ISSN 1330-3651
UDC/UDK 504.5:[556.14:662.613.13

TRANSPORT OF POLLUTANTS IN SEEPAGE WATER FROM PAVEMENT STRUCTURES WITH INBUILT FLY ASH

Marija Šperac, Sanja Dimter

Subject review

Water is an ideal solvent; some products placed on or in the soil will eventually end up in the groundwater. Seepage water from road construction can contain significant quantity of noxious substances that are transported from aquifers. The paper presents transport of pollutants in seepage water from pavement structure with inbuilt fly ash. Substances from fly ash can have a noxious impact on the surrounding air, soil, and water. Depending on the concentration of noxious substances in seepage waters, drainage can be carried out by two methods. Seepage water with a critical concentration of noxious substances is drained through the sewage system and treated. Another method is used in case of small concentrations, which can be disintegrated by means of natural purification processes in the soil, with seepage water discharged into the surrounding soil or waterway. Continual quality control of both seepage water and surface water and groundwater is necessary. If fly ash of good quality is inbuilt in pavement structure (in the right proportion), it doesn't have an adverse impact on the neighboring air, soil, and water.

Key words: *fly ash, seepage water, transport of pollutants, pavement structure*

Pronos zagađenja procjednim vodama iz kolničkih konstrukcija s letećim pepelom

Pregledni članak

Voda kao idealno otapalo pronosi različite suspendirane i otopljene tvari s površinskih u podzemne slojeve. Procjedne vode iz kolničke konstrukcije mogu sadržavati značajne količine štetnih tvari koje se dalje pronose kroz vodonosne slojeve. U radu je opisan pronos zagađenja procjednih voda iz kolničke konstrukcije u koju je ugrađen leteći pepeo, a koji zbog svog sastava može imati štetan utjecaj na okolni zrak, tlo i vodu. Ovisno o koncentraciji štetnih tvari u procjednim vodama njihova odvodnja se može izvesti na dva načina. Kod kritičnih koncentracija štetnih tvari u procjednim vodama one se odvode sustavom kanalizacije i pročišćavaju, dok kod malih koncentracija, koje se mogu razgraditi putem samopročišćavanja kroz procese u tlu, procjedne se vode mogu upustiti u okolno tlo ili vodotok. Potrebna je stalna kontrola kvalitete kako procjednih tako i površinskih i podzemnih voda. Dosadašnja istraživanja i rezultati pokazali su da, iako postoji opasnost od mogućeg štetnog utjecaja letećeg pepela iz kolničke konstrukcije na okoliš, ukoliko se pepeo ugradi kvalitetno i u pravom omjeru ne predstavlja opasnost po okolno tlo, zrak i vodu.

Ključne riječi: *leteći pepeo, procjedna voda, pronos zagađenja, kolnička konstrukcija*

1 Introduction
Uvod

Seepage water in road construction is the result of leaching of precipitation water and road wash water. Those kinds of water are among significant sources of uncontrolled contamination of both subsurface and deeper groundwater resources. Total quantities and concentrations of waste substances in seepage water are of changeable volume. Depending on their maximum values, seepage water may be drained into the drainage system or, in case of lower concentrations, discharged in underface flows and processes of natural purification (Fig. 1). Transport of pollutants is significantly affected by properties of drainage surface, particularly hydro-geological characteristics of the soil.

In the course of seeping of water under the ground, substances in the soil dissolve in the manner consistent with the composition of the soil (natural or polluted) and a part of the transport of pollutants from pavement structure. In case of soils having low porosity, all suspended substances are retained, whereas only the dissolved ones remain in the water and due to longer lasting retention under the ground they may partially be taken over by biosphere and are thus extracted from the water [2]. The process of creation, leaching, transport (underface and underground), and natural purification of pollutant is complex and not fully resolved. Therefore it significantly affects defining the quantity and concentrations of pollution and pollution risk assessment. Those processes are significantly affected by hydro-meteorological, hydro-geological, hydrological, ecological, and spatial conditions of a specific area.

