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Ecological aspects of groundwater development in the mountain regions of Slovakia

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Abstract. The water management development of groundwater resources in some mountain regions of Slovakia either reaches full capacity of their yield (in the case of natural groundwater output from springs) or by development through hydrogeological boreholes by pumping there takes place an excessive groundwater development relative to the recharg of an aquifer. In the case of deep weels is the effect of pumping observabled on the natural groundwater outputs from springs that are located in the same hydrogeological structure.In all cases this anthropogenic effect has a negative impact on the ecology of the landscape. In this paper we propose a way of decreasing the negative effect on the environment through water management by implementation of ecological and anti-devastation limits of the groundwater resources development. This concept is the first proposal aimed at the hydroecological protection of Slovakia in relation to the grounwater development.

Keywords: development of groundwater, overdeveloped groundwater resources, water management, ecological limits, antidevastation limits.

Introduction

The groundwater in the mountain regions present an important part of the total groundwater potential in Slovakia. The groundwater related to Pre-Neogene formations and Neogene volcanic rocks of mountains represent 59.5 - 85.6 $m^3.s^{-1}$ (CITEC S.A., 1997) from the total natural groundwater resources in Slovakia, in amount 101.3 - 127.4 $m^3.s^{-1}$. It is 58.7 - 67.2 % of the total sum of the natural groundwater resources in the mountain regions of Slovakia.

For many decades the water management development of the groundwater resources in Slovakia was for many decades oriented toward obtaining the maximum amount of exploitable groundwater, regardless to ecological aspects of their development. In recent years the transformation of national economy has brought about a change in this objective in that the groundwater resource is viewed as a long-term sustainable commodity. The ecological effect of the groundwater development on environment was not assessed untill 1993. This assessment led to the first proposal of hydroecological restrictions on groundwater development with an aim to ensure at least a compromise for the hydroecological protection of all parts of Slovakia (Kullman Sen. & Kullman Jr. et al.,1993). The present paper presents a summary of our proposals and water management recommendations which would significantly decrese the negative ecological impact , althought they would not eliminate it.

The water management groundwaters development has undoubtly a negative effect on ecology of landscape inasmuch as it presents an artificial interference with its hydrological regime. The need for an assessment of these anthropogenic interferences with the ecological conditions comes at a time when major water users, and water managers are becoming aware of the negative impacts on the hydrological and landscape-forming processes. We must learn to accept the water resources as a part of the natural environment and that water resource development must be viewed then define ecological effects only as clashes between respecting of ecological laws in changes of original natural environment properties for new, more suitable for the resource development needs.

The assessment of the effects of resources development and groundwater availability, and the setting of ecological limits of development presents a multidisciplinary problem. This presentation is a summary of our initial hydrologico-hydrogeological study of the problem and our initial recommendation. The consequent ecological limits will have to be the consolidation of other interdiscipilinary recommendations (biologists, zoologists etc.). On the other hand, we must be aware of future acceptable value of the groundwater development and the only value realizable in operation during the addaptation phase will present a compromise between exploitable amount decreased by recommended value of ecological discharge and possibilities of the economy to solve the open problems connecting with the deficit of groundwater amount mainly in the water supply system.

The ensuring of ecological acceptable development of groundwater is getting into foreground in Slovakia mainly in the periods:

- summer - autumn (August - October) characterized by low precipitation and large evaporation.
- winter - spring (December - March) characterized by low evaporation due to low temperature. Precipitation during this period is in the mountains in the solid state and so does not contribute to either surface and groundwater discharges.

Particularly during these periods when there is general decrease of water availability, the actual groundwater development very often decreases under calculated long-term demanded ensurance (generally mentioned as Q 80 % of the probability curve) as the state standard for water management planing. The aplication of ecological groundwaters development limits, particularly in these deficit periods will be the most pressing question. We must be aware of an ecological limit (no matter how moderate stated) that will be used into operation always unambiguously reduces existing potential of groundwater resources for water management and increase already strained state between possibilities and needs of water for water management in deficit regions of Slovakia (Figure 1).

