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Extended Abstracts

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Evaluation and management of groundwater — sustainable exploitation

title: **Factors of stability of hydrogeological systems to an exhaustion and pollution**

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Problems of system sustainability assessment and prediction of system behavior on the basis of this fundamental feature are studied in many fields of knowledge - mechanics, economics, ecology, etc. However, the mechanical placement of both the concept of sustainability and the methodology and research techniques of this feature on the hydrogeological systems (HGS) faces some difficulties.

Being the most active component of the groundwater natural resources subsurface runoff into rivers first of all determines the hydrodynamic stability of the HGS parameters and serves as a reliable indicator concerning the different types of negative processes. This component of the groundwater natural resources is the subject of the largest industrial transformations. For example, the balance between recharge amount through the infiltration of atmospheric moisture (n·10-2 ÷ n·10l/s · km2) and discharge (0 ÷ n·10) indirectly points at the massive opportunities (almost two orders of magnitude) of the HGS regulating reservoir and therefore their resistance to humidity changes of the saturated zone in the multi-year perspective. In such a way the feeding groundwater discharge (inflow or outflow) on the basis of natural resources assessments could become essential regional empirical basis, which could allow evaluating many types of stability and, therefore, reasonably regulating the development pressure on the underground hydrosphere.

Hydrodynamic stability (resistance to depletion) is determined by criteria: a) the balance between natural resources and volume of extracted water; b) identifying the extent of the depression cones, combination of local conical depressions into a single broad zone of depression which can to be ministerial to the active flux and accumulation of pollutants.

Asynchronous recharge and discharge changing is due to the inertial features of HGS and is determined by the rate of water exchange of the hydrogeological structures. This is the kind of characteristic of the dynamic component of groundwater resources, which also characterizes the stability of HGS and its elements. But on a regional scale this index is more a function of the system heterogeneous structure. It follows an important conclusion that the hydrodynamic stability of system of water-bearing strata is provided exactly by the water exchange.

Taking into account the hydrogeological conditions of formation of natural groundwater resources (Qn.r.), subsurface runoff (Qs.r.) and subsurface runoff into rivers (Qs.r.r.) are classified areas (hydro-geological structures), according to which we classified to stable HGS those systems in which there is approximately the same ratio of the listed above categories of groundwater resources.

- The most stable categories of HGS (Qn.r.≈ Qs.r.≈ Qs.r.r.) are formed within the closed bailing structures - mold, synclines, troughs, arrays, sediments, which are deeply cut by river valleys. Aquifers are not separated from the rivers by the impermeable sediments. Matured confining layer prevents the outflow of groundwater in the underlying horizons. Such conditions create the preconditions for an active (perfect) hydrodynamic connection of groundwater with rivers, conducive environment of lateral percolation to river valleys and, consequently, the active water exchange. Because of the evaporation and transpiration the discharge of the groundwater is absent or it is very small in relation to the large capacity of the aeration zone.
- Relatively stable HGS (Qn.r≈ Qs.r. >Qs.r.r.) are formed within the uplands which are dissected by river valleys; aquifers are separated from rivers by impermeable sediments and can be extended beyond the selected system (drainage area). Confining layer has disconti-

nuous character, which determines the possibility of groundwater infiltration into the lower horizons taking into account the respective free surface elevations and piezometric heads. Evaporation and transpiration are practically absent, side outflow is possible.

- Weakly stable HGS (Qn.r.> Qs.r.> Qs.r.r.) are inclined to dissected broad river valleys, which are swamped in whole or in part, which have weakly expressed hydraulic connection because of the drains imperfections and high resistance of channel alluviations, with the heterogeneous nature of the cut. The role of evaporation and transpiration increases from the slopes of the rivers to floodplains. Lateral outflow may be significant, that affects the parameters of the underground runoff into rivers.
- Unstable HGS (Qn.r.> Qs.r. >> Qs.r.r.) developed within the flat or slightly hilly topography, which is slightly dissected by river valleys partially or completely swamped, with a weak hydraulic connection because of the high channel resistance and the drains imperfection; heterogeneous nature of the cut is partially drained, leading to low rates of water exchange system in the whole. The main types of discharge except Qs.f.r. are evaporation, transpiration and outflow in other systems or underlying horizons.
- Highly unstable HGS (Qn.r.> Qs.r≈ Qs.r.r.) are created within the dissected topography within the dividing areas; there is the development of impermeable sediments which are drained by narrow valleys with close almost perfect hydraulic connection. At divides the main types of discharge are evaporation and transpiration in relation to the small thickness of the aeration zone and the development of permafrost; there are the limited quantities of underground runoff into rivers in the river valleys.
- Critically unstable HGS (Qn.r.>> Qs.r.> Qs.r.r.) predominate in the plain conditions of the topography, it has weakly expressed valleys and vast territories are intensivly swamped, which is connected with the development of impermeable sediments and in the riverine areas, which prevent active groundwater discharge into rivers. Impermeable sediments can be caused by ground-freezing processes.