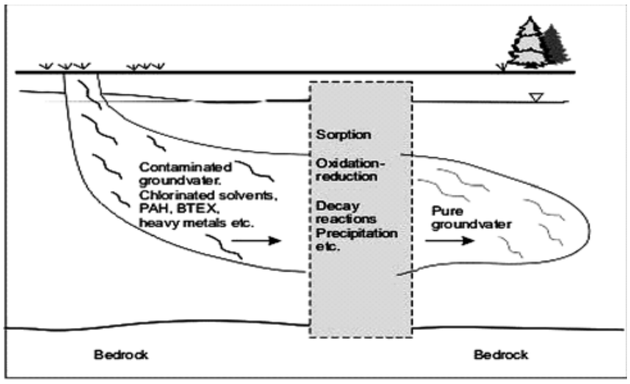

Figure 1 *Underface process of natural purification of waste water* [1]
Slika 1. *Proces potpovršinskog samopročišćavanja otpadnih voda* [1]

The type of geological medium and the degree of heterogeneity of the system specifies the velocity and quantity of water that will be infiltrated into the saturated zone and become an integral part of groundwater.

The dimensions of control volume for monitoring the underground water flux may vary from the regional scale, whose size is expressed in kilometres, and in which the groundwater balance and a change in the direction of flux in aquifers are monitored, to the control volume of molecules in which physical, chemical, and microbiological processes are monitored (Fig. 2).

Velocity and direction of transport of pollutants are connected with anisotropy of a porous medium (Fig. 3). Anisotropy is defined as a property of a material being directionally dependent. In water bearing layers anisotropy is manifested through the directionally dependent

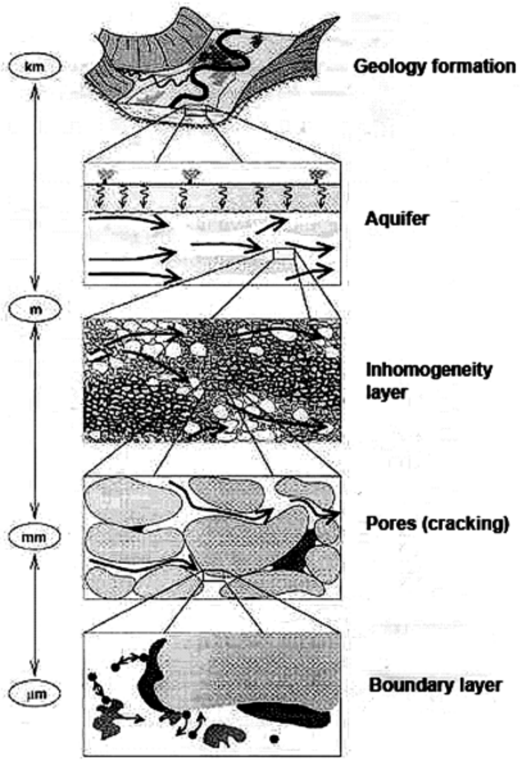

Figure 2 *Different dimensions of control volume for monitoring underground water flux* [3]
Slika 2. *Različite veličine prostora u kojima se promatra tok podzemne vode i pronos* [3]

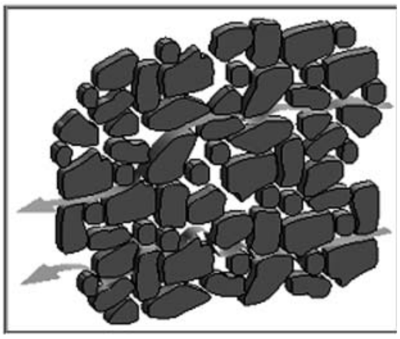

Figure 3 *Sreams across medium with grain porosity* [3]
Slika 3. *Strujnice kroz sredinu s međuzrnskom poroznošću* [3]

changeable filtration coefficient.

2 Transport of seepage water
Pronos procjedne vode

Basically, groundwater and surface water are closely connected, and it is often very difficult to separate them because they complement each other. Consequently, pollution is transported from the surface water through seepage water into groundwater. Water is an ideal solvent, as some elements from the surface or from the soil often end up in groundwater.

