FACTA UNIVERSITATIS
Series: Architecture and Civil Engineering Vol. 21, Nº 1, 2023, pp. 17-29
https://doi.org/10.2298/FUACE221224001D

Raview Paper

CONTEMPORARY METHODS FOR SOIL AND WATER PROTECTION FROM THE IMPACT OF RAILWAY TRAFFIC

UDC 656.2:626.86
502.171:546.212

Jelena Dimitrijević, Zoran Bonić, Dragan Milićević, Zlatko Zafirovski

[1]University of Niš, Faculty of Civil Engineering and Architecture in Niš, Serbia
[2]University SS. Cyril and Methodius, Faculty of Civil Engineering, Skopje, North Macedonia

Abstract. *One of the basic assignments of modern society is preserving the quality of freshwater resources, especially drinking water. Line facilities potentially pose a higher risk to the environment due to the large length of the extension and the diversity of the environment they may affect. Storm water drained from railway could pollute the surrounding land besides railway track. Based on the data from available research, it has been determined that heavy metals (iron, copper, zinc, manganese and chromium), polycyclic aromatic hydrocarbons (PAHs) and herbicides stand out in significant quantities from substances hazardous to the environment. This paper proposes the solutions using some self-sustainable techniques, based on the analysis railway drainage needs. The proposals that have been made refer to the open-air railway and railway station.*

Key words: *railway drainage, railway station drainage, self-sustainable drainage techniques*

1. INTRODUCTION

There is an increasing pressure on modern society to provide drinking water supply. Expressive urbanization and climate change are causing more frequent floods and other environmental disasters. Due to the increased global pollution, the study of pollutant migration is particularly intriguing since it aims to maintain the quality of fresh water resources, especially drinking water. Pollutant migration directly threats both the environment and human health, as it contaminates natural waterways and increases pollution [1].

Received December 24, 2022 / Revised February 22, 2023 / Accepted February 24, 2023
Corresponding author: Jelena Dimitrijević, University of Niš, Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14, 18000 Niš, Serbia
e-mail: jelena.dimitrijevic@gaf.ni.ac.rs

The railway with is defined as a line facility. Due to the variety of environments they may affect, line constructions may offer a greater risk to the environment. Groundwater and surface waters are particularly vulnerable to contaminating factors both during construction and later on during service [2]. Water rushes down the surface as a result of precipitation, carrying different particles. On this basis, harmful compounds also find their way into ground water or surface water (lakes and rivers). Because it is the primary supply of drinking water, ground water is very vital to humanity. [3, 1].

The surrounding area is contaminated by stormwater that is discharged from the railway track to its intended recipients, and certain harmful compounds are discharged directly into waterways. Some of the chemicals persist in the soil nearby and may eventually enter groundwater [4]. Several findings of previous and ongoing research on stormwater management on railroads, probable pollution sources, challenges to water management and prospective future strategies are discussed [5]. A 2005 study from Switzerland [6] was one of the first studies to be published on the subject of the mechanism of environmental pollution by contaminants railways. Prior to this time, individual studies were conducted without taking a comprehensive approach to the sources and categories of contaminants brought on by railroad traffic. Among the contaminants, polycyclic aromatic hydrocarbons (PAHs), heavy metals (iron, copper, zinc, manganese, and chromium) and herbicides (glyphosate) stand out [7]. Research has revealed that there is significant iron presence close to the railway track. Aluminum, calcium, silica and sulfur were also recorded in addition to iron [4]. The amount of precipitation in the atmosphere has a direct impact on the release of polycyclic aromatic hydrocarbons [8, 9]. Compared to the road traffic, total pollution emissions from railway systems are far lower, but not negligible [5]. Finding the sources of pollution is vital in order to regulate the outflow of dangerous compounds effectively. Pollution sources cannot be completely disregarded because they arise from the operation and maintenance of the transportation system [5, 10].

New approaches to stormwater management are required as a result of environmental issues, urbanization and climate change. To minimize these effects, stormwater management solutions must be developed [11]. New technologies for the drainage and purification of atmospheric water are looked to as the solution. The following names have been identified in self-sustaining drainage system literature reviews [12, 13]:

- Best Management Practices (BMP),
- Low Impact Development (LID),
- Sustainable Drainage System (SuDS),
- Water Sensitive Urban Design (WSUD),
- Low Impact Urban Design and Development (LIUDD).

In different regions of the world, comparable terms are defined by different names, which could cause overlap, contradiction and confusion [14]. The difference is reflected in terms of environmental laws that apply in countries around the world [15]. Technologies have names that are associated with a certain field and set of rules. Their differences also depend on whether they address certain drainage issues or the overall drainage system. Stormwater control methods used in LID (Low Impact Development) typically fall into two categories: infiltration-based methods and water retention methods [11].

2. Basic Requirements for Railways' Drainage Construction and Maintenance

The purpose of the drainage system, which consists of a network of connected pipes, is to remove surface and groundwater from sensitive structures [16]. Railway track drainage is a basic aspect in track construction and affects performance and maintenance requirements [17]. Improper operation of the drainage system or insufficient capacity can significantly damage the railway infrastructure.

