FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 3, N° 2, 2005, pp. 165 - 172

COLMATION AS ONE OF THE PROCESSES IN INTERACTION BETWEEN THE GROUNDWATER AND SURFACE WATER

UDC 551.44(045)=20

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Abstract. *This paper explains one of the processes (colmation) occurring during the interaction between the groundwater and surface water.*
Apart from the definition and type of colmation, the evolution of colmation as well as the influential factors are presented here through the review of research of this phenomena.
The practical vlaue of colmation is presented at the end. Finally is explained practice signification of colmation.

Key words: *Colmation, surface water, groundwater*

1. INTRODUCTION

Many natural processes and human activities affect the interactions of ground water and surface water.

Effects of human activities on the interaction of ground water and surface water can be observed through: agricultural development (irrigation systems, use of agricultural chemicals), urban and industrial development, drainage of the land surface, modifications to river valleys (construction of levees, construction of reservoirs, removal of natural vegetation), modifications to the atmosphere (atmospheric deposition, global warming).

For the understanding of the natural processes of ground-water and surface-water interaction it is necessary to know:

- the hydrologic cycle, including also the interaction of ground water and receiving water. For example, the interaction of ground water and streams may occur in four basic ways (Fig. 1). The figure shows that the type of interaction is determined by the relationship between water level of stream and groundwater table, so that (A) represents infiltration (leakage, aquifer-stream), (C) exfiltration, (B) leakage and (D) infiltration (on the left side of the stream) and exfiltration (on the right side of the stream)
- chemical interactions of ground water and surface water
- interaction of ground water and surface water in different landscapes

Received September 25, 2005

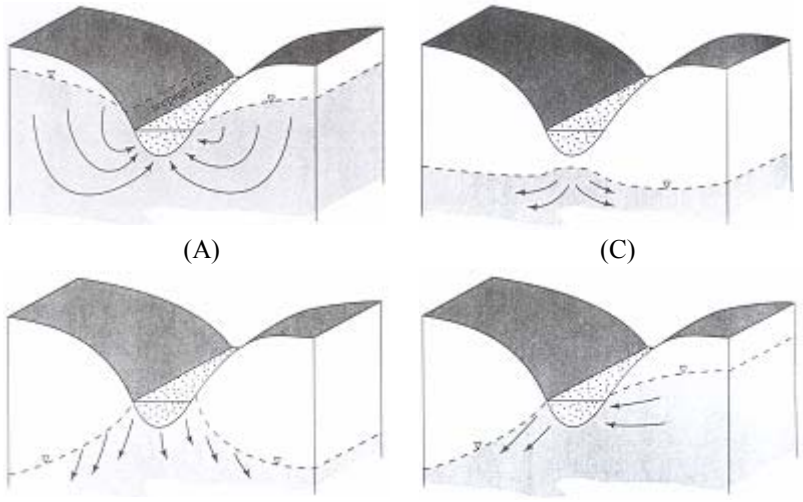


Fig. 1. Stream – aquifer relation.
(A) Gaining stream receiving water from local, intermediate, or regional groundwater flow.
(B) Losing stream connected to water table.
(C) Losing stream perched above water table.
(D) Flow – through stream.

On the other hand the amount of water flow from or into a river depends on the following physical phenomena:

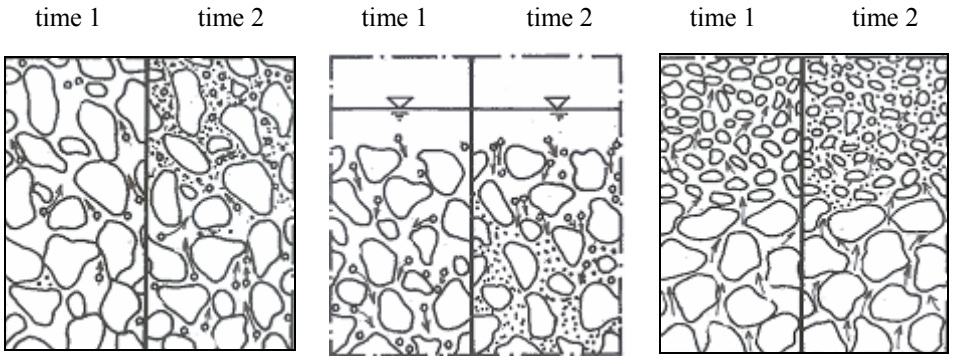
- distribution of difference between river water level and groundwater level
- distribution of permeability of the river bed and thickness of the river bed sediments
- permeability of aquifer
- geometric characteristics of aquifer
- geometric characteristics of the river bed

2. COLMATION

Definition: Colmation is a process which occurs when fine particles, transported by groundwater, are dammed in gaps of skeleton. These particles produce less porosity and permeability of porous medium while the density of the material sedimentation increases.

The basic understanding of the mechanical process is that colmation is the inverse process of suffusion. It is also necessary to understand the term depth filtration which describes the transport and retention of fine inorganic and detrital particles.

There are processes of internal, external and contact colmation (Fig. 2) and for each of them it is typical that firstly the bigger particles lodge in the pores in this way forming the 'bottle necks' where even finer particles can also can also become entrapped.



(A) internal colmation (B) external colmation (C) contact colmation

Fig. 2. Schematic description of colmation with processes development in time

(A) congestion of the interstices directly below the armor layer, may form a thin seal that disconnects surface water from hyporheic water by inhibiting exchange processes.
(B) the settling of particles under low flow condition.
(C) (for example: artificial infiltration in the pipe filter at the spring) occurs opposed to groundwater flow and independent of pore geometry. [2]

Besides the definition of colmation it is necessary to know the geometrical or hydraulic colmation criteria described in details in [2]. In brief, fulfilling the geometrical colmation criteria leads to that that the particles of certain size can go through the pores, hydraulic colmation criteria proves that the transport force in the pores itself is sufficient for the movement of the particles of certain size.

The process of colmation can also be influenced by: sedimentation, biological exchanges and ground structure formation by:

1. *physical variables:* shear stress, representing the flow conditions; the suspended load, the grain size distribution and shape of suspended particles; the hydraulic gradient of the seepage flow and its direction;
2. *chemical variables:* type and quantity of dissolved organic matter controlling sorption processes;
3. *biological variables:* the activity of epilithic algae and microbial organisms developing a biolayer with adhesive capacities.

Colmation refers to the retention processes that can lead to the congestion of the riverbed or stream bed, for example, by the deposited fine particles (the sediment of gravel-bed rivers can be separated into two components, the framework gravel and the fine inorganic particles (< 2 mm: sand, silt, clay)). Fine particles are important because their percentage in riverbed is decisive for the hydraulic conductivity.

Sediment in suspension can interact with the streambed in several ways (Fig. 3).

