ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 35 no. 2 pp. 75 - 85 2009

PL ISSN 0324-8461

EFFECTS OF GNEISS MINING ON WATER QUALITY

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Keywords: Sedimentation sump, benefication plant, effluent, gneiss, sediment, pollution.

Abstract: 70 Mg/day of fine grained waste gneiss in slurry condition, together with 700 m^3/day of water from the wet benefication plant flow from the Mikleuška gneiss quarry (Croatia) into the Kamenjača stream. The stream flows between two gneiss quarries, originating in the northern catchment area of which approximately 15 km^2 is predominantly covered by forest. The quality of water in the Kamenjača permanent stream should be protected from any contamination due to the activities in the Mikleuška quarry. The paper describes the aspects of sustainable technical, environmental and economical protection of the water quality in Kamenjača regarding gneiss mining.

INTRODUCTION

The gneiss quarry (gneiss being a structural engineering stone) is on the south slopes of Moslavačka gora at the village of Mikleuška, 19 km north of Kutina along the Popovača – Podgarić road and following the Kamenjača mountain stream. The owners of the quarry have built a 2 m high concrete dam across the stream at the 155 m level, near the plateau of the Mikleuška quarry, to secure water supply for the quarry. Since 1998, the quarry has produced and sold about 100 000 m^3 of gneiss per annum.

Gneiss is classified into the following fractions by means of screens and a wet separation classifier: less than 4 mm, 4–8 mm, 8–30 mm and 30–60 mm. The three larger fractions are transported by an open conveyor belt to the disposal sites in the open. It is estimated that some 700 m^3 of suspended gneiss particles daily passes from the sedimentation sump into Kamenjača waters. The quantity of water required for wet suspension of 20 dm^3/s is secured by a pump installed at the water retention of the stream (Fig. 1).

Sericitized and condensed rough useful suspension can be classified by wet and not dry separation only. The process lets out about 130 g/dm^3 of murky waste water with concentrated suspended matter. The matter so drawn from the wet separation, and floating on top, enters the stream every 8 to 10 hours each working day.

Gneiss excavation does not endanger seriously the quality of the stream water for gneiss mineral particles do not dissolve in water. Dissolved contaminants have not been found in the Kamenjača stream (the drainage basin of which is made of gneiss mainly),

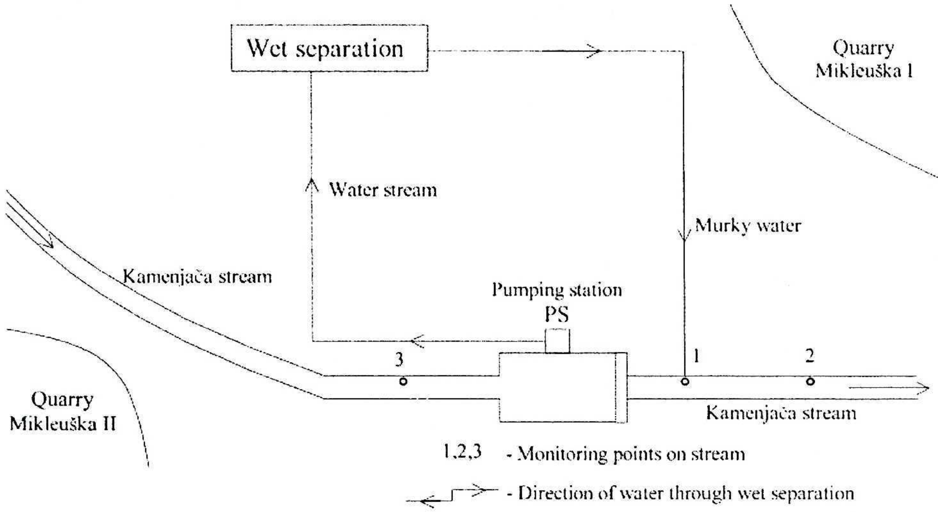

Fig. 1. Water circulation in wet separation

nor downstream from the location of the murky waste water drain used in the wet separation.