A continual measurement of all relevant parameters pertaining to the quantity and quality of seepage water, the conditions of drainage network and wastewater treatment plants, is necessary for the preservation of natural resources and for the purpose of their reuse. Real-time management is crucial for the preservation of biodiversity, human health safety, and environmental safety. It is necessary to carry out continual measurements of concentrations of the pollution by means of a model for transport of pollutants and carrying out of in situ measuring by means of piezometers. The control of concentrations of individual pollutants or a group of pollutants in water, air or soil should target the protection of human health and environment [4].

The modelling of transport of pollutants in most cases implies the application of the continuity equation (1), which shows a change of the specific flow in each point of elastic water-bearing layer, the Darcy's law defining the specific flow (2), and the equation describing the non-stationary flow of groundwater in anisotropic non-homogenous medium (3), where S_s is the specific storage coefficient.

$$-\mathrm{div}\,\bar{q} = S_s \frac{\partial h}{\partial t}\,, \tag{1}$$

$$\bar{q} = -k \cdot \mathrm{grad}\, h = -k \cdot \nabla h\,, \tag{2}$$

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial z}\right) = S_s \frac{\partial h}{\partial t}\,. \tag{3}$$

S_s is the specific storage coefficient representing the quantity of water that a unit volume of a porous medium will store or discharge when the height of water column is lowered by one. The storage coefficient S refers to the total thickness of the saturated water-bearing layer, which means that it is equal to the product of the specific storage coefficient (S_s) and the thickness of the water-bearing layer (m).

Heterogeneous characteristics in the nature, geologic forms and their impact on groundwater flow and monitoring of transport impact the characteristics of the stochastic flow model and of the transport of substances through the underground. In the stochastic approach transports of pollutants through a porous medium, as well as the flow itself, are random processes and variables. Processes in the monitoring of a porous medium illustrate the realization of the function of stochastic variable for each process separately. The phase of flow and transport of all components is always a three-dimensional process [5].

Various concentrations of some components may be a product of some chemical reactions of liquid or gaseous phase. Chemical and biological reactions that can change the concentration of pollution in groundwater may be divided into six groups:

- Adsorption and desorption processes
- Acid-base reaction
- Dissolving and sedimentation processes
- Oxidation and reduction processes
- Ionization processes
- Synthesis of cell microbes.

The creation and valorisation of a mathematical description of transport of pollutants require measurements in a natural porous medium and measurements on physical models made in the laboratory. Laboratory research is often used for the description of physical processes in an ideal medium – a porous medium in homogenous and isotropic conditions is presumed. Measurements in an aquifer are significant for engineering practice. Studying of the transport of pollutants in an aquifer requires a mandatory carrying out of "in situ" measurements.

Observation of the distribution of specific components of a pollutant necessitates the preparation of a series of monitoring wells (piezometers) and frequent measurements of concentrations of pollution.

Observations should be conducted in the following order:

- updating and confirming the impact of the planned procedure
- providing information to be used for planned longer time trends, containing data on possible changes in natural environment as a consequence of a human activity.

A sufficient number of in situ monitoring activities may define (and pinpoint) the areas at risk for pollution.

Key parameters that need to be monitored at all pinpointed areas of groundwater streams are the following:

- oxygen content
- pH value
- hydraulic conductivity
- nitrates
- ammonia.

Areas rated as extremely high-risk areas for attainment of the "good status" of water should also be examined in terms of all parameters that indicate an impact of pollution.

A continual monitoring should be carried out during periods between individual observations in the following:

- identify the chemical status of all underground aquifers or parts that are marked as at risk
- forecast possible trends of pollutants produced by human activities.