In light of the above-mentioned regularities we offer the following rating system (Table 1) in order to determine the stability of HGS.

Table 1. Assessment of HGS stability for lowland areas.

Categories of HGS stability	Possible ratio of natural resources composing	Modules, l/s·km²: Natural resources	subsurface runoff	subsurface runoff into rivers	Coefficient of ground water inflow (underground recharge) %	Power (thickness) of the aeration zone, m
The most stable	$\frac{Q_{n.r.} \approx Q_{s.r.} \approx Q_{s.r.r.}}{1:1:1}$	$\frac{>10}{>50}$	$\frac{>10}{>50}$	$\frac{>10}{>50}$	>40	>10
Relatively stable	$\frac{Q_{n.r.} \approx Q_{s.r.} > Q_{s.r.r.}}{1:1:0,75}$	$\frac{8-10}{40-50}$	$\frac{8-10}{40-50}$	$\frac{6-8}{30-40}$	30-40	8-10
Weakly stable	$\frac{Q_{n.r.} > Q_{s.r.} > Q_{s.r.r.}}{1:0,75:0,50}$	$\frac{6-8}{30-40}$	$\frac{4-6}{20-30}$	$\frac{2-4}{10-20}$	20-30	6-8
Unstable	$\frac{Q_{n.r.} > Q_{s.r.} >> Q_{s.r.r.}}{1:0,75:0,25}$	$\frac{4-6}{20-30}$	$\frac{2-4}{10-20}$	$\frac{<2}{<10}$	10-20	4-6
Highly unstable	$\frac{Q_{n.r.} > Q_{s.r.} \approx Q_{s.r.r.}}{1:0,5:0,5}$	$\frac{2-4}{10-20}$	$\frac{<2}{<10}$	$\frac{<2}{<10}$	5-10	2-4
Critically unstable	$\frac{Q_{n.r.} >> Q_{s.r.} > Q_{s.r.r.}}{1:0,5:0,25}$	$\frac{<2}{<10}$	$\frac{<2}{<10}$	$\frac{<2}{<10}$	<5	<2

* Note: there are the possible coefficients in the denominator

Let us take the estimates of stability and standardization of geochemical load on the basis of hydrogeochemical parameters.

Hydrogeochemical stability will be determined by the ratio of surplus quantity of component Mdi which is derived from the aquifer system to its additionally received quantity Mri. Hydrogeochemical stability can be expressed in percentages or fractions of units, so coefficient of stability is Csi = Mdi / Mri.

Calculations are based on a basin approach with assessing the balance of pollutants entering the aquifer. This method is widely used for regulations of wastewater discharge into surface streams. The catchment area of river basin is considered to be the elementary object and it is expected to be the equal distribution of concentration for the basin (Fig. 1).

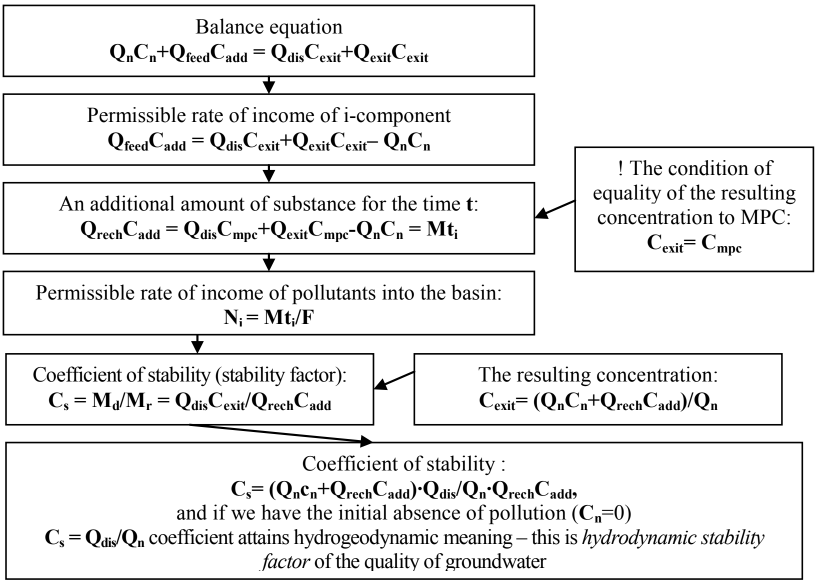

Figure 1. The scheme of the calculation of the hydrodynamic coefficient of stability. Qn - natural resources (incoming part) of groundwater in the given elemental basin; Qrech - additional feeding which is received by aquifer in the area of the basin; Qdis - groundwater discharging on the area of the basin (drainage system, water intake facilities); Qexit - underground runoff from the area of the given elemental pool to adjacent basins Cn, Cadd, Cexit - concentration of component in natural conditions, in additional inflow as a result of pollution and the resulting concentration; Cmpc - maximum permissible concentration; F - catchment area.