The paper shows the results of testing the properties of waste water in the stream and the procedure for dimensioning the rectangular horizontal sedimentation sumps, used as the cheapest procedure for elimination of suspended matter from waste water. In order to improve present conditions and to secure better exploitation of quarry resources, a study showing the effects of the Mikleuška quarry on its environment has been done [8]. It recommends excavation of useful substances at the levels of 162 to 155 m and from the 175 to 160 m in the Mikleuška I and the Mikleuška II quarries, respectively. Excavation of the area below the present working plateau in the Mikleuška I quarry may free up space for the sedimentation sump, and a lagoon must be arranged for additional sedimentation of finer particles at the lowest levels in the quarry (151.2 to 153.5 m). Following extraction, the sedimentation sumps will be reshaped into sports or recreation pools. The lagoon may be used for fish breeding.

GEOLOGICAL CONDITIONS

The sedimentation basin is similar to a lake and lies upon a transgressively folded base of crystalline foundation. The end of the Helvetic period marked the beginning of the influence of marine sedimentation. The Helvetic sediments contain transgressively torton conglomerates, infirmly bound coarse grained sandstones and locally developed limestone inside them. The Pliocene rhomboidea sediments consist mainly of sands and marls, less frequently of sandstone and clay. Quaternary sediments of heterogeneous grain size distribution often occur on the hillsides of Moslavačka gora, especially in the stream valleys [10].

The exploitable part of the Mikleuška I and II quarry beds is found in the crystalline massif at the south-eastern border of Moslavačka gora. Magmatic, biotitic and double-micaceous gneissic rocks are predominant in the area.

Large portion of gneiss in the open bed is sericitized. Therefore, the site contains sodium-calcium clay-stones with large quantities of lamellar sericite (H_2, KAl_3, SiO_3, O_3). The claystones like those are prone to intensive crumbling during excavation and transportation. For this reason, the rock must be washed in wet separation [3]. The cover of the useful suspension is made of humus, yellow-brown sandy clays and crumbling, condensed gneiss.

The intrusion of the Moslavina granite into the older metamorphic complex caused its metasomatic alteration with partial or complete re-melting. This formed a waist of heterogeneous and homogeneous magmatic rock of hectometers to kilometers sizes. Gneiss has a similar chemical composition to that of granite, consisting of about 45% flint, 40 to 45% claystone, 10 to 15% mica and some other silicates in smaller amounts. Gneiss components are mainly water non-soluble and do not endanger the quality of water.

POTENTIAL POLLUTION OF THE WATER FLOW IN THE QUARRY

The quarry in the process of wet separation of rock now uses 20 dm^3/s of the water from the Kamenjača stream during each 8–10 hour per workday. Approximately, the same quantity of 700 m^3/day of water flows back to the stream carrying suspended gneiss particles. The quarry owner estimates that some 10 000 m^3/year of market-valued stone fractions is lost in this way.

Potential risks which may have a bad effect on the water quality in the Kamenjača stream [11] are: stationary gas oil tank, small stock of machine oil, *in situ* septic pit for quarry personnel, occasional washing of equipment, constant washing of stone, various waste materials from the office, and equipment maintenance shop. Intensive mine erosion due to the effects of precipitation has not been observed. Also, there is no increase of suspended particles in the Kamenjača stream caused by removal and excavation of gneiss in relation to the drain of precipitation water from forest paths and ploughland.

No dissolved detrimental matter has been found in precipitation water samples falling, draining and/or being collected in the open pits of the Mikleuška gneiss quarries and in useful suspension and waste accumulation sites. Silicate, insignificantly soluable rock-gneiss, showing no significant effect on the quality of the stream, with the exception of solid particles in water at the wet separation draining location have been found and excavated [3].

The Kamenjača stream is properly protected against small supplies of fuel and lubricants, excrements in solid waste and other pollutants in the water system. However, the consequences of gneiss beneficiation in wet separation are not acceptable for the quality of the stream water. Larger quantities of suspended stone particles are present in the water used for occasional washing of equipment and regular washing of fine stone fractions in wet separation. It comprises a washing cylinder, 3 screens with the openings of 30 mm, 8 mm and 4 mm, continuous conveyors and a spiral classifier. Some 40 m^3/hour of 0–60 mm stone in approximately 8 dm^3/s water is washed in the cylinder. The same quantity of stone is washed on three screens, using approximately 12 dm^3/s water.

WATER ANALYSIS AND REMOVAL OF SOLID PARTICLES

The water quality at the separation drains and downstream the quarry was not investigated in the past. On this occasion, samples of water were taken for quality tests in the laboratory of the Faculty of Geotechnical Engineering in Varaždin, the Faculty of Mining, Geological and Petroleum Engineering in Zagreb, and "Petrokemija" d.d. in Kutina.