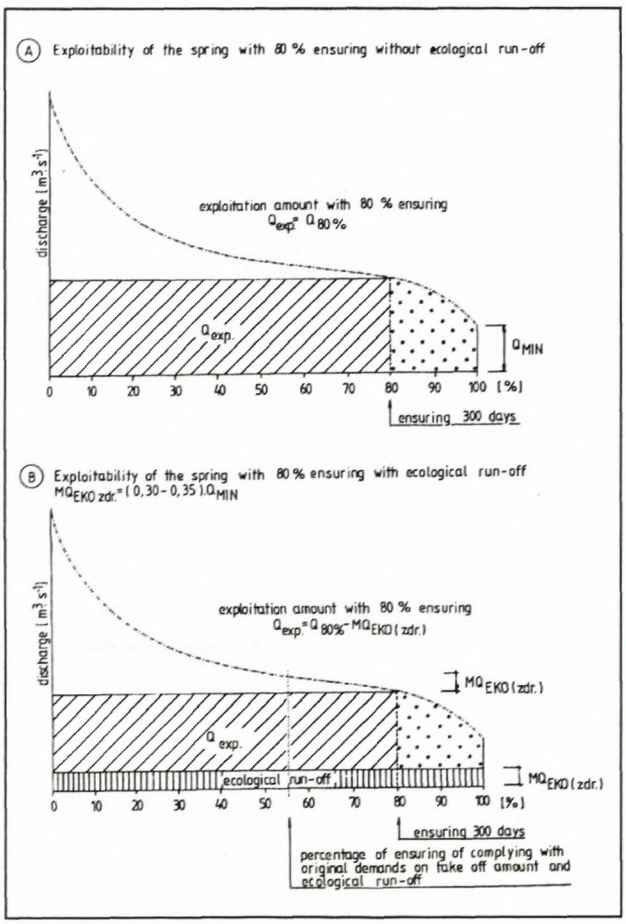

Fig. 1 Comparison of exploitability of the spring groundwaters with 80 % ensuring with and without ecological run-off

Concept of the ecological limits assessment in the groundwater development

Our proposal of the ecological limits assessment in groundwater development is based on a primary assumption of ensuring the general ecological protection of the territory being evaluated - global limit (i.e. the relation between the sum of the exploitable groundwater resource amounts and ecology in the estimated region), as well as following detailed assessment of individual exploitable groundwater resources related to ecology - local limit. With these aims in mind the ecological protection of the groundwater resources development was divided into three parts:

- Proposal and ensuring of compliance with *global ecological limit* (MQ_{EKO}) in the development of all resources in the evaluated territory as a whole, which cannot be mistaken for the MQ (minimum balance discharge, presenting compliance with conditions for normal, biological life in stream and its adjacent area). The global ecological limit of the catchment has an aim to preserve the catchment area as a whole.
- Proposal, assesment and ensuring of compliance with ecological limits of individual water management exploited water resources ($MQ_{EKO(zdr.)}$). The main aims of these *local ecological limits* are both to ensure the maintenance of of local hydroecological conditions of groundwater development on the each groundwater sources, and on the other hand ensuring of global ecological limits for whole area.
- Detailed assessment of mutual effecting of exploited water resources, resp. possible impact of exploited groundwater resources (by pumping from boreholes) on natural groundwater outputs (springs), as well as on groundwater levels within the framework of evaluated territory - *anti-devastation limits.*

Methods of estimating of global ecological limits in the groundwater development of the evaluated territory

Utilizable groundwater amounts (utilizable resources + utilizable reserves) present the part of natural resources and groundwater supplies which can be exploited by water management with existing technical potential. Utilizable groundwater resources represent the dynamically renewable part of exploitable groundwater amounts where, with their appropriate determination do not take place overdevelopment of the waters of hydrogeological structure take, resp. their parts, or certain aquifer in relation to exploited water resource, resp. a group of resources. Exploitable groundwater amounts determined in such way, are on average lower, or at least the same, as utilizable groundwater resource. They have a sustainable character of development. Unregulated groundwater development exceeding such determined value has a negative impact because it reduces the groundwater resources yields. The exploitable amounts exceeding recommended resource yield then are overestimated by static groundwater reserves. Anyway, exhausted static groundwater reserves, in the final stage will cause a decrease of an exploitable component of water resource under recommended value. There will be also significantly changed rainfall-runoff conditions of the territory because effective precipitation in the first phase ensure recharging of the static reserves to the detriment of dynamic component. This phenomenon must be unambiguously demonstrated on discharges decrease of the surface waters discharging an evaluated territory because a reduction of the underground component of runoff will take place.

During dry periods with little precipitation surface water is much dependant on recharging from groundwater supplies. This means that it is possible to assess a degree of over-development of the groundwaters by the quantification of a certain minimum discharge in the surface flow in the determine profile on the river (close profile measuring the discharge of surface water of evaluated territory).

Ecologically evaluated territories are limited by watershed contour lines and present subcatchments or partial catchments of water flows. Limiting element will be given by hydrographic watershed contour lines, only in well-founded cases also hydrogeological watershed contour lines can be used.