3 Impact of fly ash from road construction on water pollution
Utjecaj letećeg pepela iz kolničke konstrukcije na zagađenje voda

Civil engineering uses very large quantities of natural aggregates from excavations, and a significant part of those quantities is used specifically for purposes of road and bridge construction. Such a continual demand for natural materials leads to depletion of natural resources, and procurement and transport costs in areas with scarce supplies of good quality aggregates significantly inflate construction costs. Waste materials and industrial by-products may, therefore, as an alternative, be important from a number of aspects. First of all, the use of those materials contributes to a more rational spending of stocks of a good quality aggregate, and in addition it has a positive impact on the resolving of environmental problems which arise from disposal of waste material.

Fly ash has a special place in the wide range of alternative materials used in road construction. Its advantage in comparison with other materials is in that it can be used in the original form, i.e. without any processing and changing of the composition. Fly ash can be used in a dozen different ways, indirectly and directly, in all layers of pavement structure and road embankment.

Fly ash is produced in thermal power plants as a by-product of the process of combustion of fine-grain coal in coal combustion furnaces. In such plants, when coal is exposed to the temperature of 1000-1600 °C, volatile substances and organic ingredients burn out, whilst mineral impurities from coal (such as quartz and clays) are left behind as unburned residue.

Despite years of application of fly ash and its good properties, when making a decision about its use, one should definitely consider the possible detrimental consequences for the surrounding soil and water. Namely, as a material produced by combustion of coal in thermal power plants, it is of changeable chemical and mineralogical composition and during its application problems may emerge related to leaching of toxic elements into water and soil, as well as the problem of potential radioactivity.

The changeable chemical composition of fly ash may contain elements that will thus infiltrate into surface or underground water, which may present a risk for flora and fauna. Particularly dangerous are toxic elements: arsenic, barium, chromium, cadmium, selenium, silver. The methods of determining pH values and elements (As, Cd, Cr, Va, Cu, Ni, Pb, Zn, Cl, NO_3, and SO_4) are defined by the European norm EN 12506 "Characterization of Waste – Chemical Analysis of Eluantes" [6].

When determining the possible degree of leaching, in addition to the data on the share of hazardous elements mentioned above, one should also be familiar with hydrological conditions of the environment and permeability of the material and surrounding soil.

Numerous research projects have examined potential leaching from construction materials and its infiltrating through surrounding soil to surface and ground water. Baldwin et al. [7] examined the leaching potential of industrial by-products used in road construction (including fly ash). In their study a leachate test method was used to produce an evaluation of the pollution potential of investigated materials. They found that many of the tested materials contained significant amounts of rapidly leached alkali metal ions (Sodium and Potassium) whereas the leaching of the alkaline earth irons (Magnesium, Calcium and Barium) appeared to be controlled by the limited solubility of these species. In the conclusion to a comprehensive research, Baldwin et al. [7] pointed out that the possible detrimental effect of toxic elements is consistent with very strict regulations in force on the quality of water, i.e., it does not exceed allowed values. Arnold et al. [8] investigated the leachates and radon emissions from fly ash embankments constructed between 1967 and 2000. In that project, authors analysed samples of groundwater and surface water adjacent to and from the up flow side and down flow side of the fly ash embankments. They concluded that concentrations of contaminants in ground water were rather low, five determinants (Magnesium, Selenium, Potassium, Sodium, Sulphate) gave values above normal drinking water quality levels on at least one occasion, only Potassium, Sodium and Sulphate appear to be of any significance, Radon was not detected and finally, on the basis of investigation, fly ash in embankments poses no significant cause of contamination of groundwater or hazard to health. Board at al. [9] investigated the physical and chemical properties of two cement stabilized materials, one produced from a contaminated made ground and the other from fly ash. The treated materials were laid as slabs and exposed to ambient weather conditions for over three years then cored and tested at six time intervals. Samples were analysed to determine total chemical content and leaching. Comparison of the leachate data with Great Britain environmental quality standards and published dilution factors showed that both stabilized materials posed no potential risk to a water resource.

Tab. 1 shows the usual elements from fly ash whose presence in water and soil is determined in Great Britain [10], by DIN 38414-S4 method.