The job of the railway drainage system is to drain water from several sources, including atmospheric water (rain and snow), water that flows onto the track from nearby areas, and groundwater [18]. The hydrological cycle is made up of the major components surface and groundwater, precipitation and evaporation. All water that is kept in permeable subsurface layer is considered groundwater. Runoff and all types of watercourses, both regulated and natural, are considered surface water [2].

Regarding the drainage of the railroad track, there are a number of requirements. In order to maintain the track's stability during periods of heavy rainfall, the fundamental one is to remove water from the railway track as quickly as possible [19]. Only when drainage routes, such as ballast, subballast, and the proper drainage channels, are as permeable as necessary can water successfully eliminate from the ballasted track [20, 21]. Depending on the kind of track, different drainage methods are used on railways. There is a traditional railroad with ballast and rails installed on a concrete foundation [17]. This article discusses the topic of ballasted railroad tracks in more detail.

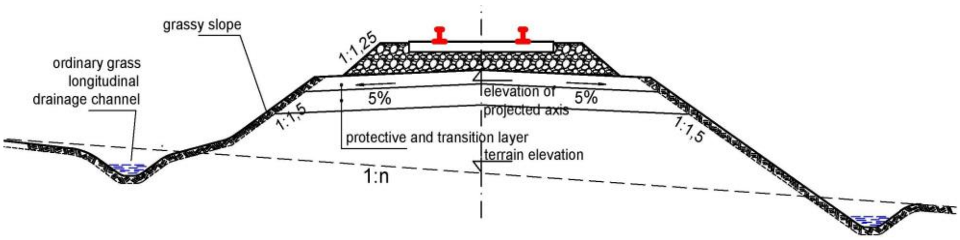


Fig. 1 Characteristic transverse profile of the railway track with drainage elements

Due to the high porosity of the ballast, which effectively drains water from the track, the layer under the ballast has an acceptable slope. The slope of the impermeable track body and subballast is typically 3 to 5 % [17, 21–23]. Depending on whether it is a single-track or double-track, the slope's orientation will change. This slope allows water to evacuate into drainage pipes. Drainage channels are linear in design and can be open or closed. On the case of a traditional drainage system, open-type channels in an open air railway are the most typical (Fig. 1). At the stations, closed drainage channels between the tracks are in use [23]. A characteristic of these types is that the transverse collectors positioned underneath the track are either directed straight to the recipient or to a larger common collector before the recipient. The nearest river is known as the recipient. Drainage channels can be categorized as longitudinal, transverse or axial depending on their position in relation to the track axis [17].

Further investigation into surface water is important since it may carry harmful compounds and may even get to groundwater. For open-air railways, a track and all supporting elements of the lower track layer are present. The following surfaces and objects at railroad stations are significant in terms of precipitation runoff, according to studies on the subject:

- station buildings, warehouse facilities, maintenance facilities for railroad vehicles and other facilities required for the control and efficient operation of traffic,
- platforms, plateaus and trails,
- a free green surface and
- railway track.

Because of the roof surfaces from which the water merges, all types of buildings are of interest. This water is transported to the nearest recipient via appropriate underground drainage channels after draining and passing through verticals. Furthermore, if it is a large station with a large number of facilities, runoff may exceed the capacity of the drainage system during critical periods of sudden and heavy rainfall, resulting in floods. Floods can seriously damage the track's and railways' overall stability. There will be pollutants inherent in railway traffic in the water flowing from the track, in addition to air pollutants that will be washed through the layer of ballast with atmospheric runoff. Aside from the tracks, the station's drainage channels accept catchments from all types of platforms and nearby free surfaces.

The central theme of the paper is the drainage of railway tracks in all configurations (open-air and in-station) using self-sustaining modern technologies. The primary goal is to propose a proper application of technologies that have previously been used in the drainage of other urban areas, now in the field of railways. The previous section provided an overview of the traditional drainage method and the classification of drainage elements on railways. In the following, we will not deal with these ways of drainage, but we will give certain proposals through a parallel analysis of drainage needs, but with the help of new technologies.

3. LID TECHNIQUES

Low Impact Development is defined as a special approach to construction or reconstruction that aims to mimic natural and hydrological processes in the area where it is being built, as close to their pre-construction state as possible [24]. Whatever they are called (LID, WSUD, or SuDS), self-sustaining drainage techniques have very similar goals [25, 26, 27]: hydrologic water cycle regulation in a sustainable way, maintaining or returning the flow regime as close to the natural level as possible, water quality protection and remediation (both surface and groundwater), conservation of water resources (treating stormwater as a source) and contributing to the improvement of a landscape and biodiversity of a treated area.

These objectives can be divided into two categories: regulation of hydrological processes (control of peak runoff and reduction of runoff volume) and maintenance of water quality (improving drainage and water storage) [19]. The performance of LID techniques is evaluated based on the achievement of these two goals [11]. The requirements and guidelines for design are determined by national or regional environmental legislation as well as hydro-climatic conditions [28]. An integrated LID approach to stormwater drainage involves a precise schedule of natural and engineering technologies that include: water reuse, water retention, infiltration, evaporation, filtration and plant treatment, all in a comprehensive system with the above-mentioned goal.