By summarization of foreign and national knowledge in the given sphere, with taking into account relative simple and in water management operation applicable limit value, we proposed the value, under which a natural discharge on surface flow in close profile of evaluated catchment could not decrease (subcatchments, partial catchments) - value $MQ_{EKO} = (0,65 - 0,70).Q_{(364)}$. This discharge should be ensuring a biological life in rivers on the capacity limit and also in case that the discharge of the surface flow decreases under this value its dokument an exceeding groundwater development within an evaluated catchment. Value will present a global ecological limit, as critical - threshold value of discharge which will have to be unconditionally preserve by appropriate operating of water management groundwater abstraction facilities within evaluated catchment belonging to evaluated, close profile.

Effect of surface water quality worsening and following MQ_{EKO} correction are not solved in this methodics, because mixing processes in flows classified in III and IV class of purity must be taken into account in more details. In taking into account of these quantitative properties of the surface waters a correction of proposed coefficient 0,65 - 0,70 upwards unambiguously must take place.

Methodics of assessemnt of the local ecological limits of individual important water management exploited groundwater resources

Although global ecological limit and its balancing with discharge on the surface flow indicates an excessive development of the groundwaters endangering an ecosystem of landscape, indicates it for the whole catchment, resp.subcatchment relating to close profile. Limit to a considerable extent presents an average of negative anthropogenic effects of water managers, but discharges over this stated limit in close profile (resp. profiles) do not give us the guarantee that local ecological devastation does not take place in regions of individual water resources, resp. in individual parts of an evaluated territory. An assessment of an extent of effect of the surface water take-off effect on individual water management important water resources individually, i.e. determination of local ecological limits of the exploited groundwater resources ($MQ_{EKO\ (zdr.)}$) must be an inseperable part of solution.

Effect of the groundwater development on the ecology of landscape differs in dependence on retaining variant, and because of this the methodics of local ecologicl limits determination is divided into two parts:

a) determination of local ecological limits of water resources retaining natural groundwater outputs - springs.

b) determination of local ecological limits of water resources retaining the groundwaters by hydrogeological boreholes.

Determination of local ecological limits of water resources retaining natural groundwater outputs

An extent of natural groundwater outputs development in form of springs is finaly presented by relation between retained groundwaters amount for water management and unaffected component which run off free and present a landscape-forming and ecological element. Sum of these values in time corresponds with the total yield of the spring.

Local ecological limit so presents determination of this natural run-off groundwater output anthropogenicly uneffected. Present discussions on size of this limit are mostly oriented on asserting of minimum yield of spring, sometimes till Q_{355} of spring, presenting a guaranteed natural groundwater run-off which must be predominantly unaffected in development. It is explained by statement that this discharge presents in the natural spring regime an absolute minimum, resp. value close to minimum, and in nature occurs independently on anthropogenic effect. This theory is understandable but in actual operation unaccepted because it would lower an exploitable groundwater resources amount, even would eliminate the groundwater resources from development on during a certain period in case their yield decrease under Q_{355}.

With regard to compromise solution, it is recommended to determine $MQ_{EKO\ (zdr.)}$ as natural groundwater run-off from springs in development, equal to $(0,30 - 0,35).Q_{MIN}$ spring, which must run off 50m downstream from the groundwater abstraction poin. If the spring is closer than 50m from surface flow with sufficient discharge (adherence to MQ_{EKO}), spring can be absolutely exploitable (exploitability 100 %). Q_{MIN} of spring presents a minimum documented yield of spring.

Local ecological limit 0,10 $l.s^{-1}$ is recommended to be determined for springs with $Q_{MIN} \leq 0,35\ l.s^{-1}$.

It is possible to discuss a suitability of such determined coefficient with round-the-year validity, regardless of for instance seasonal component of run-off. But an endeavour in proposing local ecological limit was to find out a way which on one hand will respect ecological criteria and at the same time will be actually applicable in water management operation. During the year, changing local ecological resourse limits (for instance in dependence on yield of resource) will certainly better correspond with natural conditions but they demand unactual, regular technical inspection at the groundwater abstraction facilities, resp. take-off and effluent amounts of groundwater must be supported by technical tools of automated

changes. Technical ensuring of round-the-year observed local ecological limit (0,30 - 0,35). Q_{MIN} could be solved by simple locating of pipe with precisely determined profile in connection on determined discharge (local ecological limit) in the lower part of the guiten storage box directly in the development point of the spring. Free groundwater run-off ensured in such way would ensure with a sufficient accuracy an observing of local ecological limit of exploited groundwater resources and significantly would mitigate negative, an absolute groundwater resources development.

