Open Eng. 2016; 6:412–417 DE GRUYTER OPEN

ICEUBI 2015* Open Access

Paulo Belizario, Paulo Scalize, and Antonio Albuquerque*

Heavy Metal Removal in a Detention Basin for Road Runoff

DOI 10.1515/eng-2016-0060
Received Mar 31, 2016; accepted Jun 23, 2016

Abstract: Road runoff produced during rainfalls has significant pollutant load, which can cause important environmental impacts on waste and soil. The efficiency of a detention basin for removing heavy metals (Cr, Cu and Zn) in road runoff was evaluated for 8 rainfalls over one year with different intensities (between 16 mm and 103 mm) and durations (higher than 3 hours). The basin showed good performance for removing all metals for precipitation intensities between 16 mm and 103 mm and rainfall durations up to 3 hours. The volume of the basin is suitable for retaining all the road runoff coming from rainfalls with intensities lower than 29.4 mm and duration longer than 6 hours. This type of monitoring should be introduced in Environmental Monitoring Plans of roads because it allows evaluating the effectiveness of treatment systems and preventing the possible impacts of discharges into the environment.

Keywords: Detention basin; environmental monitoring; heavy metals removal; impact prevention; road runoff; rainfall intensity

1 Introduction

Road runoff is produced by rainwater runoff in contact with roads and surrounding watershed. In roads, pollutants are produced due to wear of the track and security guards (*e.g.* hydrocarbons, copper, chromium, lead, nickel and zinc), other are released by vehicles (*e.g.*, copper, cadmium, chromium, nickel, lead and zinc) and transported from surrounding soil (*e.g.* biodegradable organic matter, pesticides, nitrogen and phosphorus) [1, 2].

The characteristics of this stream are variable and depend on factors such as road type, average daily traffic (ADT), vehicle type and traffic conditions, use of the surrounding soil, vegetation type, intensity and duration of rainfall, dry period without precipitation, type of drainage system and speed and wind direction [1, 3].

Road runoff is considered a source of diffuse pollution, given their discontinuous nature only occurring during rains, which can cause significant environmental impacts on surface water, groundwater and soil over long distances [4]. To minimize the effects of polluting the environment, this stream is usually treated in infrastructure downstream road drainage systems, which normally include bar tracks channels, grit chambers, oils and fats removing tanks, and detention and storage basins or retention basin or infiltration basins, with or without vegetation, for removing contaminants [1, 5–7].

To evaluate the effectiveness of treatment basins in removing pollutants it is necessary to monitoring several rainfalls throughout years, with different intensity and duration of precipitation, and collecting water samples of road runoff along the rainfall [7–9]. This procedure allows identifying the *first flux*, which usually occurs in the first minutes and contains the higher pollutant load [3, 10]. Albuquerque *et al.* [9] has found higher pollutant loads in high intensity rainfalls associated to previous low periods of dry weather conditions, which that somehow contradicts the results and conclusions of Kayhanian *et al.* [11] and Polkowska *et al.* [10].

The results of monitoring performed by Barbosa [3], Antunes and Barbosa [12], Crabtree *et al.* [8], Kayhanian *et al.* [11] and Polkowska *et al.* [10] present different concentrations for organic materials, nitrogen, phosphorus and heavy metals (Cd, Cu, Cr, Fe, Ni, Pb and Zn). The determinations were made in the drainage basin, drainage ditches, junction boxes and at inlet of treatment systems. Thus, the characterization of pollutants is an important

Paulo Belizario: Department of Civil Engineering and Architecture, University of Beira Interior and FibEnTech, Calcada Fonte do Lameiro, 6200-001 Covilhã, Portugal
Paulo Scalize: School of Civil and Environmental Engineering, University Federal of Goiás, Av. Universitaria, 1488, Setor Universitaŕio, CEP 74605-220, Goiañia-GO, Brazil; Email: pscalize.ufg@gmail.com
***Corresponding Author: Antonio Albuquerque:** Department of Civil Engineering and Architecture, University of Beira Interior and FibEnTech, Calcada Fonte do Lameiro, 6200-001 Covilhã, Portugal; Email: antonio.albuquerque@ubi.pt
* International Conference on Engineering 2015 – 2–4 Dec 2015 – University of Beira Interior – Covilhã, Portugal

step in this type of study because, besides allowing the early identification of potential negative environmental impacts, and for the definition of mitigation measures, it allows having data for the design or assessment of treatment systems.