LID techniques are divided into two categories: infiltration-based techniques and retention-based techniques [11, 26]. LID elements can also be classified as dotted, linear, or superficial [29]. Following a review of available and tested self-sustaining techniques, only those that can be implemented in railway drainage conditions (stations and open-air railway) will be presented.

3.1. Open air railway

Ordinary grass swales are commonly used as drainage line structures on open-air railways (Fig. 1). A review of the available literature has not provided any data on the characteristics of such channels, both in terms of hydrological properties and water quality. Highway drainage channels are very similar in position and geometry to railway drainage channels. In this regard, we conducted a search and obtained the following results. Swales on highways and railways can only differ in size. Both are made of local soil with grassed channels to prevent erosion [21]. Because of their design and layout flexibility, these channels are useful for line structures. Their primary function is to filter or infiltrate runoff and reduce runoff velocity [11, 19, 30]. Swales with no special filtration properties can perform partial infiltration, as shown in [30]. The research was conducted in the case of highway drainage and it was discovered that with less precipitation, there is almost no runoff from the channel, because infiltration is complete. The channels are used to transport water during intense rainfall. Because of the low velocity caused by vegetation, sedimentation is the primary pollutant removal mechanism. Water quality can be achieved through infiltration, filtration, sorption (adsorption and absorption), and some biological processes [19, 31, 32]. According to (Stagge, 2012), grass swales significantly reduced TSS, metals (lead, copper and zinc) and cadmium. Only nitrate removal is improved by vegetated check dams in swales.

In [33], the effectiveness of pilot swales in managing water quality was tested for four micropollutants (zinc, glyphosate, pyrene and phenanthrene). Standard swales (silt loam soil) and filtering swales (sandy core area surrounded by silt loam embankments) were two different types of swales that were examined. High pollutant reduction was achieved by the filtering swale's ability to totally infiltrate water runoff. According to a study, filtering swales are more effective in treating pollutants than regular swales. Swales that receive lateral stormwater runoff do a better job of cleaning up micropollutants than those that receive longitudinal stormwater runoff. Another set of experimental results in [34] compared the hydraulic abilities of swales made of filters to those made of conventional soil. The ordinary swale was characterized by large overland flows. Filtering swales control the entire volume of inflow without using overland flow. The filtering swales were not affected by the tested longitudinal slope (2-4%). The inflow rate and medium water content were the only variables that were significant. In relation to the local rainfall pattern, the proposed models can be utilized to dimension and predict the performance of swales for filtration.

Swale design was primarily focused on hydraulic needs, ignoring the possibility of swales treating water quality. Well-maintained grass swales are the best option for reducing runoff volume and removing sediment and heavy metals. This type of green infrastructure uses natural processes to treat stormwater pollutants, providing the community with cost-effective environmental, social, and economic benefits [28, 35]. Laboratory and field experiments and observations are conducted in the winter and on days with low temperatures [36]. Swales designed to national guidelines perform satisfactorily under winter conditions in the Alpine region, although with reduced performance.

Permeable soil mix, geotextile or material layering to control flows within layers, and perforated drain pipe in a gravel drainage layer are typical bio swale design elements [32, 37]. The appearance of a grass channel with filter layers in the case of railway track drainage is suggested by the example in Fig. 2a.

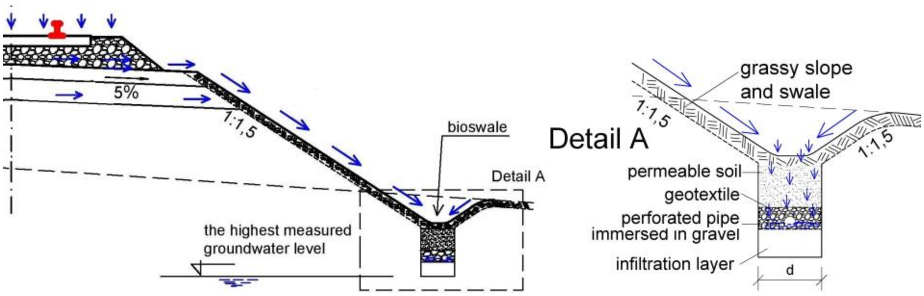


Fig. 2 a) Proposal for the location and shape of the bio swale, **2b** Detail of the bio swale

In general, the following considerations should be made when implementing a bio swale solution: the highest determined groundwater level must not enter the infiltration level, adjust the width of the channel to the performance possibilities and if possible, do not deviate too much from the width of standard channels so that the solution can be applied even when replacing standard channels with bio swales. In addition to the general requirements presented, the following should be addressed in greater detail with a determination of:

- the filter layer's content and dimensions,
- the drainage layer's content and dimensions.

3.2. Railway station

When analyzing the contents of a railway station for mixed traffic (passengers and cargo), all possible facilities that can be located at the station must be identified. Such stations can be quite simple, with only a couple of tracks, namely tracks for receiving and dispatching passengers and a track for train passing. Fig. 3 illustrates a much more complex type of station for mixed traffic with all possible facilities. In addition to passenger traffic, such stations deal with a variety of freight operations, including receiving, unloading, loading, shipping, repairing and maintaining vehicles, checking dimensions and weights and communicating directly with road traffic for the purpose of taking over and transporting goods.