***Table 1** Filtration elements as a result of method DIN 38414-S4*
***Tablica 1.** Filtrati elemenata pronađeni metodom DIN 38414-S4*

Typical range of leachable elements for UK PFA (mg/L except pH)			
Aluminum	<0,01* to 9,8	Manganese	<0,01*
Arsenic	<0,1*	Molybdenum	<0,1* to 0,6
Boron	<0,1* to 6	Sodium	12 to 33
Barium	0,2 to 0,4	Nickel	<0,01*
Calcium	15 to 216	Phosphorus	<0,1* to 0,4
Cadmium	<0,04*	Lead	<0,01*
Chloride	1,6 to 17,5	Sulfur	24 to 510
Cobalt	<0,01*	Antimony	<0,01*
Chromium	<0,1*	Selenium	<0,01* to 0,15
Copper	<0,01*	Silicon	0,5 to 1,5
Fluoride	0,2 to 2,3	Tin	<0,1*
Iron	<0,1*	Titanium	<0,1*
Mercury	<0,001*	Vanadium	<0,01* to 0,5
Potassium	1 to 19	Zinc	<0,02*
Magnesium	<0,1* to 3,9	pH	7 to 11,7
Notes: the above data include a seawater-conditioned sample resulting in higher chloride values. The Boron content may also be increased. *Indicates below detection limit			

On the basis of the data mentioned above, it can be concluded that a small quantity of fly ash (2-3 %) is soluble in water, with the highest share of calcium and sulphates, and a smaller share of sodium, potassium, and magnesium.

Carrying out of works in the construction of pavement structure includes a number of operations such as transport and storage of materials, spreading, mixing, compaction, building in, and removal of constructed layer during reconstruction. Adverse effects with a negative impact on human health and the environment may be observed as early as during the construction works, for example, releasing of large quantities of fine dust or leaching of toxic elements into surrounding soil and water, which occurs subsequently.

The following data are important when assessing the adverse environmental impact of fly ash: the position of the layer in pavement structure and its designed thickness, whether fly ash is bound by bitumen or cement, and what quantity of it was applied.

More precisely, materials bound by bitumen or cement have a significantly lower leaching capacity for two reasons: first, fly ash particles are surrounded by a layer of bitumen or cement that prevents water passage, and second, bound materials are mostly used for upper base courses which are thinner in comparison with lower base courses.

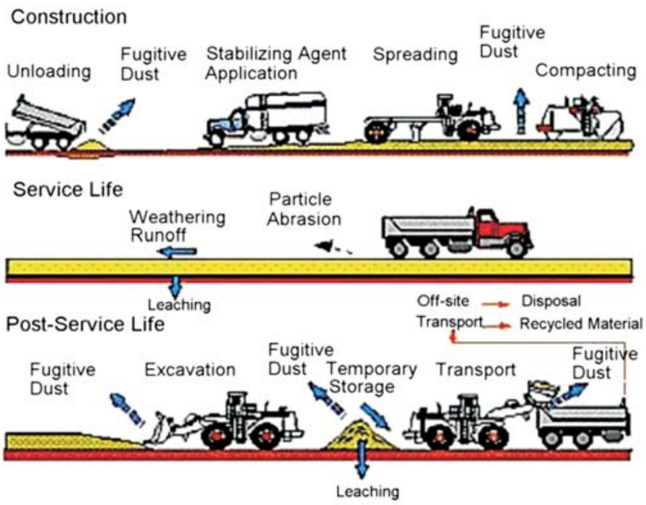

***Figure 4** Stabilized base course: the construction, exploitation and reconstruction* [11]
***Slika 4.** Stabilizirani nosivi sloj: izgradnja, eksploatacija i rekonstrukcija* [11]

Permeability of the hardened fly-ash stabilized base course is very low. It depends on granulometric composition of the mixture aggregate, its density, and in most cases permeability decreases with the increase in the compressive strength of the base course. Permeability of the hardened base course is within the limits of 10^{-5}-10^{-6} m^3/s, and as pozzolana reaction in the layer continues, values of the permeability coefficient change and amount to 10^{-6}-10^{-7} m^3/s.