The resulting correlation of the coefficient Cs = Qdis/Qn once again confirms the thesis about the crucial role of water exchange in the filtration resistance of HGS. From the viewpoint of maintaining ecological health of surface waters the most dangerous elementary basins are the basins with the maximum coefficient of stability of groundwater quality; it is so because it is assured by the removal of pollution in the river network. Therefore there is an important conclusion: the factors influencing the formation of surface runoff stability are different from the factors that determine the stability of underground runoff into rivers.

From these positions its discharge into the river network is of great interest. It is known that variations in the spatial and temporal context are determined by a number of factors; the stability margin of HGS is formed under the influence of this factors. This is a kind of "corridor" within it a fluctuation state of the object takes place. The upper and lower limits of the stability of HGS can be set by the calculations according to the known relations between the module of underground chemical runoff into rivers Mucr 5% and 95% of security:

$$M_{ucr\ 95\%} = \frac{Q_{max} \cdot C_{min}}{F}, \quad M_{ucr5\%} = \frac{Q_{min} \cdot C_{max}}{F},$$

where: Mucr5% is the quantity of the module of UCR 5% (t/km2 per year), which is calculated as the product of minimum flow of the river during summer low water period (Qmin) times appropriate mineralization of water or normalized chemical element (Cmax); Mucr95% is the product of quantity of minimum flow in rivers during the winter time (Qmax) times the quantity of maximum mineralization (Cmin); F is the catchment area, km^2.

Stability margin (Δ) is calculated in relation to the contamination of groundwater by substances which flow to the surface of the river catchment (with precipitation or from other sources); in the first approximation it can be calculated as the difference between different secured volumes of USR:

$$\Delta = M_{ucr5\%} - M_{ucr95\%}$$

At its core Δ is the amount of salts leaching under the different conditions of drainage of certain amounts of dissolved rocks, partly affecting the unsaturated zone of catchment.

High rates of water cycle include an intensive removal of pollutants from aquifers, at the same time they include minimum time of contact with enclosing rocks and determine the low degree of natural purification of groundwater as the result the insignificance of the processes of sorption and diffusion. Here it should be noted that the rapid removal of contaminants from groundwater leads to a predominance of the surface waters pollution prosesses. This conclusion once again confirms that the mechanisms of emerging resistance for surface and groundwater catchments are different despite the close relationship between surface water and groundwater in the basins of the northern rivers.

Quite different regularities inhere in the formation of stability of runoff forming complexes in conditions of long-term permafrost. Thus, it increases from south to north correlating with the reduction of periods of water exchange and it is due to the discreteness of the interaction of surface and groundwater. As a result of repeated glaciations, transgressions and regressions of the Arctic Sea in the Quaternary period, the freezing of the rock and types of structure of the cryolithic zone have pronounced latitudinal direction according to the data.

It is important to emphasize that for any HGS stability can be assessed only in relation to specific types of technogenesis, because every system has the property of the selectivity against the disturbances sources. This suggests that all natural systems, including the HGS, are characterized by multiple forms of stability, which are controlled by the power of resistance.

Apparently estimates of stability of HGS will be long conducted on an empirical basis, because the theoretical universal apparatus of similar estimates for the natural systems has not been created yet, and the assessments themselves have a specific purpose depending on the nature of charge (depletion of aquifers, its pollution, industrial waste injection, flooding areas, etc.). In addition, any HGS has the property of selectivity towards reactions on environmental loads and is characterized by multiple types of resistance. In this context introduction to substantiation of norms of the impact the concept of "limiting factor" becomes relevant.

These limiting factors on the basis of regularities of natural groundwater resources formation for the platform areas are:

- significant differences of the shares of participation of groundwater from different hydrodynamic zones;
- the most intensive feeding of aquifers in the side parts of the artesian basins due to vertical cross-flow which is a key element of water exchange;
- rivers draining effect can be traced not only to a depth of downcutting, but it also covers the deeper parts of the cut, if they are not covered by weakly permeable sediments;
- watershed areas are the areas of nutrition with a predominantly downward movement of water and they are the most vulnerable to aerogenical pollution;
- reducing the rate of lateral filtering occurs for all horizons as they deep from the periphery to the center, which creates prerequisites for the accumulation of pollutants;
- in the riverine (lowland) part of the aquifer there is a growth of the rate of lateral filtering speeds, as well as the vertical from the lower horizons and the active mobilization of dissolved substances occurs, including man-made pollution;
- amplitude of the vertical speeds of water exchange in interfluvial arrays is more constant with the deep of aquifer than the lateral speeds; it is connected with an increase of the relative role of vertical water exchange with the depth;
- the intensity of vertical water exchange is due not only to facial irregularities of overlying sediments, but also to a small-block structure of the sedimentary basin which creates conditions for local groundwater pollution throughout its thickness, and for the removal of pollutants in the overlying horizons and at the surface of the earth;
- the rate of transit water exchange through the slightly permeable thickness in the vertical direction is disproportionately higher than those that are for the full water exchange.

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