Determination of local ecological limits of water resources exploited by hydrogeological boreholes

The main limitation factors of these groundwater resources is such state of the ground-water changes course in time at the territory of development (such course of depression cone creating) which allows an optimum groundwater resources development (with possible connecting of regulating groundwater resources! without lasting and significant quantitative disturbance of accumulated groundwater resources. In these territories it is possible to determine level ecological limits for development, ensuring at least compromise hydro-ecological conditions. Under such conditions, it is obvious that effect of the groundwater development must be in accordance with global ecological limits (with MQ_{EKO}).

Anti-devastation groundwater development limits of hydrogeological structures exploited by hydrogeological boreholes

In the groundwater development by hydrological boreholes in the mountains of Slovakia there take place two ways of their devastation due to oversized, resp. unsuitable development. They are as follows:

- Lasting oversized groundwater development in relation to their recharging.
- The groundwater development by pumping from predominantly deep hydrogeological bore holes negatively effecting both exploited and unexploited spring waters.

In both cases this groundwater development has also an important effect on hydroecology of the corresponding territories. At least compromise proposals limiting development in the mentioned cases and being included among protecting hydroecological measures we have summarized under a general title: anti-devastation groundwater development limits. It is quite possible that more truthful term for these limitations will be proposed and introduced into operation for these limitations in future.

Oversized groundwater development in relation to their recharging

A significant part of the groundwater development has to a disposal certain groundwater resource amounts (dynamic component) and a certain volume of accumulated groundwater reserves. A function of the groundwater resources transformation on groundwater reserves and reverse the groundwater reserves on groundwater resources is ensured by regulating reserves, being changing in time. The groundwater level change is a reflection of a regulation effect of regulating groundwater reserves (level fluctuation between minimum and maximum). The groundwater reserves which are under minimum groundwater level (static reserves in quantitative sense) do not contribute to this process without anthropogenic effecting (without oversized water development). With lasting development of the static groundwater reserves there take place their discharging which is demonstrated by permanent groundwater levels decrease and at the same time by quantitative water devastation of hydrogeological structure and negative effects on ecology in result of large groundwater level decreases.

From this point of view (as we mentioned it with an ecological limits) at the territory of the groundwater development a limiting was a such state of the groundwater levels course (such course of the drawdown curve creating) which allows an optimum groundwater withdrawal, with connecting of the regulating groundwater reserves but without more significant, and mainly without more lasting quantitative disturbance of the static groundwater reserves. Under such conditions of the groundwater explotation, an effect on ecology is still acceptable in most cases.

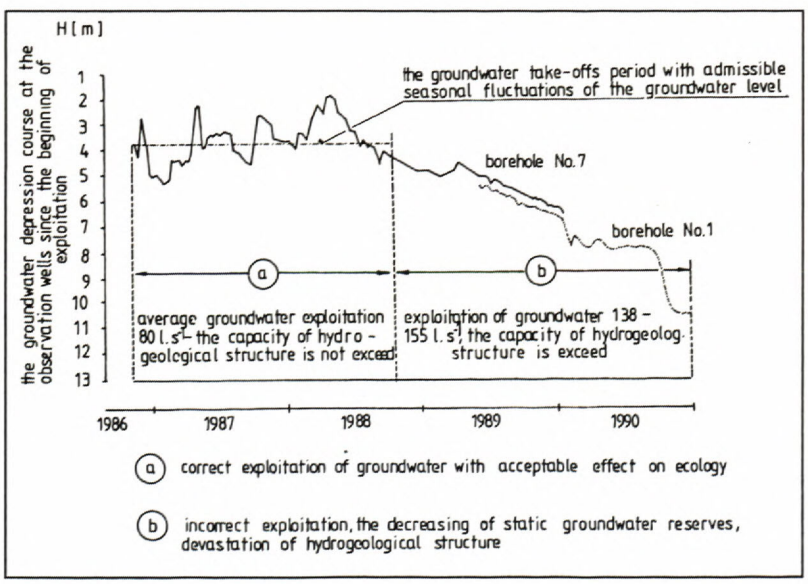

Fig. 2 An example of the quantitave groudwater course devastation due to oversized grpounwater take-off with result of systematic continued groundwater levels decrease and widespread negative effects on ecology of the region since 1988

We demonstrate this problematics on a concrete case of a quantitative groundwater devastation of the hydrogeological structure of the Čachtické Karpaty Mts. with the groundwater devastation in the locality Štvrtok nad Váhom (Figure 2). In this region, there took place a significant lasting decrease of the groundwater levels, the drainage of an extent territory and significant resulting ecological changes due to an oversized groundwater devastation.