Taking into consideration all the facts stated above and the results of the research, it can be concluded that there is no significant impact of noxious elements from stabilized layers, due to seepage into the surrounding soil and water.

A similar conclusion could be made in relation to unbound base courses only provided that they are of average thicknesses (up to 30 cm) and that they are not permanently in humid conditions in the construction.

Large quantities of fly ash are used in road embankments, whether as base material in embankment construction or as added material when it is necessary to improve the granulometric composition of the base material. With such large quantities of used fly ash, the quantity of toxic elements that may seep into the water and surrounding soil becomes significant. For that reason the embankment with inbuilt fly ash is constructed so that under the embankment a drainage layer is placed that will prevent water capillary lift, whereas embankment humose capping is protected by a humus layer or vegetation. By using such a solution the fly ash in the embankment is effectively isolated from the environment and does not represent an environmental hazard. Risk from penetration of water, which might emerge, is due to the cracks on the surface, but this would also be for a limited time period, whilst the effect itself would be small due to fly ash non-permeability.

A big problem appears in case when embankment drainage is directly discharged into waterways, so such pollution can pose a significant risk for fauna of the waterways. If the waterways are intended for water supply of the local population or if the embankments with inbuilt fly ash "jeopardize" the sources of the groundwater intended for the same purpose, the problems intensify. Although in those circumstances the toxicity effect is small, it should be taken into consideration because it may be the reason of the change in the taste and smell of the water.

Fig. 4 illustrates various works during the construction and reconstruction of stabilized base course of pavement structure and the sources and possible types of adverse impact of specific (waste) materials on the environment.

Construction works include transport of material, its unloading at the construction site, spreading, mixing with binder, and compaction. All works specified above result in the appearance of a large quantity of dust in the air whose effect is local and instantaneous, and is terminated with the termination of works and does not have a significant environmental impact.

Intensive leaching of noxious elements from the constructed layer into surrounding soil and water appears in the course of the construction at the moment when the constructed layer surface is unprotected and exposed to rain. As a rule, this occurrence decreases significantly already in the course of the construction of a new layer of the base or pavement surfacing.

4 Conclusion
Zaključak

Surface water and groundwater are natural renewable resources; partially, the task for maintaining of a good status of groundwater is carrying out timely activities and a stable long-term planning of protective measures, together with natural conditions of formation and recovery. This time period may be included in the balance when improvement measures contribute to the good status of groundwater and each latest increase in the trend (significant and even) in the concentration of any pollutant in groundwater. For the purpose of the protection of the environment, qualitative and quantitative aspects for surface water and groundwater should be connected, taking into consideration the balance in natural conditions of flowing together with water in the hydrological cycle. Given the protection and control of pollution, one should adopt a combined approach to pollution control through limited values of discharged pollutants and environmental quality standards.

The quality of wastewater (water that fly ash and seepage water are transported by) should be assessed based on the knowledge of the current practice of treatments such as sedimentation and control of pH. Planning of any water treatment requires the water balance of specific areas. It includes the assessment of the inflow of natural flows (if any), precipitation, evapotranspiration of surface run-off, velocity of run-off of seepage water, and velocity of flowing of water by which fly ash is transported. Quantities that are missing in the balance provide an approximate value of the quantity of wastewater that is infiltrated into the groundwater. This will largely depend on the geological situation and existence or non-existence of waterproof bases.

In general, the observed negative impacts of in-built fly ash in pavement structure may cause destruction of landscape and pollution of land and water in the following manners:

- Changes in the hydrological system in terms of redefining underground flows and their chemical composition.
- Pollution of adjacent surface water bodies.
- Potential pollution of groundwater, and in particular fresh water sources.
- Pollution of air and deposits of fly ash particles.
- Penetration of polluting substances such as heavy metals into ecological systems and potential penetration of those polluting substances into the food chain.