Figure 2 shows the grain size distribution of the matter suspended in the water samples taken at the waste water drain site (following wet separation), and 50 m downstream the drain. Its data are determined by aerometric tests and by sieving the sediment separated from the water sample. Curve 1 refers to the waste water drain in the stream in December 1998. Curve 2 refers to the drain of the water from the wet separation during January 1999. Values of 33.26% of sand, 55.80 silt and 10.94% of sediment clay are noted on the sample 1 curve (Fig. 2). The total amount of dry matter in suspension measured is 133 g/dm^3.

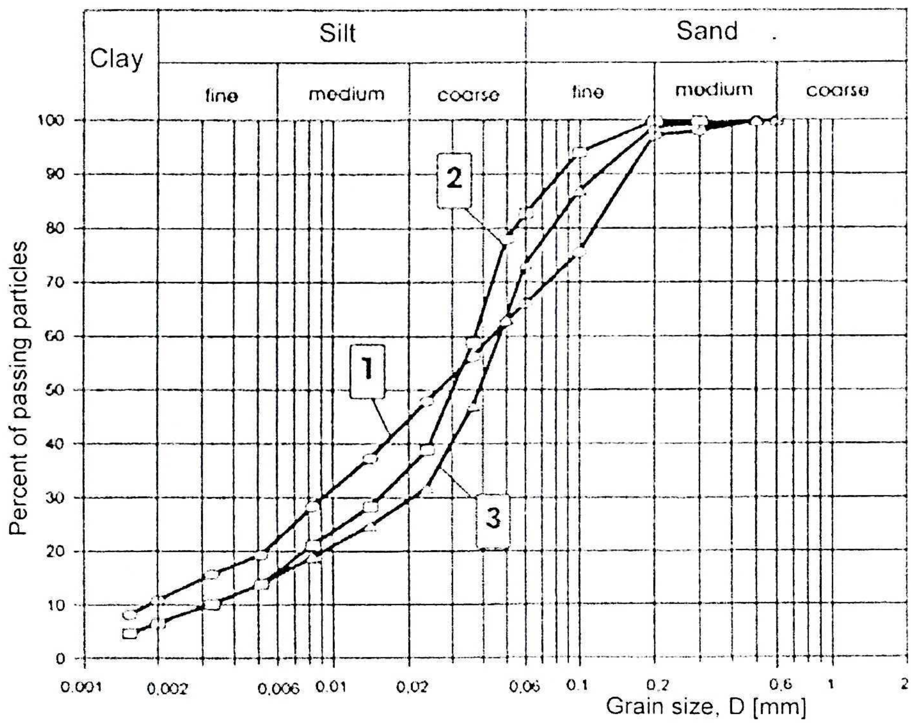

Fig. 2. Grain size distribution curves of particle sedimentation from the sample of waste and saturated waters 1 – sample from the drain, December 1998; 2 – sample from the drain, January 1999; 3 – sample 50 m downstream the drain, January 1999

Investigations carried out in the laboratory of Petrokemija, d.d. in Kutina [2, 5] determined the necessity of purification of waste water used in the process of wet separation due to a high drift content. These investigations have shown that the quality of water in the sample taken 50 m downstream the waste water drain does not meet standard water quality values due to increased content of SiO_2 and pollution/murkiness values too high for maximum permissible concentrations.

Table 1 shows the values determined in the laboratory of the Faculty of Geotechnical Engineering in Varaždin [6]. The possibilities of relatively fast sedimentation of gneiss particles suspended during the quiescence of the water sample or the laminar flow of water should be pointed out. The fastest clearing of water was observed in the quicker-transported water sample taken in January 1999 at the wet separation drain site, then in the fresh water sample taken 50 m downstream the drain site, while the longest time of sample clearing belongs to the longer-transported water sample taken in December 1998 at the waste water drain site. The differences found are probably the results of additional crumbling of coarse grained gneiss particles of colloidal size settling very slowly without the application of flocculants (rich in non-sericitized clay stones), when transported in a vessel or in the stream. For this reason, it is recommended to build the sedimentation sump as close to the wet separation plant as possible.