For ensuring at least compromise ecological conditions of the groundwater development and their ensuring in such cases an inevitable seems to be a monitoring system as well as its running evaluation and based on its results a regulation of the groundwater withdrawal. As a suitable way of monitoring we assume:

1) Ensuring of systematic groundwater level measurements together with systematic measurement of the groundwater withdrawal amounts at the observation boreholes at the territory being exploited.

2) Ensuring of the systematic groundwater level measurement on 1-2 correlated observation bore holes outside the territory effected by the groundwaters development.

3) Running assessment of the groundwater level measurements in the course of development with an aim to identify inhomogeneity parameters in the exploited locality by confrontation with results of running groundwater level measurements in correlated observation boreholes. In this evaluation a method of double mass curve was proved.

Groundwater development by pumping from predominantly deep hydrogeological boreholes negatively effecting exploited and unexploited springs

Significant factors disturbing a hydrogeological balance seems to be new trends of important groundwater amounts exploited by hydrogeological boreholes in Pre-Quarternary rocks (mainly water-bearing Mesozoic and Paleogene sediments overlapped by impermeable Neogene and Paleogene sediments) in lowlands, hollows and intermountain flows. This up to day ways of the groundwaters development by hydrogeological boreholes reduce yields of the springs and are of a great negative

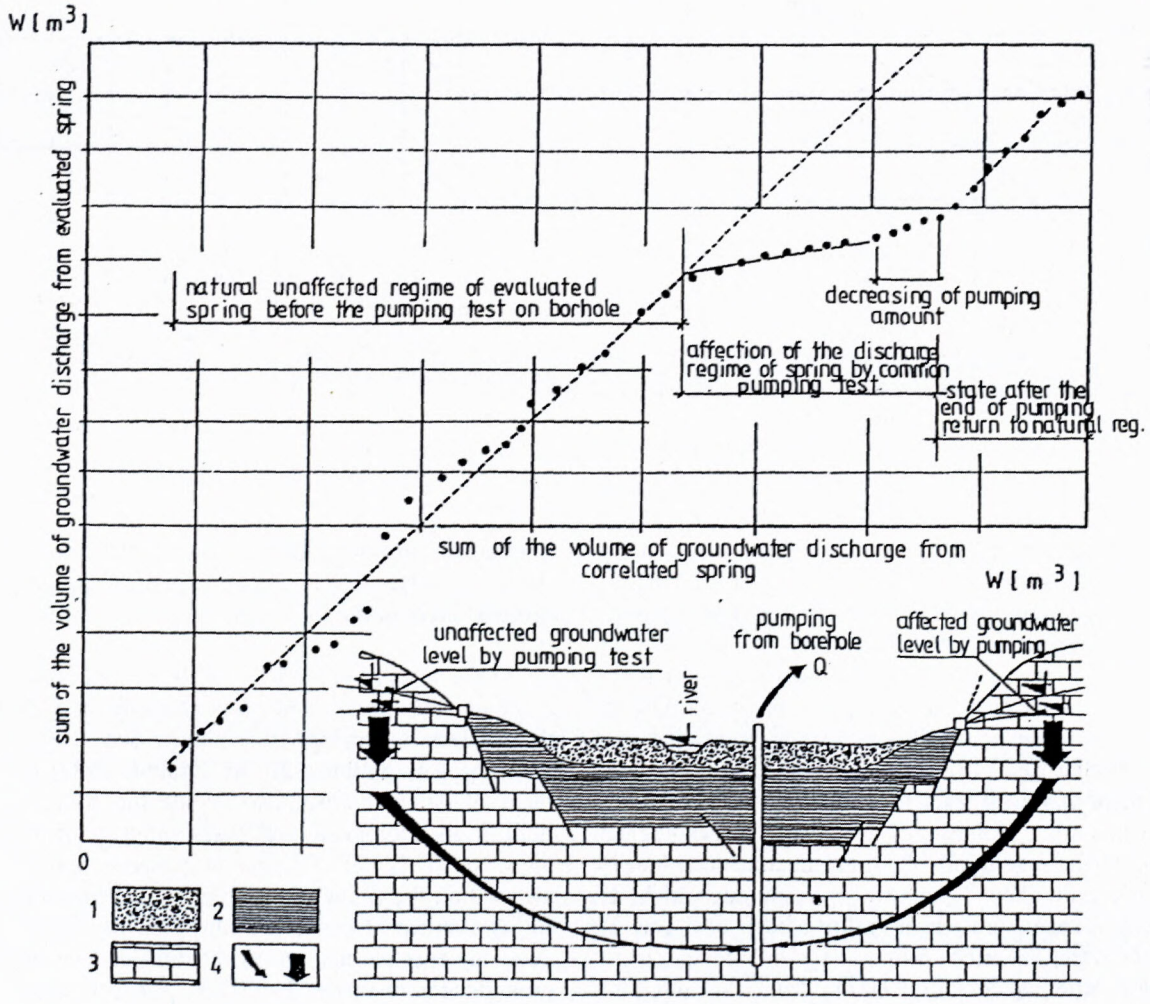

Fig. 3 Scheme of anthropogenic quantitative affection of the springs by exploitation of hydrogeological boreholes and its evaluation of double volumes method