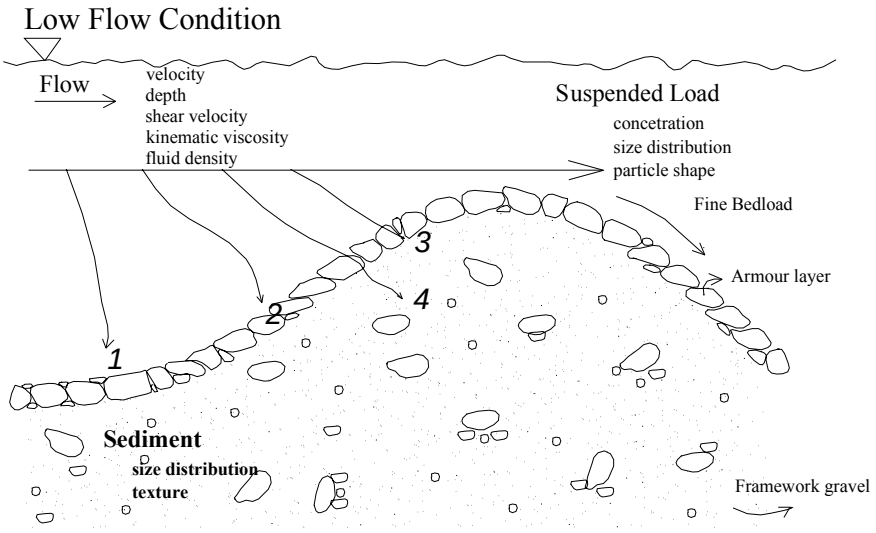


Fig. 3. Factors that influence the retention of fine particles in streambeds. Numbers 1 - 4 are described in the text. According to [1]

1. Sediment may settle on the top of the streambed in areas of low water velocity (e.g. in pools, or between coarser gravels) under low flow conditions.
2. A thicker layer of fine particulate matter that reduces the permeability of the streambed (external colmation), may develop after an extended period of low current velocity.
3. Fine sediment that passes the coarse armor layer may accumulate beneath the armor layer; if low discharge continues a compact layer that reduces the porosity and hydraulic conductivity of the streambed may develop and stabilize the streambed against erosion (internal colmation).
4. Particles may penetrate the armor layer but not contribute to the congestion of the top layer (depth filtration); such particles undergo alternating phases of deposition and resuspension.

2.1. The evolution of colmation

Schälchli [6] developed a model of the evolution of colmation where he distinguished three phases (Tab. 1) by using the different filtration mechanisms of Herzig et al. [3]. In details in [1].

Table 1. Processes and phases of internal colmation according to [6].

	Large Particles (∅ > 30 μm)	Medium Particles (∅3 – 30 μm)	Small Particles (∅ < 3 μm)	Permeability of the Streambed
Phase I	***decisive process:*** congestion of larger pores directly between and below the gravels and stones of the armor layer	deposition mainly in the pores of the upper sub armor layer; transport into deeper strata is possible (depth filtration)	partial deposition on surfaces due to physicochemical interactions; transport into framework gravel (depth filtration)	Minor reduction of hydraulic conductivity
Phase II	filling of some voids, limited deposition on the armor layer; role of large particles is largely terminated,	***decisive process:*** mechanical congestion of fine pores; sedimentation in voids with low current	attachment on substrate of the filter layer effects further narrowing of pore channels	Substantial reduction of hydraulic conductivity
Phase III	only minor deposition	reduced deposition between larger particles	***decisive process:*** further attachment effects a reduction of the interstitial velocity to a lower limit due to a decreased import of particles into the filter layer	hydraulic conductivity reaches a minimum value

2.2. Factors that influence colmation

Factors influencing the colmation or the development of colmation in time are given in Table 2.

Colmation is a process, and the most frequently measured characteristic of colmation are permeability and thickness of the river bed (river bottom) sediments. The permeability of river bottoms varies in time, and is influenced mainly by the sedimentation - erosion processes and the morphological changes in the river bed. The sedimentation of fine particles is a function of water flow velocity.

Finally we can conclude that, the colmation depth depends mainly on the grain size distribution of the bed sediment.

According to [6] the depth of colmation can be roughly estimated on the basis of an empirical formula:

$$d_c = 3d_m + 0{,}01\ [m]$$

d_c depth of the colmated layer

d_m the main grain size

Table 2. Summary of factors that influence the temporal course of colmation, the colmation depth, and the min. value of decreased hyd. conductivity [1].