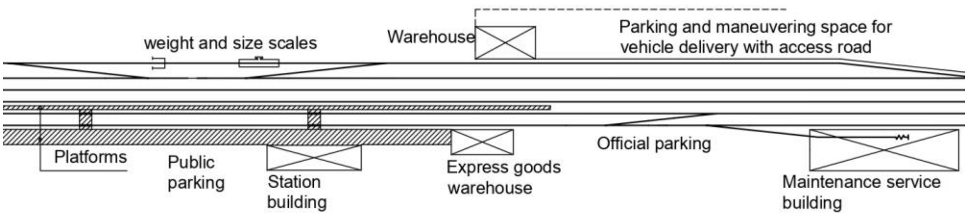


Fig. 3 Standard content of a railway station for mixed traffic, without showing entrance and exit points

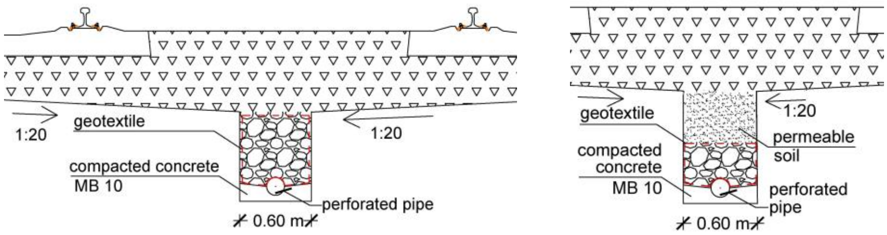
Rainwater tanks (rain barrels) are a simple solution for reducing stormwater runoff. Roof runoff is captured and stored in a typical rainwater tank system. Runoff collected could be reused or simply collected for flood prevention. The water in barrels can be used for technical purposes or to irrigate green spaces. The primary goal of installing barrels is to reduce the volume of draining, particularly during intensive rainfall, so that the drainage network and thus the final recipient are relieved. It is perfectly acceptable to reduce the peak runoff until the amplitude precipitation has passed. Following that, if similar precipitation is expected and the recipient can easily receive that amount of water, the affected water can be discharged into the recipient. [27]. There is also the possibility of screening stormwater runoff [27, 40]. Rain barrels are commonly used. Depending on the needs of the observed area, the reasons for use range from hydrologic regulations to reuse [41]. Furthermore, rainwater from rain barrels can be directed to the appropriate LID elements for purification before being discharged into the recipient. If it is not possible to place them above ground due to a lack of space, an underground variant with electric pumps and the required overflow branch can be planned [38]. These elements of LID technology are absolutely applicable in the case of railway stations, owing to the presence of facilities under the roof.

Permeable pavement is another technique used for railway station purposes. Water can pass through permeable pavements into the underground porous medium [38]. Porous asphalt pavers, pervious concrete and permeable interlocking concrete pavement are examples of permeable paving [39]. Grid pavement systems are another type of concrete element that can be used in place of permeable paving [27]. Asphalt and concrete are both suitable for the surface paving of platforms and pedestrian paths at railway stations.

According to a review of the literature in [42], the use of permeable concrete pavements provides several environmental benefits, including stormwater runoff regulation, water quality achievement (via the infiltration process), noise reduction, improved durability and urban heat island reduction. When permeable concrete pavement is subjected to winter maintenance activities, its long-term effectiveness is compromised. Mix design, pavement design, construction practice, service environment and maintenance activities all influence these characteristics. A new type of permeable concrete pavement known as high-strength clogging resistant permeable pavement can overcome standard permeable concrete pavement's low strength and sensitivity to sediment clogging. This is significant because they have the potential to be used in areas with high traffic loads, which are ideal for delivering goods to station warehouses. There is comparison provided in [43] of standard permeable concrete pavements to the new one. Asphalt layers performed admirably in terms of stability and permeability, depending on the composition [44]. Pervious concrete had slightly better filtration properties than other types of permeable pavements [45]. Permeable pavement modules made of concrete blocks provide good filtering results, but maintenance is critical. Hydrological performance and pollutant removal are satisfactory during the structure's life cycle with proper maintenance [46].

According to [39], permeable pavements can be categorized by the type of layers had been using, which are selected based on their purpose. The proper type for heavy vehicle loads consists of pavement surface permeable only. Other under layers are not permeable. In case of roads and parking lots with light traffic load, both surface and base layer are permeable. For pedestrian zones, a fully permeable pavement structure is appropriate. [39]. When installing these surfaces at railway stations, it is essential to differentiate between pedestrian paths (paths and platforms) and vehicle approach areas (access road to the warehouse and space for maneuvering).