Measures that need to be undertaken in fly ash embedding into pavement structure with a view to preserving the environment are the following:

- Fly ash should be bound by bitumen or cement due to its lower seeping capacity.
- It should be used in upper pavement base courses, which are significantly thinner.
- By thorough compaction of material with fly ash small permeability should be secured, thus reducing adverse impacts on surrounding soil and water.
- When applying fly ash in the construction of road embankments drainages should be constructed on a mandatory basis. By means of the drainages seepage water is drained through the draining system for analysis and treatment (it should under no circumstances be discharged into surrounding soil and waterways) and fly ash is "closed" in the embankment by construction of embankment humose capping.
- Constant control of concentrations of noxious elements in seepage water should be conducted.
- Construction of such pavement structures in water supply zones should be avoided.

Research and results so far have shown that, although there is a risk of possible adverse impact of fly ash from road construction on environment, if the recommendations indicated above are taken into consideration in construction, fly ash does not pose a risk for surrounding soil, air, and water [12].

Particularly important for environmental protection is the system of monitoring environmental status. By means of the monitoring system changes are recorded, compliance with norms is controlled, and familiarization with processes and forecasting changes in the environment are enabled. The monitoring system in the Republic of Croatia for the majority of parts of the environment is in early stages, whereas the most developed environmental monitoring system is the one for water – monitoring of the quality of surface water is carried out on the national level and may be considered developed and well organized.

In the application of alternative materials in civil engineering, such as fly ash described above, and adoption of regulations related to its application, Croatia lags significantly behind industrially developed countries in which such materials have been applied for a number of years.

5 Literatura
References

[1] Wanielista, M.P. Hydrology and water quantity control, New York, 1990.

[2] Margeta, J.; Fistanić, I.; Šarić, M. Procjena zagađenja od oborinskih voda u krškim područjima. // Građevinar. 54, 5 (2002), str. 265-275.

[3] Miletić, P., Heinrich-Miletić, M. Uvod u kvantitativnu hidrogeologiju, RGN, Zagreb, 1981.

[4] Šperac, M.; Dimter, S. Water contamination by fly ash from road construction. // The XXIV Conference of the Danubian Countries. Bled, Slovenia, 2008. str. 126-126.

[5] Šperac, M. Stochastic Approach to the Pollution of Groundwater. //7-mi simpozium za teoretska i primeneta mehanika. Struga, Republika Makedonija, 2000. str. 412-418.

[6] Dimter, S.; Rukavina, T. Use of industrial by-products in road construction: Environmental effects of fly ash.// 23th World Road Congress. Paris, France, 2007.

[7] Baldwin, G.; Addis, R.; Clark, J.; Rosevear, A. Use of industrial by products in road construction-water quality effects, CIRIA Report 167, 1997.

[8] Arnold, G.; Dawson, A.; Muller, M. Determining the extent of ground and surface water contamination adjacent to embankments comprising pulverized fuel ash (PFA), Project report by the University of Nottingham, School of Civil Engineering, Nottingham Centre for Pavement Engineering. 2002.

[9] Board, M. J., Reid, J. M., Fox, D. J., Grant, D. I. The long-term assessment of a cement stabilised/solidified contaminated made ground for use as a road construction material, Land Contamination&reclamation, 8(2) 2000, str.75-85.

[10] Sear, L.; Weatherley, A.; Dawson, A. The environmental impacts of using fly ash-the UK producers perspective.//

International Ash Utilization Symposium, Center for Applied Energy Research. University of Kentucky, 2003.

[11] Chesner, W.; Collins, R.; MacKay, M.; Emery, J. User Guidelines for Waste and Byproduct Materials in Pavement Construction. FHWA; FHWA Publication Number: FHWA-RD-97-148.

[12] Environmental Risk Assessment available. URL: www.ukqaa.org.uk (01.04.2010)

Authors' addresses
Adrese autora

Marija Šperac, Ph.D., Assistant Professor
Faculty of Civil Engineering Osijek
University J. J. Strossmayer in Osijek
16a Drinska, Osijek
e-mail: msperac@gfos.hr

Sanja Dimter, Ph.D., Assistant Professor
Faculty of Civil Engineering Osijek
University J. J. Strossmayer in Osijek
16a Drinska, Osijek
e-mail: sdimter@gfos.hr