1 – Quaternary sediments with groundwater without hydraulic relation with deeper aquifer; 2 – Impervious layers; 3 – Aquifer (dominantly Mesozoic or Paleogene); 4 – The direction of groundwater flow and the decreasing course of groundwater level in the spring area during the exploitation of the hydrogeological boreholes

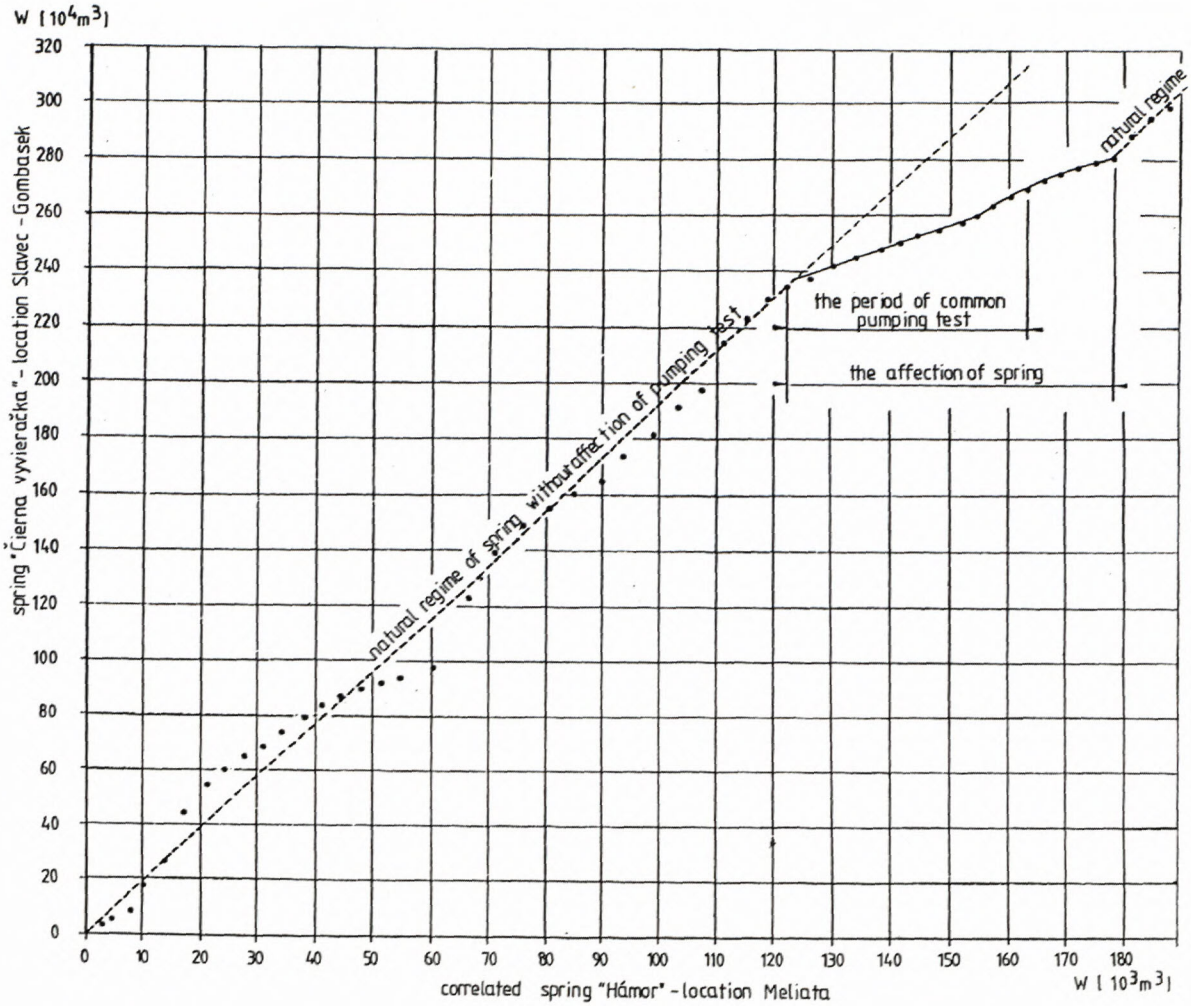

Fig. 4 The affection of discharge of the spring „Čierna vyvieračka" (Slavec - Gombasek, Slovenský kras, Mts.) by common pumping test on the hydrogeological boreholes GP-1, GP-1a, GP-2, GP-3, AK-15 the relation: spring „Čierna vyvieračka - spring Hámor", hydrogeological year 1991