Drainage filter channels are planned between the tracks, which are classified as underground closed channels due to their location. They accept the drainage from the track and guide it to the transverse collectors [17, 23]. They are composed of a coarse aggregate layer, perforated drainage pipe and a concrete base (Fig. 4a). Geotextile is used to keep small fractions from affecting the lower layers. These channels are about 60 cm wide. The appearance of a classic drainage channel is shown in Fig. 4a, and the proposal to improve its filter properties is convenient to develop in the direction of adding a single filter layer, as shown in Fig. 4b. Since there is no grass cover, this solution is very similar to the proposal for bio swales. As ballast pollution significantly reduces its permeability, ballast maintenance is considered crucial [47].



a) b)

Fig. 4 a) Classic drainage channel example, b) Possible appearance of a drainage channel with biofilters

Water biofiltration is a method of improving water quality by filtering it through biologically formed media. A multidisciplinary approach is required for successful design and implementation. A typical biofiltration system is made up of a vegetated swale or basin that is overlaid with a porous, sand-based filter medium and a drainage pipe at the bottom. Biofiltration systems' hydrological function is reflected in lower runoff volumes and peak flow. Another goal of biofiltration systems is to improve the quality of water discharged into urban waters through physical, chemical and biological processes [48, 49]. It is preferable to use the variant with a drainage pipe for the needs of a railway station. In terms of performance, this is a surface structure that is simple to install. There are several typical layers in a biofilter, including a mulch layer, ponding zone, filter media, transition layer and drainage layer. Depending on the typical water volume, the drainage layer could have a drainage pipe or an infiltration layer just below it. Typically, transition and drainage layers are found in the submerged zone [1, 49].

In Table 1 of Adoption Guidelines for Stormwater Biofiltration Systems [49], research findings about pollutant removal capacity of biofilters that are optimally designed, constructed and maintained are represented.

It is demonstrated in [50] the effectiveness of filter layers in removing total petroleum hydrocarbons (TPHs), glyphosate, dibutyl phthalate (DBP), bis-(2-ethylhexyl) phthalate (DEHP), pyrene and naphthalene by more than 80%. The first variant was made of sand, while the second was made of loamy sand, with drainage underlay in both. The loamy sand layer produced better filtration results. The frequency of precipitation had a greater influence on the efficiency of the filter layer in removing pollutants than their volume, confirming that the efficiency is higher when the distance between significant precipitations is longer. These studies were carried out to determine the efficiency of biofiltration as a pretreatment in the purification of drinking water. According to this systematic review, the percentage of pollutants removed is as follows: nitrogen (N) >50%, phosphorus (P) >65%, sediments >95%, heavy metals >90%, pathogens >90%, hydrocarbons (TPHs) >99%, PAHs (pyrene and naphtalene) >80%, pesticides and herbicides (glyphosate >80%, atrazine and simazine 20 to 50%), THMs (Chloroform) 20-50%, phthalates (DBP, DEHP) >80% and phenols (PCP,phenol) 50 to >80%.

Table 1 Removal and transformation ways of stormwater pollutants according to [49]

Sediment	Settlement during ponding and physical filtration by media.
Nitrogen	Nitrification, denitrification, biotic assimilation, decomposition, physical filtration of sediment-bound fraction and adsorption.
Phosphorus	Physical filtration of sediment-bound fraction, adsorption, biotic assimilation and decomposition.
Heavy metals	Biotic assimilation by plants and microbes, physical filtration of sediment-bound fraction and oxidation/reduction reactions.
Pathogens	Adsorption-desorption, physical filtration by media and die off (natural or due to competition or predation)
Organic micropollutants *	Adsorption and Biodegradation

*hydrocarbons, pesticides/herbicide, polycyclic aromatic hydrocarbons (PAHs), phenols, phthalates

Stormwater biofilters are a popular stormwater harvesting measure due to their high treatment performance, self-sustainability, and compatibility with urban areas [49, 51]. A review [1] discovered that stormwater biofilters provide very good results as a pre-treatment for drinking water purification. The only concern could be finding available space at the station, but that is a genuine problem that can only be resolved as such.

4. Discussion

The paper describes some of the LID technologies that have already been tested on some urban designs of green infrastructures. The majority of these solutions have proven to be extremely effective in terms of hydrological characteristics and pollutant reduction in runoff. The general division of these technologies is made based on the application's priorities, whether it is the regulation of runoff rate and peak runoff, which belongs to hydrological properties, or the reduction of runoff pollution. The techniques are known as retention and filtration in this context. Other areas at stations and official locations along the open-air railway can be treated as urban areas and facilities. As a result, the applied solutions can be taken from urban practice. These solutions involve drainage for all high-rise buildings, pedestrian areas (paths and platforms), access roads to warehouse buildings and express goods and parking spaces at the station building.

According to the exposed, we can offer suggestions based on the exposed drainage method on how to arrange the surfaces in which atmospheric confluence occurs in order to prevent pollutants from reaching watercourses. In general, runoff is categorized into two kinds: those that come into contact with track content and those that are only reached by air pollutants.