Heavy metals present in the road runoff result mainly from combustion processes in vehicles and are responsible for releasing Pb. Tire wear is a strong source of Zn, the brake wear is a source of Cu, Pb and Cr, and engine wear and stroke liquids are a source of Cr and Zn [3, 4]. Typically, the main fraction of metal is in suspension associated to suspended solids or colloid organic matter, and only a small fraction of it, is in the dissolved form, which is considered the most toxic part [2, 13]. It is therefore important assessing if heavy metals are conveniently removed in the retention and treatment structures sized for pollution control of road runoff.

The objective of this study was to evaluate the efficacy of a detention basin in removing chromium (Cr), copper (Cu) and zinc (Zn), which are typical heavy metals present in road runoff and can cause significant environmental impacts on the environment.

2 Materials and Methods

2.1 Location and characteristics of the detention basin

The detention basin (Figure 1) used for this study is located next to the access of the A23 motorway (Covilhã, Portugal), very close to the Zêzere river, in an agricultural area classified as sensitive to pollution by the Environmental Impact Study of the motorway [14]. The drainage catchment has an area of 10 097 m^2 of agricultural land and an area of 4 275 m^2 of road [14]. By considering the drainage coefficients presented by Chow *et al.* [15], 0.9 for roads and 0.4 for agricultural soils, the effective drainage areas are 3 847 m^2 and 4 038 m^2, respectively.

The basin has a total height of 2.35 m, a maximum surface area of 172.6 m^2 and an effective volume of 232 m^3. The structure was sized for a minimum of 3 hours of detention time and to store the entire volume of a runoff with a flowrate of 21.5 L/s. According to calculations of Belizário [14], the basin can retain all runoff from rainfalls up to 29.4 mm and lasting less than 6 hours (*i.e.* it can retain a runoff less than 232 m^3).

The basin only retains the volume between two consecutives precipitation and should be effective in removing the pollutant load by precipitation (*e.g.*, heavy metals) and biodegradation (*e.g.* organic matter) [14].

Figure 1: Detention basin for road runoff.

2.2 Water sampling

To assess the efficacy of the basin in removing heavy metals, it was considered 8 rainfalls over one year with different intensities (between 16 mm and 103 mm) and durations (higher than 3 hours). Level measurements were performed for determining the inflow flowrate to the basin and water samples were collected at the inlet and outlet of the structure, for the following periods of time: 0, 0.17, 0.33, 0.5, 0.67, 0.92, 1.17, 1.67, 2.17, 3.17, 4.17, 5.17, 6.17 and 7.17 hours after the beginning of each precipitation.

For level measurement it was installed an ultrasonic level meter HydroRanger Plus (Milltronics, USA), with a data acquisition system DAS 8000 over a small Bazin weir, installed in a channel with a 0.6 m width upstream the entrance to the basin. The flow law Bazin was used for estimating the flowrate according the formulation given in Quintela [16]. Water samples were collected manually and sent to laboratory for determination of the following quality parameters: Cr, Cu and Zn, according to the methods defined in APHA-AWWA-WEF [17]. The pH was measured locally with a sensor Sentix 41 and a multiparameter Multiline P4 meter (WTW, Germany).

3 Results and Discussion

The flowrate measurement results show that in the rains of February 19, March 24, October 25 and November 16, the average flowrate was 25.8 L/s, 34.8 L/s, 33.7 L/s and 33.6 L/s,