effect on both exploited and unexploited springs. Very serious danger of this effecting for ecology as well as for exploited groundwater resources for springs consists mainly in masked seasonal variability of the yield of springs. From the water management point of view these effects have a tendency to lower yields of springs, to change a character of stable springs for occasional one and in extreme cases lead even to their end. From ecological point of view it leads to draining of foot of slopes and with this connected negative hydroecological changes. In these solutions there are documented "new", significant exploitable groundwater resources which, in predominant cases, present in reality a shift of a part of the groundwater resources from springs into development boreholes. Effectiveness of solution from this point of view is not assessed. From the water management point of view and from the point of view of groundwater resources expressed in numbers they bring a chaos into general evaluation of the groundwater amounts because verified groundwater yields at the development boreholes have been summarized with documented exploitable yields of uneffected springs (based on their long-term permanent measurements), i.e. in facts, a part of the exploitable groundwaters in the hydrogeological structure is assumed twice.

In the recent years there has been successfully applicated an appropriate methodics allowing an evaluation of these effects on springs (E. Kullman Sen., 1992, E. Kullman Sen. - E. Kullman Jr., M. Drahoš, 1992) and on the basis of obtained results to decide the suitable variant, both from ecological and water management point of view, too. This methodics we proposed to applicate again also within the framework of ecological limits evaluation for assessment of negative anthropogenic effects of these developments on ecology of territory and on exploitable groundwater resource decreases. The proposed statistic method of double volumes (la methode de doubles mases) follows a basic principle that yield of the effected spring substantially depends mainly on two factors: climatic factor and factor of effecting, i.e. anthropogenic factor. Method allows to separate an effect of climatic factor and subsequently to evaluate an anthropogenic factor effect in