Table 2 Individual presentation of LID technology elements' application with possible paths of water movement

Draining surface	Primary measure	Secondary measure	Final destination
Open-air railway	Bio swale	Biofiltration area*	▪ Biofiltration area ▪ Recipient
Railway track (station)	Drainage filtration channel	Biofiltration area*	▪ Biofiltration area ▪ Recipient
Offices and maintenance buildings	Rain harvesting (rain barrels and tanks)		▪ Green areas (irrigation) ▪ Technical use ▪ Recipient
Paths	Permeable pavement ▪ Porous concrete ▪ Porous asphalt ▪ Concrete blocks		▪ Recipient
Platforms	Permeable pavement ▪ Porous concrete ▪ Porous asphalt ▪ Concrete blocks		▪ Recipient
Access roads	Permeable pavement ▪ Porous concrete ▪ Porous asphalt	Biofiltration area*	▪ Biofiltration area ▪ Recipient
Parking	Permeable pavement ▪ Porous concrete ▪ Porous asphalt	Biofiltration area*	▪ Biofiltration area ▪ Recipient

*Application of biofiltration technique depends on the available space. Also, depending on the amount of precipitation, it may be the final destination of runoff if the capacity of biofilter can receive the affected amounts.

5. CONCLUSION

The stormwater drainage problem is solved through integrated, multidisciplinary teamwork and the implementation of a series of administrative and technical measures aimed at mitigating the negative effects of altered hydrological regimes of runoff and pollution of atmospheric water carried into water recipients. Green infrastructure components are ideal for promoting and achieving environmental sustainability. These are innovative approaches that rely on environmental principles for planning and designing in accordance with natural drainage methods. In comparison to the traditional approach, the most significant advantage of an integrated approach to atmospheric planning and water management is its extremely positive impact on the characteristic biophysical features of the urban environment (prevents the formation of thermal islands, reduces the negative impact of atmospheric waters on the urban area and the recipient) with optimal economic effects. It alleviates or even eliminates the effects of climate change by improving the microclimate and mitigating the effects of drought [49].

More study demonstrates the advantages of filtration channels over ordinary ones. Although the results shown are for highway drainage, nothing prevents us from applying the same techniques to an open-air railway. The situation is similar to the other LID technology elements presented at railway stations. Their application is more significant because, with minor modifications, these technologies can also be used to rebuild existing traditional drainage systems.

The review of available literature leads to the conclusion that there is no evidence of the use of LID technologies for railway track drainage, both in the open air railway and in the railway station. The proposal in this paper should be further implemented on the specific example of a railway and the hydrological performance we could really expect from such solutions should be determined using an appropriate software package, as well as the percentage of wastewater treatment before discharging it into the recipient. For the time being, no other comparisons can be made because there are no known practice examples of this type.

REFERENCES

1. W. Feng, Y. Liu and L. Gao, "Stormwater treatment for reuse: Current practice and future development-A review", Journal of Environmental Management, Vol.301, 113830, 2022.
2. E. Murnane, A. Heap and A. Swain, Control of water pollution from linear construction projects. Technical guidance, CIRIA, CIRIA C648, London, 2006.
3. S.H.H. Al-Taai, "Ground water: A study of its importance, its sources, and the causes of its pollution", Materials Today: Proceedings, 2022, https://doi.org/10.1016/j.matpr.2021.05.557
4. R. Lorenco, R. Kaegi, R. Gehrig and B. Grobéty, "Particle emissions of a railway line determined by detailed single particle analysis", Atmospheric Environment , Vol.40, pp.7831-7841, 2006.
5. P.T. Vo, H.H. Ngo, W. Guo, J.L. Zhou, A. Listowski, B. Du, Q. Wei and X.T. Bui, "Stormwater quality management in rail transportation – Past, present and future", Science of the Total Environment, 512-513, pp.353-363, 2015.
6. M. Burkhardt, L. Rossi, N. Chévre, M. Boller, L. Steidle, J. Abrecht, F. Gächter, S. Knabl and Kuppelwieser, Gewässerschutz an Bahnanlagen- Emittierte Stoffe im Normalbetrieb der SBB sowie Grundlagen zu deren Umweltverhalten (Water protection at railroads – emitted substances from regular operation of SBB and fundamentals of their environmental behavior), Report of the Eawag, Duebendorf, Switzerland, 2005
7. M. Burkhardt, L. Rossi and M. Boller, Release of various Substances to the Enviroonment by Regular Railway Operations, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland, 2014
8. S.-M. Kang, J.J. Morell, J. Simonsen and S. Lebow, "Creosote movement from treated wood immersed in fresh water", Forest Products Journal, Vol.55, No.12, pp.42-46, 2005.
9. L. Becker, G. Matuschek, D. Lenoir and A. Kettrup, "Leaching behaviour of wood treated with creosote", Chemosphere, Vol.42, pp.301-308, 2001.
10. M. Burkhardt, L. Rossi and M. Boller, "Diffuse release of environmental hazards by railways", Desalination, Vol.226, pp.106-113, 2008.
11. K. Eckart, Z. McPhee and T. Bolisetti, "Performance and implementation of low impact development –A review", Science of the Total Environment 607-608, pp.413-432, 2017.
12. J.S. Rijke, R.E. De Graaf, V.H.M. Van de Ven, R.R. Brown and D.J. Biron, Comparative case studies towards mainstreaming water sensitive urban design in Australia and the Netherlands, 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK, 2008
13. L.M. Ahiablame, B.A. Engel and I. Chuabey, "Effectiveness of Low Impact Development Practices: Literature Review and Suggestions for Future Research", Water Air Soil Pollut, Vol. 223, pp.4253-4273, 2012.
14. T.D. Fletcher, W. Shuster, W.F. Hunt, R. Ashley, D. Butler, S. Arthur, S. Trowsdale, S. Barraud, A. Semadeni-Davies, J.-L. Bertrand-Krajewski, P.S. Mikkelsen, G. Rivald, M. Uhl, D. Dagenais and M. Viklander, "SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage", Urban Water Journal, Vol.12, No.7, pp.525-542, 2014.
15. C.L. Mak, Linking sustainable drainage system (SuDS) together with ecosystem services and disservices: New connections in urban ecology, Ecosystem and Environment Research Centre, School of Environment and Life Sciences, University of Salford, Salford, UK, 2015.
16. T. Spink, I. Duncan, A. Lawrence, M. MacDonald, A. Todd and Atkins, Transport infrastructure drainage: condition appraisal and remedial treatment, CIRIA, Griffin Court, 15 Long Lane, ECIA 9PN, UK, 2014
17. R. Sañudo, M. Miranda, C. García and D. García-Sanchez, "Drainage in railways", Construction and Building Materials, Vol.210, pp.391-412, 2019.
18. F.J. Heyns, Railway track drainage design techniques, University of Massachusetts Amherst, USA, 2000
19. U.S. Environmental Protectional Agency(USEPA), Low Impact Development (LID): A Literature review, U.S. Environmental Protection Agency, Washington, D.C., 2000.