Table 1. Sedimentation velocity of coarse particles in 1000 cm^3 of water used in wet separation

Sampling date		Turbid and clear water volumes [cm^3]			
Decanter components		1 hour	3 hours	24 hours	48 hours
Outlet December 1998	coarse residue	100	120	120	120
	total residue	915	640	500	440
	clear water	85*	360*	500*	510
Outlet January 1998	coarse residue	80	80	80	80
	total residue	870	680	430	380
	clear water	130	390	570	620
50 m downstream January 1999	coarse residue	15	15	15	15
	total residue	15	150	85	64,5
	clear water	985*	850*	915	865

*water above sediment in graduated glass was not completely clear

Table 1 shows the background for the explanation of regulating the sedimentation sumps with adequate dimensions for removal of suspended matter from water before being drained into the stream. In the sedimentation sumps adequately designed, built and maintained it is possible to decrease the suspended matter content to the value of 25 mg/dm^3, as observed in the water samples upstream the quarry.

DESIGNING SEDIMENTATION SUMPS

Draining murky water from the wet separation into the Kamenjača stream is a fundamental threat to water quality. Clarity of water has been a long-standing water quality criterion [4]. The quarry owner must remove solid matter suspended in the waste water used in the operation process. The sale prices of the quarry products are relatively low. The same applies to investments and maintenance of equipment for removal of waste matter from the water: descender, desilter, centrifuges and tools for using the flocculator (alumina, ferrochloride, lime and similar chemicals), a device used for acceleration of settling. The quarry has enough space for sedimentation sumps. It is necessary to see the possibilities for clearing the murky water by using the sedimentation sumps mentioned.

In addition to dimensions of the particles suspended, an important effect on the sedimentation velocity of solid particles belongs to the density difference existing between suspended particles/fluid and fluid viscosity [7]. This is further proved by the Stockes formula for laminar streaming of liquids with suspended matters.

$$v_t = \frac{g \cdot (\rho_c - \rho) \cdot d_c^2}{18\mu} \quad (1)$$

where:

v_t – sedimentation velocity of individual particles in given conditions [m/s],
g – gravity acceleration [m/s²],
ρ_c – density of suspended particles [kg/m³],
ρ – fluid density [kg/m³],
d_c – particle diameter [m],
μ – dynamical viscosity of suspension [Pa s].

Figure 3 shows idealized rectangular sedimentation sump that will serve for computation of relevant basin dimensions securing laminar streaming and necessary detention of water in the basin. The entrance zone in which a mass of water with suspended particles is distributed and forming a laminar flow is marked 1. Sedimentation of particles occurs in Zone 2, through which the water flows to the exit/drain Zone 3, where the clarified water converges. Separated sediments accumulate in Zone 4. From there, sediments are removed by cleaning the basin bottom in accordance with the regime of work of the separation, i.e. sedimentation basins.

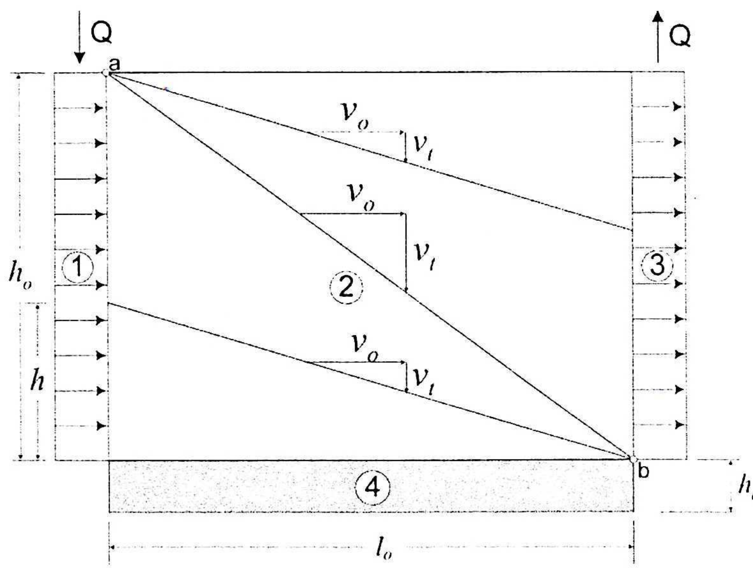

Fig. 3. Rectangular horizontal sedimentation sump

Decisive particle for dimensioning the sedimentation sump is the one entering at point a, settling along the entire length of the sump and reaching the point b after a certain period of time. Trajectory of sedimentation of such a particle represents the resultant of the streaming velocity vector v_o and vector of the sedimentation velocity v_t [4]. Thus, all particles sinking with velocity $v_t > v_o$ settle in the sedimentation basin (Zone 4) and do not reach the draining Zone 3 (Fig. 3).