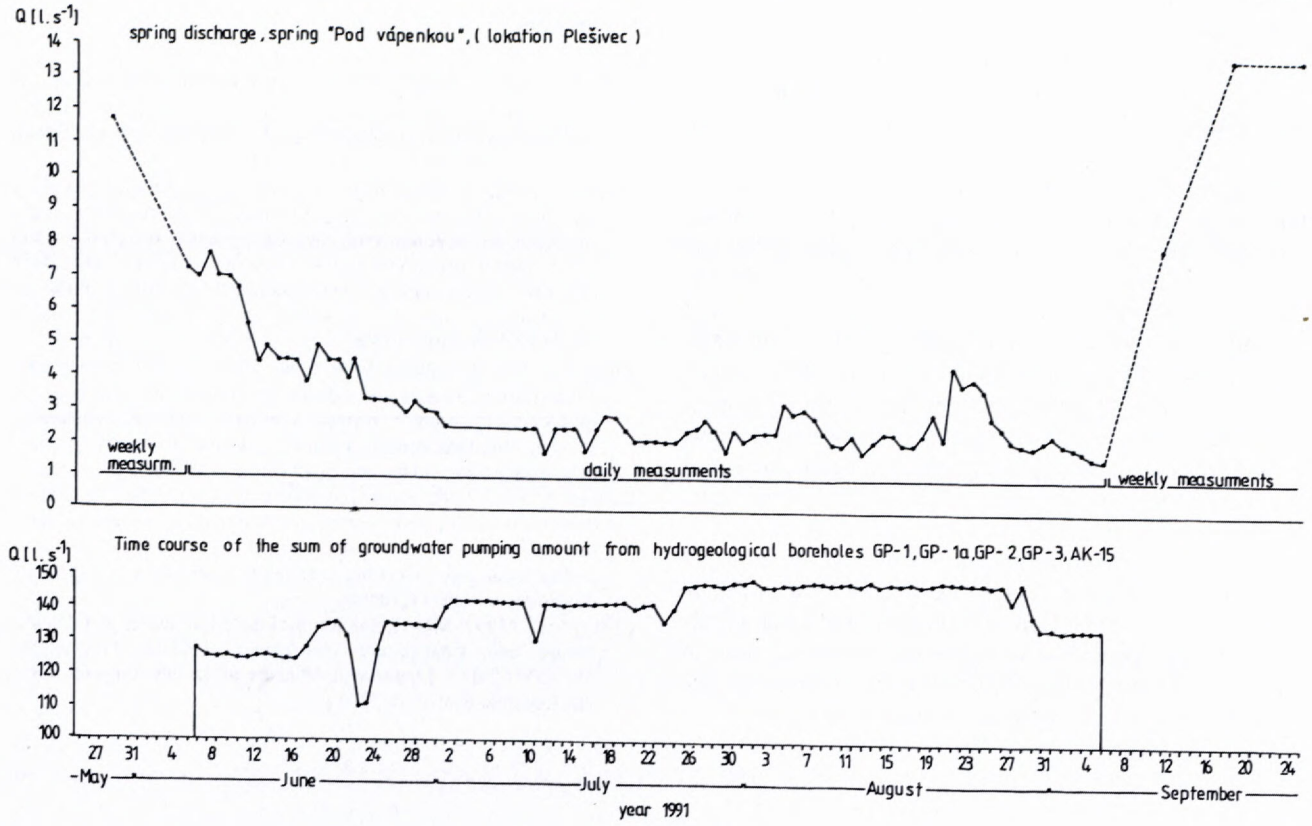

Fig. 5 The impact of collective pumping test from the hydrogeological boreholes GP-1, GP-2, GP-3, AK-15 on the groundwater discharge of the spring „Pod vápenkou", Plešivec in Slaná valley

time - i.e. a quantitative effect of the groundwater pumping from hydrogeological boreholes on yield of a spring during the pumping test as well as after it till the balanced state. The same is also valid in evaluation of the permanent groundwater development on yield of a spring.

For monitoring there are necessary:

- Permanent measurements of yield of springs which are assumed to be effected by pumping from hydrogeological boreholes namely in sufficient advance, before, during and after the pumping test finishing.
- Permanent measurements of 1-2 correlated springs in evaluated region for the corresponding time period, at which a possibility of the pumping test effecting is eliminated based on geological and hydrogeological conditions.
- This monitoring should take place in a course of survey,as well as in the course of the groundwater development.

Till to now obtained results of concrete solution seems to be alarm ones. There are documented 30 - 80 % decreases of the yield of springs and impacts within 9,20 km.

Methodics and results are illustrated on Figure 3 documenting in more details described methodics as well as concrete situation in the mountain region Slovenský kras Mts. as well as the hydrogeological section from the water management point of view. Concrete evaluation results of the effecting of important karst spring "Čierna vyvieračka" in Slovenský kras Mts. by common pumping test at 5 hydrogeological boreholes pumping groundwaters from Mesozoic carbonates in bedrock of impermeable Neogene sediments in the Slaná river valley is illustrated on Figures 4 and 5. That is why we propose, within the framework of hydrogeological surveys for ensuring of new exploitable groundwater resources in Pre-Quarternary rocks by hydrogeological boreholes to solve also this problematics aimed mainly on ecological and water management effects on groundwater resources of important springs in an evaluated hydrogeological structure and in such way to state maximum exploitable groundwater amount from exploited hydrogeological boreholes.

A complete elimination of these negative factors effect is very difficult till unreal mainly in result of effecting on long distance, uncontrolled effecting of unmeasured springs and groundwater transfer into surface waters. With regard to ecology, also in these cases became clear a necessity of a complex evaluation via ensuring at least of compromise anti - devastation limits in cooperation with global and local ecological development limits.

Conclusion

In this paper a summary of a complex proposal of hydrecological limits in the groundwater development in the mountain regions of Slovakia is presented. It is the first study aimed on areal hydroecological protection of the territory in relation to the groundwater development. An aim of autors was to present hydrologico-hydrogeological

examination and elaboration of methodics allowing in admissible extent to limit, but not entirely to prevent, negative ecological impacts caused by water management groundwater development. Application evaluation in many pilot territories of Slovakia (in catchment of the upper flow of the river Nitra and others) demonstrated the possibility of practical application of the proposed methodic procedures for ecological protection of the territory. A possible way of a complex evaluation of the exploited groundwater resources with resulting assesment of suitability of existing water management groundwater development of individual resources in mountain regions of Slovakia was suggested. At the same time a prospective proposal of quantitative change of exploited amounts with regard to decreasing of negative ecological impact of these anthropogenic activities would be also at the same time a part of assessment.

Although values of ecological limits proposed in paper by authors could be in future qualified and elaborated in more details, the basic idea of ecological protection of territory and its application to operation is the only way of limitation of future lasting devastation of environment due to human effect on groundwater resources and reserves.

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