20. Pravilnik o tehničkim uslovima i održavanju gornjeg stroja železničkih pruga, Beograd, Službeni glasnik Republike Srbije, 2016.
21. Pravilnik o tehničkim uslovima i održavanju donjeg stroja železničkih pruga, Beograd, Službeni glasnik Republike Srbije, 2016.
22. D. Li, J. Hyslip, T. Sussmann and S. Chrismer, Railway Geotechnics, Chapter 3– Substructure, CRC Press, 2015, https://www.routledgehandbooks.com/doi/10.1201/b18982-4
23. S. Fisher, B. Eller, Z. Kada and A. Németh, Railway construction, UNIVERSITAS-GYŐR NONPROFIT KFT, GYŐR, 2015.
24. USEPA (United States Environmental Protection Agency), Low Impact Development, 2016
25. Y. Huang, Z. Tian, Q. Ke, J. Liu, M. Irannezhad, D. Fan, M. Hou and L. Sun, Wiley Interdisciplinary Reviews:Water, 2020, DOI:10.1002/wat2.1421
26. T.D. Fletcher, H. Andrieu and P. Hamel, "Understanding, management and modeling of urban hydrology and its consequences for receiving waters: A state of the art", Advances in Water Resources, Vol.51, pp.261-279, 2013.
27. A. Hoban, Water Sensitive Urban Design Approaches and Their Description-Chapter 2, Potential, Design, Ecological Health, Urban Greening, Economics, Polices and Community Perceptions, pp.25-47, Brisbane, Australia, 2019.
28. S.A. Ekka, H. Rujner, G. Leonhardt, G.-T. Blecken, M. Viklander and W.F. Hunt, "Next generation swale design for stormwater runoff treatment: A comprehensive approach", Journal of Environmental Management, Vol.279, 111756, 2021.
29. L.A. Rossman, Storm Water Management Model User's Manual, Version 5.0, Water Supply and Water Resources Division National Risk Management Research Laboratory, Cincinati, 2010.
30. P.A. Davis, J.H. Stagge, E. Jamil and H. Kim, "Hydraulic performance of grass swales for managing highway runoff", WATER RESEARCH, Vol.46, pp.6775-6786, 2012.
31. J.H. Stagge, A.P. Davis, E. Jamil and H. Kim, "Performance of grass swales for improving water quality from highway runoff", WATER RESEARCH, Vol.46, pp.6731-6742, 2012.
32. S. Ekka and B. Hunt, Swale Terminology for Urban Stormwater Treatment, Urban Waterway series , NC State University Cooperative Extension, Raleigh, North Carolina, 2020, Available at: https://www.researchgate.net/publication/342899063_Swale_Terminology_for_Urban_Stormwater_Treatment
33. A. Fardel, P.-E. Peyneau, B. Béchet, A. Lakel and F. Rodriguez, "Performance of two contrasting pilot swale designs for treating zinc, polycyclic aromatic hydrocarbons and glyphosate from stormwater runoff", Science of the Total Environment, Vol.743, 140503, 2020.
34. C. Monrabal-Martinez, J. Aberle, T.M. Muthanna and M. Orts-Zamorano, "Hydrological benefits of filtering swales for metal removal", Water Research, Vol.145, pp.509-517, 2018
35. C. Davies, R. Macfarlane and C. Mcgloin, Green infrastructure, 2017, URL: https://www.epa.gov/green-infrastructure
36. S. Fach, C. Engelhard, N. Wittke and W. Rauch, "Performance of infiltration swales with regard to operation in winter times in an Alpine region", Water Science and Technology, Vol.63, Iss.11, 2658-2665, 2011.
37. R.A. Purvis, R.J. Winston, W.F. Hunt, B. Lipscomb, K. Narayanaswamy, A. McDaniel, M.S. Lauffer and S. Libes, Evaluating the Water Quality Benefits of a Bioswale in Brunswick Country, North Carolina (NC), USA, Water 10, number 2 :134., 2018, https://doi.org/10.3390/w10020134
38. J. Hoyer, W. Dickhaut, L. Kronawitter and B. Weber, Water Sensitive Urban Design- Principles and Inspiration for Sustainable Stormwater Management in the City of Future- Manual, Berlin, ISBN 978-3-86859-106-4, 2011.
39. Y. Zhu, H. Li, B. Yang, X. Zhang, S. Mahmud, X. Zhang, Bo. Yu and Y. Zhu, "Permeable pavement design framework for urban stormwater management considering multiple criteria and uncertainty", Journal of Cleaner Production, *Vol.293*, 126114, 2021.
40. M.J. Burns, A.R. Ladson and T.D. Fletcher, Chapter 13- Impact of rainwater tanks on urban hydrology and stormwater quality (Rainwater Tank Systems for Urban Water Supply – Design, Yield, Energy, Health Risks, Economics and Social Perceptions, IWA Publishing, London), 2019.
41. A.K. Sharma, D. Begbie and T. Gardner, Rainwater Tank Systems for Urban Water Supply – Design, Yield, Energy, Health Risks, Economics and Social Perceptions, IWA Publishing, London, 2019.
42. N. Xie, M. Akin and X. Shi, "Permeable concrete pavements: A review of environmental benefits and durability", Journal of Cleaner Production, Vol.210, pp.1605-1621, 2019.
43. A. Kia, J.M. Delens, H.S. Wong and C.R. Cheeseman, "Structural and hydrological design of permeable concrete pavement", Case Studies in Construction Materials, *Vol.15*, e00564ts, 2021.
44. M.N. Akhtar, A.M. Al-Shamrani, M. Jameel, N.A. Khan, Z. Ibrahim and J.N. Akhtar, "Stability and permeability characteristics of porous asphalt pavement: An experimental case study", Case Studies in Construction Materials, Vol.15, e00591, 2021