For the given inflow of waste water from wet separation $Q = 0.020$ m³/s, height of sedimentation sump $h_o = 0.5$ m and minimal time of retention in the sump $t_o = 10\,800$ seconds, it is possible to calculate the surface of the sedimentation sump A, the volume of the sump V and the velocity of the particle flow through the sedimentation sump v_o (Fig. 3) using the following formulae:

$$v_o = h_o / t_o \tag{2}$$

$$t_o = V / Q \tag{3}$$

$$A = V / h_o \tag{4}$$

$$v_o = Q / A \tag{5}$$

On the basis of the above parameter values, i.e. the rectangular horizontal sump, the values of all other parameters are calculated using the above formulae as follows:

$$V = Q \cdot t_o = 0.020 \cdot 10800 = 216 \text{ m}^3 \tag{6}$$

$$A = V / h_o = 216/0.5 = 432 \text{ m}^3 \tag{7}$$

CONSTRUCTION OF SEDIMENTATION SUMPS AND POSSIBILITY OF CHANGING THEIR FUNCTION

Excavation of sedimentation sump gneiss using the existing equipment, in engineering and financial view, is always favorable for the quarry owner. However, securing a permanent use of correctly dimensioned structures for removal of suspended matter after a relatively short period of quarry life is of particular economic importance. According to Sport Encyclopaedia published by Miroslav Krleža Lexicographic Institute [9], the size of sport basins is most often 25×18×2.2 m or 33.33×20×(2.20 to 0.90 m) or 50×25×2.20 m. For this reason, architects are advised to apply the sizes above for sedimentation sumps as well as to provide the sizes for future sports/recreation facilities.

The terrain configuration and the surface area owned by the quarry between the Kamenjača stream and the wet separation plant are suitable for laminar flow without the use of additional pumps. Therefore, an average content of solid particles in the water cleared by sedimentation, desired frequency of cleaning the sediment from the sumps to sediment gathering places for additional drying (Fig. 4) and standard sizes of sports pools have a decisive influence on designing sedimentation sumps.

Available useful substance surface is sufficient for one future sports pool having standard dimensions of 50×25×2.20 m and two smaller pools covering an area of 25×18×2.20 m. A part of the alluvial lagoon sediment area can later be used for fish breeding. If two necessary sumps, and a likely third one similar in size, are situated in a future large basin instead of the sediment collection site with fine grains (using existing equipment in the useful substance), an excavation approximately 55 m long, 3.5 m deep and 30 m wide will be rationally performed, then divided into two equal parts 13 m wide (w) with a dividing 4 m wall of natural gneiss rock. Drain pipes will be installed at the bottom of the sumps to drain water through the settled sediment, particularly the coarser one, at the entrance closer to the second part of the sump (up to 10 m). Following is the verification of the length and width of sumps:

$$A = l_o \cdot V; \tag{8}$$

$$l_o = A / w = 432/13 = 33.3 \text{ m, or } 55 \text{ m respectively.} \tag{9}$$