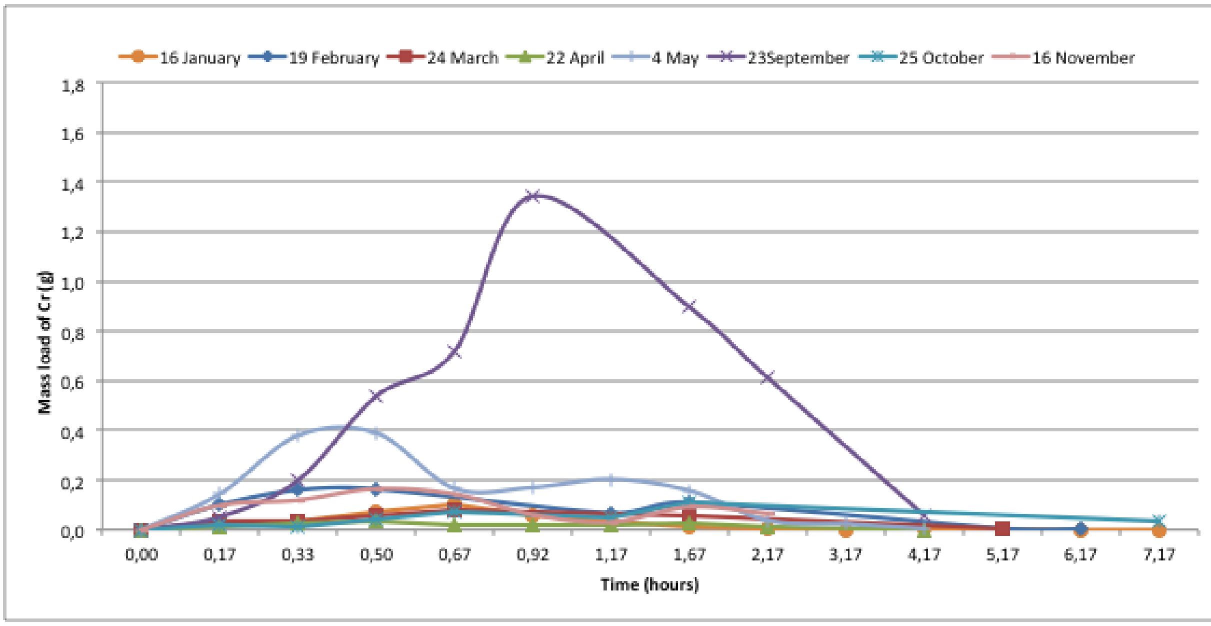

Figure 2: Variation of the mass load of Cr for the 8 raining events.

higher than the average reference value given for the retention of pollutants in the basin, which is 21.5 L/s [14].

After calculating the accumulated volume that entered the basin after each rain, it was found that the capacity of the detention basin was exceeded after 1h 40min in 4 events (February, March, October and November), and therefore there were discharge of the final effluent into the Corges stream for the remainder of the rainfall. The average time of detention in these 4 events were 2.5, 1.85, 1.91 and 1.92 hours, that are lower than the values suggested internationally as suitable for a good metal removal [3].

Thus, for events with precipitation exceeding 29.4 mm (*i.e.* with intensities exceeding 8.15 mm/h) and duration between 3 h and 7 h, the basin has no holding capacity for all the road runoff volume and the pollutant load is discharged into the environment. The negative consequences of this circumstance may be minimized by adding an adsorption material in order to retain more metal loads, since it is difficult to increase the volume of the basin.

It is common to characterize the quality of road runoff through its average local concentration, which is the average or the median of the average concentrations of monitored events [3, 11]. When the number of events monitored is relatively low, the calculation of the average local concentration is more indicated by the average of the average concentrations of events, or simply by analysing the latter parameter, as seen in Barbosa [3].

To better assessing the mass of heavy metals entering the basin over the precipitations and in all the events, it was calculated its average mass load between two successive water samplings, using the Eq. (1). The calculated values correspond to the pollutant mass, which entered the basin at each sampling time interval [14].

The variation of mass load for the 3 heavy metals over the 8 rainfalls is shown in Figures 2 to 4. The pH ranged between 7.0 and 7.3 in all rains, values that have with no interference in the removal of metals.

$$CM_{i(n,n+1)} = \left(\frac{C_{i(n)} \times Q_n + C_{i(n+1)} \times Q_{(n+1)}}{2} \right) \times \Delta t_{(n,n+1)} \quad (1)$$

$CM_{i(n,n+1)}$ - Mass load of the parameter i in the times interval $\Delta t_{(n,n+1)}$ (g)
$C_{i(n)}$ - Concentration of the parameter i the sampling perion n (g/m^3)
Q_n - Flowrate in the sampling period (n) (m^3/minutes)
$Q_{(n+1)}$ - Flowrate in the sampling period ($n+1$) (m^3/minutes)
$C_{i(n+1)}$ - Concentration of the parameter i in the sampling period ($n+1$) (g/m^3)
$\Delta t_{(n,n+1)}$ - Time interval between sampling in the periods n $e(n+1)$ (minutes)