		Variable	Key Parameter	Relevance
Primary Influence	Flow	- current velocity - dimensionless shear stress	Θ	requirement: $\Theta < \Theta_k$; low
	Suspended Particles	- concentration - size distribution - shape - adhesion, cohesion	C^s/ρ_w	requirement: $C^s > 0$
	Sediment	- size distribution - armor layer - texture	d_{10}/d_m	high
	Hydraulic Gradient	-infiltration - exfiltration	- *VHG* + *VHG*	Medium decolmation at $+VHG > +VHG_k$
	Temperature	- kinematic viscosity	R_e	low
Secondary Influence	Morphology	- riffle-pool sequences - longitudinal and cross profile - zones of preferential bedload movement	*VHG*, Θ, $d10/d_m$	variable

Θ dimensionless shear stress
Θ_k critical dimensionless shear stress (beginning of decolmation)
C^s concentration of suspended particles
ρ_w density of water
d the grain size
VGH vertical hydraulic gradient

2.3. Importance of colmation

The colmation assumes great importance in hydro engineering. Several processes that are significantly influenced by the colmation will be indicated here.

With rivers and streams – influences the pollutant transportation in the underground in several ways. It can reduce the amount of water and the pollutant that is transported into the underground flow, at the same time the pollutants are deposited at the river bed, which

has negative influence on the river's ecosystem. Conditions are created for development of algae and other microorganisms that can have positive as well as negative sides. Apart from the physical, the deposited material can cause also chemical and biological processes with uncertain consequences. Biological processes can be very negative especially in lakes, because they lead to considerable reduction of the accumulation but at the same time, because of the stoppage that the colmation makes, the water leakage (infiltration) in the artificial accumulations is reduced.

The colmation requires thorough cleaning and rehabilitation. During the exploitation of the wells a reduction of well yield occurs due to the well ageing. It means that the complex chemical and microbial processes reduce the permeability of the screen and filter pack. This phenomenon also occurs in the aquifer (in close proximity of the well). The increase of the hydraulic resistances is due to coagulates, particularly from Iron (Fe) and Magnesium (Mn) compounds, in the ground water, which clog up the screen and the porous environment around it. So, while the depth of the groundwater table remains the same, the well yield is reduced.

The knowledge of the colmation can help also, with understanding and solving the problems occurring with the damage of the sewer systems.

3. CONCLUSION

Colmation mechanisms can be observed through five processes: physical colmation, biocolmation, chemical colmation, generation of gas and compaction/compression. This gives a reason for an interdisciplinary study of this phenomenon. A study from an engineering point of view, exclusively, without observation of biological activity and chemical processes, would not give relevant results.

The part that is important for engineers is related to the colmation as a physical process. The most frequently measured characteristics of colmation are permeability and thickness of the riverbed sediments. The permeability of river bottoms varies in time, and is influenced mainly by the sedimentation - erosion processes and the morphological changes in the riverbed. The protection of a sufficiently high permeability means keeping the riverbed free of finer particles, such as mud. The sedimentation of fine particles - mud - is a function of water flow velocity. Therefore, the main criterion of colmation is water recharge of the aquifer or the water infiltration rate via the river bottom. If the ground water level increases too much, because of high infiltration rate (low colmation), the drainage canals carrying away the surplus infiltrated water should be constructed (for example: the seepage canals bordering the reservoir and bypass canal).

Generally, an evident problem of the results related to this field of research is the fact that there is only a small number of them, which is mainly caused by the lack of techniques necessary for carrying out the measurements and assessments, not recognizing their importance and in fact that all measurements are expensive. Good theoretical base which can be found in literature should be an adequate introduction to future researches which will obviously be needed especially because of the climatic changes, which are more and more present, with different consequences (floods, droughts) which would affect directions, quantities and interaction between groundwater flow and surface water.

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KOLMACIJA KAO JEDAN OD PROCESA U INTERAKCIJI IZMEĐU PODZEMNE I POVRŠINSKE VODE

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Za ovaj rad najznačajnije je da se objasni jedan od procesa (kolmacija) koji nastaje tokom interakcije između površinskih i podzemnih voda.

Osim definicije i tipa kolmacije predstavljena je njena evolucija kao i uticajni faktori kroz kratki pregled stanja istraživanja ovog fenomena.

Na kraju je objašnjen značaj kolmacije u praksi.