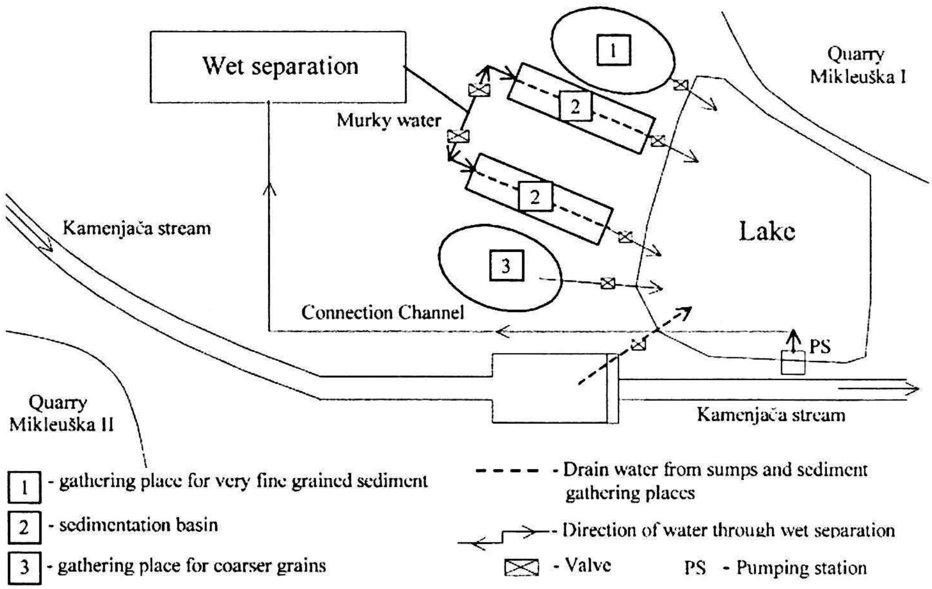

Fig. 4. Layout of sumps, sediment collecting sites and the lagoon

In this way, the useful volume of each sump equals 55.13×3.30 m = 2360 m³. If 0.020 m³/s of murky water flows through for a maximum of 10 hours a day, the total comes to 720 m³/day. The same volume of water can flow out 24 hours/day, i.e. Q_l = 0.0083 m³/s. In this case the average velocity of water v_o on the spillway into the Zone 3 (Fig. 2) at the level of the spillway top (adjusted according to requirement) with 0.20 m water in the sump is determined as follows:

$$v_p = Q_1/A_1 = 0.0083/13 \cdot 0.20 = 0.00319 \text{ m/s} \tag{10}$$

The space available in the sump for settling of sediment is:

$$V = l_o \cdot w \cdot h_t = 55 \cdot 13 \cdot 1.8 = 1237.5 \text{ m}^3 \tag{11}$$

The height of the sediment:

$$h_t = H - h_c - h_o = 3.5 - 0.2 - 0.2 = 3.10 \text{ m} \tag{12}$$

where:

H – total depth of excavation [m],

h_c – decrease of sump depth due to drain pipes [m],

h_o – height of spillway in the sump that will be adjusted according to requirements [m],

w – width of sump.

It is necessary to verify the laminar flow in the sumps of given dimensions and velocity of flow, because only the flow along constant streamlines secures effective settling of suspended particles.

The equation for calculating the Reynolds number is used here. For a rectangular sump, this number must be less than 580, which is the critical value characterizing the transition from turbulent to laminar flow regime [1].

$$R_{eR} = \frac{v_p \cdot R}{\mu/\rho} = 344 < 580 = R_{eR\ critical} \tag{13}$$

where:

v_p – average velocity in the sump, 0.00319 m/s;

R – hydraulic radius – ratio between surface of flow and circumference of flow in the sump,

R – $A/O = w\ (h_o/w + 2h_o)$, as $h_o < w$, $R = h_o = 0.2$ m;

μ – value of water viscosity with suspended fine particles, 0.002 Pa s;

ρ – water density with suspended fine particles, 1800 kg/m^3.

The above calculation confirms the laminar flow, because the value of the Reynolds number is 344 only. For this reason, the planning consists of a standard-sized pool measuring 50×25×2.20 m for two sumps, and two sports pools measuring 25×18×2.20 m for drying the sediment.

Based on laboratory-determined average inflow water drift content of 0.133 m^3 per 1 m^3 of water, 720×0.133 = 95.76 m^3/day is being settled. Filling of the sedimentation sump with such dimensions by the sediment from water with known content would last 2216.5/95.76 = 23.15 days.

Interruption in using one sedimentation sump after a period of 23 days and its emptying from sediment into two supporting basins until next use after the following 23 days (until the second sump is filled), necessitates a moderate frequency of cleaning out the sumps.

If the spillway (i.e. spill-over point) of the sump is adjusted to the height of 3.10 m in relation to the top of the drain pipe on the bottom of the sump, the sump can receive the following amount of murky water in its space V_2 (up to the spillway):

V_2 = 55×13×3.10 = 2216.5; thus, the filling of this space would last t_2 as follows:

$$t_2 = \frac{V_2}{Q} = \frac{2216.5}{0.020} = 110825 \text{ s or } 30.78 \text{ hours.} \tag{14}$$

The value t_2 is longer than 3 days of wet separation work (10 hours a day). This secures a several times more complete settling of the sediment with respect to the conditions of earlier assumed value of t_0 = 10800 s, because:

$$\frac{t_2}{t_0} = \frac{110825}{10800} = 10.26;\ (t_2 >> t_0) \tag{15}$$

During the time of original filling of the sump lasting t_2 = 110.825 seconds, the sediment volume is expected to be $V_3 = V_2 \times p_n$ = 2216.5×0.085 = 188.40 m^3, corresponding to the following height of sediment in the sump:

$$h_2 = \frac{V_3}{A_2} = \frac{188}{55 \times 13} = 0.26 \text{ m} \tag{16}$$

This is also the time it takes to open the valve on the drain pipe and for gradual draining of water. Due to the water being filtered into drain pipe through the sediment (which is an effective filter), clearer water is expected in the drain pipe than on the spillway.