Zn had the higher concentration over the monitored events, with maximum values close to 1 mg/L, while Cr and Cu reached maximum values of approximately 0.04 mg/L. These values are within the ranges presented by'[3] and [12] in studies developed in Portuguese roads, where it was observed Zn concentrations from 2 to 6 mg/L, but for approximately ten times the ADT, different drainage conditions, approximately five times the drainage areas and precipitation characteristics. The concentrations of the three

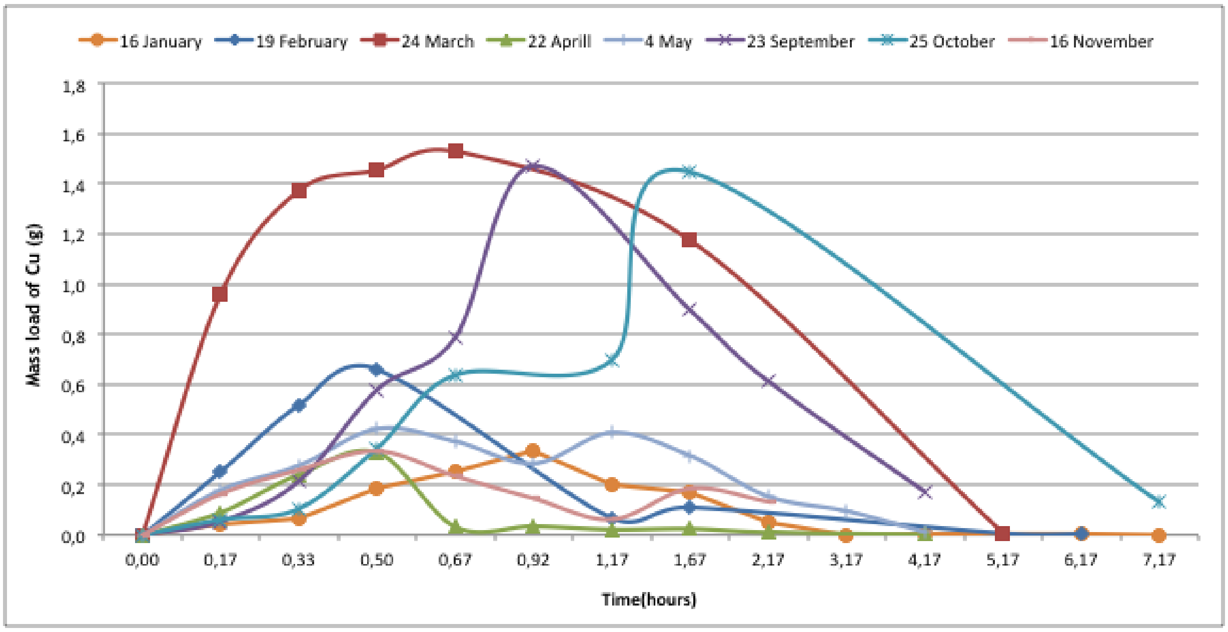

Figure 3: Variation of the mass load of Cu for the 8 raining events.

