaceous sediments), and reaches an age up to more than 1,000 years. Therefore, the thermal water is well protected from civilisation pollutants.

The thermal water is used by water extractions for spa purposes and reinjections for geothermal use, only. Except for the decreased temperature, the reinjected thermal water is of the same quality as the extracted water. There is no other use that might have caused groundwater contamination. So, there is no risk that groundwater will be contaminated if sufficient care is taken for the reinjections.

The thermal water users/operators of geothermal plants have to carry out inspections to provide information on the thermal water quality. Annually, they have to report chemical values of the thermal water, and every 5 years they have to provide authorities with an expert opinion on the changes of the thermal water quality. Therefore, possible changes in the chemistry of the ther-

mal water can be observed/detected early. Anthropogenic pollution excluded, changes in quality can be caused by geogenic processes, only, depending on water extraction. So far, no significant changes of chemical values have occurred.

The groundwater body is, thus, well protected and there are no uses with a risk of groundwater pollution. So, the groundwater body is not and will not be at risk.

Monitoring. According to annex V. 2.4.2 WFD, transboundary groundwater bodies shall also be monitored for those parameters which are relevant for the protection of all the uses supported by the groundwater flow.

As temperature is one of the most important parameters for the intended uses, the Permanent Water Commission

(Regensburg Treaty) decided that the thermal effects of thermal water uses should be investigated in the central and border area where the majority of the uses takes place. The Commission recommended to initiate this project within the Interreg III A programme, financed by the European Union. The project will start in 2005.

Impact of human activities on the groundwater. The two accomplished models and the planned project answer sufficiently on the impact of human activities on the groundwater.

CONCLUSIONS

The success of the groundwater model, and good results of the expert group work have finally shown that the both sides — German and Austrian — join efforts were worthwhile. The most important results are the excellent cooperation and the exchange of information between the Bavarian and Austrian authorities, and the gained knowledge that reinjection of thermal water for geothermal use is mandatory in order to avoid a decreasing closing pressure of the thermal water wells in spas. Finally, the last Figure 4 shows that since 1999, the closing pressure is again increasing in this transboundary groundwater body due to a sustainable management of the groundwater resources.

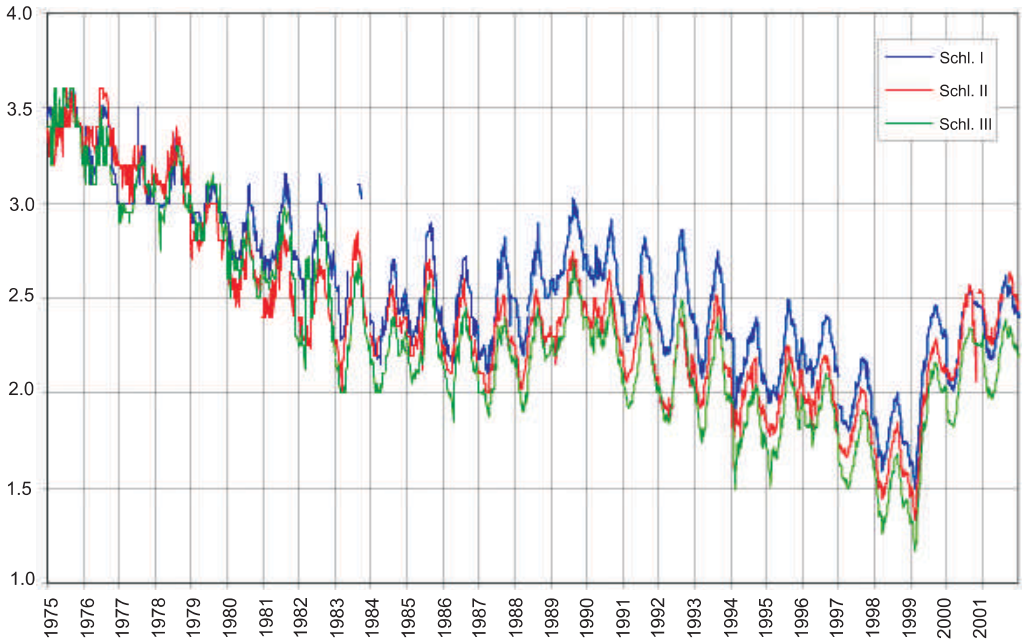

Fig. 4. Increasing closing pressure in Bad Füssing since 1999

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