45. W.R. Selbig, N. Buer and M.E. Danz, "Stormwater-quality performance of lined permeable pavements systems", Journal of Environmental Management, Vol.251, 109510, 2019.
46. M. Kamali, M. Delkash and M. Tajrishy, "Evaluation of permeable pavement responses to urban surface runoff", Journal of Environmental management, Vol.187, pp.43-53, 2017
47. C. Paiva, M. Ferreira and A. Ferreira, "Ballast drainage in Brazilian railway infrastructures", Construction and Building Materials, Vol.92, pp.58-63, 2015
48. A. Deletic, D. McCarthy, G. Chandrasena, Y. Li, B. Hatt, E. Payne, K. Zhang, R. Henry, P. Kolotelo, A. Randjelovic, Z. Meng, B. Glaister, T. Pham and J. Ellerton, Biofilters and wetlands for stormwater treatment and harvesting, Cooperative Research centre for Water Sensitive Cities, Monash University, Australia, ISBN 978-1-921912-22-1, 2014.
49. E. Payne, B. Hatt, A. Deletic, M. Dobbie, D. McCarthy and G. Chandrasena, Adoption Guidelines for Stormwater Biofiltration Systems, Cooperative Research Centre for Water Sensitive Cities, Monash University, Australia, ISBN: 978-1-921912-27-6, 2015.
50. K. Zhang, A. Randelovic, D. Page, D.T. McCarthy and A. Deletic, "The validation of stormwater biofilters for micropollutant removal using in situ challenge tests", Ecological Engineering, Vol.67, pp.1-10, 2014.
51. K. Vijayaraghavan, B.K. Biswal, M.G. Adam, S.H. Soh, D.L. Tsen-Tieng, A.P. Davis, S.H. Chew, P.Y. Tan, V. Babovic and R. Balasubramanian, "Bioretention systems for stormwater management: Recent advances and future prospects", Journal of Environmental Management, Vol.292, 112766, 2021.

SAVREMENE METODE ZAŠTITE TLA I VODE OD UTICAJA ŽELEZNIČKOG SAOBRAĆAJA

Jedan od osnovnih zadataka savremenog društva je očuvanje kvaliteta slatkovodnih resursa, posebno vode za piće. Linijski objekti potencijalno predstavljaju veći rizik po životnu sredinu zbog velike dužine prostiranja i raznovrsnosti okoline na koju mogu uticati. Atmosferske vode koje se odvode sa trupa železničke pruge mogu zagaditi i površine u neposrednoj blizini. Prema dostupnim istraživanjima, od materija opasnih po životnu sredinu u značajnim količinama izdvajaju se teški metali (gvožđe, bakar, cink, mangan i hrom), policiklični aromatični ugljovodonici (PAHs) i herbicidi. U radu su predložena neka od rešenja samoodrživih tehnologija, a na osnovu analize potreba pri odvodnjavanju trupa železničkih pruga. Predlozi koji su dati, odnose se na prugu na otvorenom i železničku stanicu.

Ključne reči: *drenaža pruge, drenaža železničke stanice, samoodrživi sistemi za odvodnjavanje*