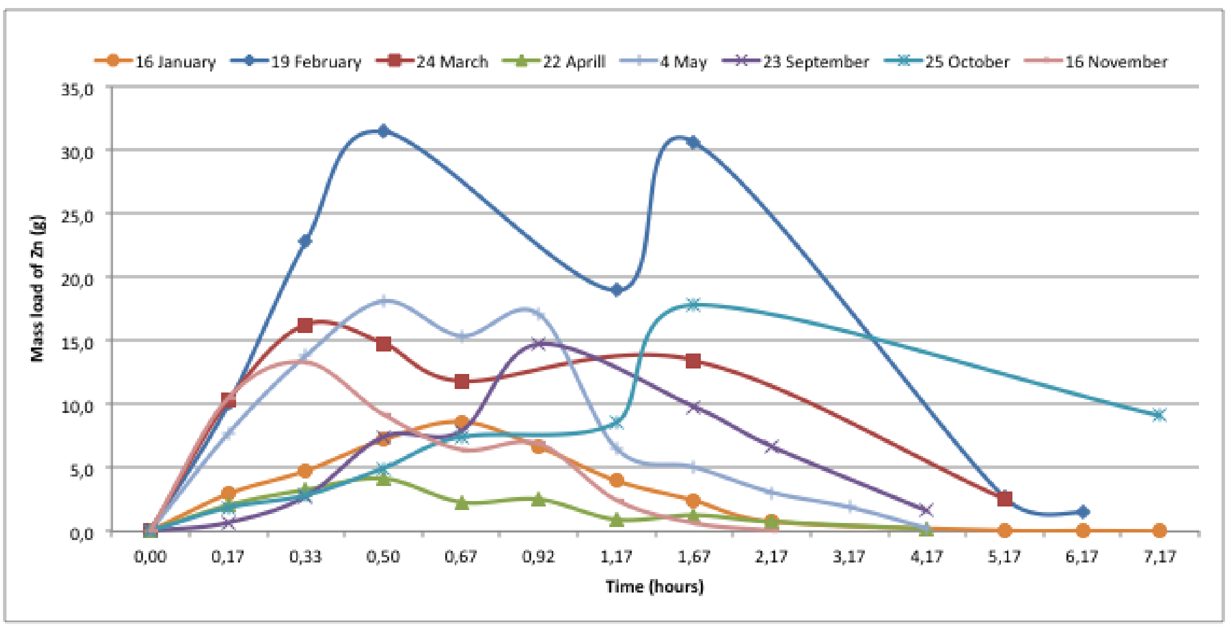

Figure 4: Variation of the mass load of Zn for the 8 raining events.

metals were higher in the first 20 minutes (0.33 hours) and then decreased in most of the precipitation events until to reach not datable values.

The identification of the peak of pollutants entering the basin (called the *first flux*) is important for the analysis of the mass loading pollutant in the road runoff, since it can give important information on the load source, its accumulation on the road and surrounding catchment in dry periods. This registration, in particular if it is calculated as mass loading, as noted in Albuquerque *et al.* [9] and Polkowska *et al.* [10] can give important indications either on the load origin or on their accumulation on the road and surrounding basin in dry periods. The peak load in the pollutogram may occur before the maximum peak runoff flow and, in periods of heavy rainfall, it may not occur.

The results show that the first flux for the 3 metals, in most of the rainfalls, passed between 10 and 30 minutes

Table 1: Results for the final effluent.

Parameter	Jan	Fev	Mar	Apr	May
pH	7.12 – 7.13	7.01 – 7.05	7.19 – 7.21	7.21 – 7.28	7.15 – 7.19
Cu (mg/L)	0.015 – 0.016	0.001	0.001	0.001 – 0.002	0.006 – 0.009
Cr (mg/L)	0.003 – 0.004	0.001 – 0.002	0.000 – 0.001	0.000 – 0.001	0.006 – 0.010
Zn (mg/L)	< 0.10	0.16 – 0.21	< 0.10	0.01 – 0.02	< 0.12
Parameter	**Sept**	**Oct**	**Nov**	**VLE**	
pH	7.08 – 7.12	7.21 – 7.25	7.21 – 7.26	6 - 9	
Cu (mg/L)	0.001 – 0.003	0.001 – 0.002	0.001 – 0.002	1	
Cr (mg/L)	0.001 – 0.004	0.001 – 0.002	0	2	
Zn (mg/L)	< 0.10	< 0.10	0.10 – 0.16	-	

(0.17 and 0.5 hours) after arriving the road runoff, although there were 2 rainfalls where the first flux was detected beyond the 1 h (the events of January and May).

There was no significant variation in mass quantities of Cr and Cu entering the basin, with the exception of September precipitation, where values roughly 6 times higher than those obtained during the other events were detected. Zn has a mass range that extends through precipitations, with several peaks, which would mean that it is not a pollutant mainly dragged in the first flow, continuing to be removed from the road along the precipitation.

Due to technical difficulties related to the output sampling point (located in the outside box), it was only possible to collect some samples of the treated effluent. The range of values for each analysed quality parameter is presented in Table 1. It is also presented the Emission Limit Value (ELV) allowed by the Portuguese Decree-Law No. 236/98 [18] (legislation on water quality for several uses).