ADDITIONAL PROTECTION OF THE WATER FLOW

In order to protect the Kamenjača water flow from the finest solid matter in a more complete manner, a shallow lake (lagoon) with a surface of about 10 000 square meters is also planned downstream the sumps (Fig. 4). The surface of the future lagoon is covered with humus that will be removed with existing equipment and transported to the final surfaces of excavation to be used as green areas. Following the removal of humus from the bottom of the lagoon, significant infiltration of water into the water bearing alluvium is expected, as well as an increase of underground water level in the downstream wells in Mikleuška housing estates, which is an additional positive effect of the lagoon.

If ecologists have justified objections to the quality of water tested at the drainage point from the lagoon into the stream, it is recommended to reuse the lagoon water in wet separation.

SEDIMENT DISPOSAL

Figure 4 shows the layout of sedimentation sumps, the future lagoon contours and contours of locations for disposal of sediments. Two sediment disposal locations are planned, since a segregation of suspended particles in sedimentation sumps according to grain size is expected. Sedimentation of coarser grains that have value on construction materials market (for civil engineering purposes) is expected to be found at the first 10 to 15 m of the sump. Sediment predominately containing the finest particles is expected in the remaining part of the sump. Therefore, as shown in Figure 4, two collecting places for sediments drying on the sun are planned; one for the sediment with coarser grains to be sold on the market, and another for the finest particles used in forming the water flow in the lagoon, filling the quarry pits and for leveling final excavation surfaces before being covered with humus and plants.

The coarser fraction from the sedimentation sumps will be additionally dried in a specially arranged gathering place before being supplied to customers, while the drained water will be taken to the active sedimentation sump. Sediments of finest particles (mud) will be additionally dried in the basins, where an additional drain similar to the above described is recommended.

The lagoon water will be directed towards the spillway into the stream by a longer channel that will gradually form by the mentioned mud of finest particles settling in the sedimentation sumps. To achieve a more effective settling method for the finest particles in the lagoon and to remove the remainder of colloidal matter in the water after the flow through the sedimentation sump in the layout, a canal for laminar flow of water will be designed and built. The study [8] envisions a concept of facilitating the basin for gathering sediments for standard size swimming pools, and the lagoon for fish spawning, both advantageous in view of economic effects.

CONCLUSION

A public utilities company from Kutina regularly takes away fecal matter and solid waste from the quarry. No cases of uncontrolled effusion of lavatory content, gas or machine oil into the stream were recorded. Equally so, no amounts of settled matter in the precipitation water flowing into the stream from open surfaces of the quarry and poor rock heaps higher than those in the water flowing from ploughland and forest paths were observed. Additional measures securing the surroundings from these and other dangers have been successfully implemented. The process of purifying water used for washing equipment and stone in the wet separation has not yet been planned and implemented in the quarry.

Guidelines for construction of sedimentation sumps and the lagoon for removal of suspended matter are given in the study [8]. The prescribed clearness of water at the drain into the stream has to be adhered to. Further investigation of properties of particles suspended in water, systematic monitoring of the efficiency of sedimentation of particles with different coarseness in the sedimentation sumps and in the lagoon, leading to improved process during construction and use of these facilities are also recommended. We can also recommend the facilitation of a third sump, at the point of the northern sediment-gathering location, as well as special forming of the lagoon shape in order to secure a more effective settling.

If ecologists make justified objections relating to the quality of water tested at the draining point from the lagoon into the stream, it is then recommended to reuse the lagoon water in the wet separation.

In spite of the fact that no dissolved harmful matter has been found in the water samples used in wet separation or in the precipitation water falling and flowing over excavations, useful substances and waste heaps, special care in excavation is recommended in order to avoid erosion and drawn sediments during precipitation. Regular tests in chemical laboratories are strongly recommended. Any stronger clouded waters in the quarry should be directed to the lake (lagoon) downstream the sumps for sedimentation of colloidal particles and systematic control of water quality.

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Received: April 14, 2008; accepted: March 2, 2009.