It can be noted that the basin showed a good capacity for retention of the 3 heavy metals, with removal efficiencies above 95%, and final concentrations of metals below the emission limit values defined in legislation.

4 Conclusions

The detention basin showed good ability for removing Cr, Cu and Zn for precipitation intensities between 15 mm and 103 mm and rainfall durations up to 3 hours. However, the basin does not have a suitable volume for retaining all the volume coming from rainfalls with intensities greater than 29.4 mm and durations longer than 6 hours and, therefore, pollutants can be discharged into the water stream for those conditions. This type of monitoring should be setup in Environmental Monitoring Plans of roads because it allows evaluating the effectiveness of treatment systems and preventing the possible environmental impact of discharges into the receiving waters. Additionally, it can provide a good source of information on pollutant load, its sources and variation over rainfalls.

References

[1] Jones D., Development and evaluation of best management practices (BMPS) for highway runoff pollution control, MSc Thesis, University of Nebraska, Lincoln, USA, 2012.

[2] Wium-Andersen T., Reduction of stormwater runoff toxicity by wet detention ponds, PhD Thesis, Aalborg University, Denmark, 2012.

[3] Barbosa A., Highway runoff pollution and design of infiltration ponds for pollutant retention in semi-arid climates, PhD Thesis, Aalborg University, Denmark, 1999.

[4] Burton J., Pitt R., Stormwater Effects Handbook. A Toolbox for Watershed Managers, Scientists, and Engineers, CRC Press LLC, 2002.

[5] Barrett M., Roadside vegetated treatment sites (RVTS) study. Final Report CTSW-RT-03-028, California Department of Transportation (CALTRANS), 2003.

[6] Healy M., Rodgers M., Keating E., Constructed wetlands for the treatment of highway runoff. In: Robert H. Theobald (Ed.), Environmental Management, Nova Publishers, 2008.

[7] Barbosa A., Fernandes J., Assessment of treatment systems for highway runoff pollution control in Portugal, Water Science & Technology, 2009, 59(9), 1733-1742.

[8] Crabtree B., Moy F., Whitehead M., Roe, A., Monitoring pollutants in highway runoff, Water and Environment Journal, 2006, 20, 287–294.

[9] Albuquerque M., Barbosa A., Albuquerque A, Evaluation of the road runoff treatment basin of the A23 motorway (Covilhã Norte), In: Proceedings of the 12th Encontro Nacional de Saneamento Basico (24-27 October 2006, Cascais, Portugal), APESB, 2006 (in Portuguese).

[10] Polkowska Z., Skarzynska K., Dubiella-Jackowska A., Staszek W. and Namiesnik J., Evaluation of pollutant loading in the runoff waters from a major urban highway (2007,Gdansk, Poland), Global NEST Journal, 2007, 9(3), 269-276.

[11] Kayhanian M., Suverkropp C., Ruby A., Tsay K., Characterization and prediction of highway runoff constituent event mean concentration, Journal of Environmental Management, 2007, 85(2), 279-295.
[12] Antunes P., Barbosa A., Effects of atmospheric salt deposition on highway runoff characteristics, Technical report, Hydraulics and Environment Department, LNEC and EST-IPV, Lisbon, Portugal, 2005 (in Portuguese).
[13] Huber M., Welkerb A., Helmreicha B., Critical review of heavy metal pollution of traffic area runoff: Occurrence, influencing factors, and partitioning. Science of The Total Environment, 2016, 541, 895–919.
[14] Belizario P., Evaluation of the treatment capacity of a detention basin located at the north connection of the A23 motorway in Covilha, MSc Thesis, UBI, Covilhã, Portugal, 2014 (in Portuguese).
[15] Chow V. T., Maidment D. R., Mays L. W, Applied hydrology, McGraw-Hill International, Student Edition, Singapura, 1988.
[16] Quintela A. C., Hydraulics, Fundação Calouste Gulbenkian, 7th Edition, Lisbon, Portugal, 2000 (in Portuguese).
[17] APHA-AWWA-WEF, Standard methods for examination of water and wastewater, 20th Edition, American Public Health Association, American Water Works Association & Water Environment Federation, Washington DC, USA, 1999.
[18] Decreto-Lei no. 236/98, Water quality for different uses, Portuguese Law, 1998, Lisbon, Portugal (in Portuguese).