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An evaluation of the impact of alternative pipe materials on stormwater quality

Évaluation de l'impact de matériaux de canalisation alternatifs sur la qualité des eaux pluviales

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RÉSUMÉ

L'impact de l'exposition d'eaux de ruissellement (pluviales et de fonte de neige) à des conduits de différents matériaux a été évalué en les faisant circuler dans des sections de conduits de 500 mm de long pendant deux cycles de 20 minutes. Les résultats indiquent une légère augmentation du pH des eaux de circulation pour tous les matériaux. La circulation dans les nouveaux tuyaux en béton a conduit à des valeurs de conductivité électrique (CE) élevées dans les eaux pluviales (de 279 $\mu\text{S}/\text{cm}$ à 309 $\mu\text{S}/\text{cm}$) et dans la fonte des neiges (de 920 $\mu\text{S}/\text{cm}$ à 946 $\mu\text{S}/\text{cm}$), tandis que la CE a légèrement diminué à travers le chlorure de polyvinyle (PVC), l'acier galvanisé (GS) et les anciens conduits en béton. A travers les tuyaux en PVC les concentrations de Cu, Pb et Zn ont très peu changé, alors qu'à travers le GS les concentrations de Zn total, dissous et vraiment dissous ont augmenté dans les deux types d'eau. Les fractions de Cu, Pb et Zn totales, dissoutes et réellement dissoutes ont diminué dans le cas des nouveaux conduits en béton alors qu'à travers les anciens il apparait une légère augmentation du Cu dissous et réellement dissous dans les deux types d'eau. Seuls les nouveaux conduits en béton ont libéré plus de Cr et de K dissous dans la fonte des neiges. Les résultats montrent que les matériaux des tuyaux peuvent contribuer aux changements des phases de métaux dissous et réellement dissous dans les eaux de ruissellement et peuvent contribuer à la pollution des eaux réceptrices.

ABSTRACT

The impact of exposing runoff to pipes composed of four different materials was evaluated by circulating stormwater and snowmelt samples from one site through 500 mm length pipe sections for two 20 minutes cycles. Results indicate that the pH level in circulating waters showed minor increases on transfer though all pipe materials. Circulation through new concrete pipes led to elevated electrical conductivity (EC) values in stormwater (from 279 $\mu\text{S}/\text{cm}$ to 309 $\mu\text{S}/\text{cm}$) and snowmelt (from 920 $\mu\text{S}/\text{cm}$ to 946 $\mu\text{S}/\text{cm}$) whereas EC was slightly decreased on circulation through polyvinyl chloride (PVC), galvanized steel (GS), and old concrete pipes. Minimal changes in Cu, Pb and Zn concentrations were observed on circulation through PVC pipes, whereas circulation through GS led to increased Zn total, dissolved and truly dissolved concentrations in stormwater and snowmelt. Circulation through new concrete pipes led to decreases in total, dissolved, and truly dissolved Cu, Pb, and Zn fractions in circulating waters compared to circulation through old concrete pipes which led to minor increases in dissolved and truly dissolved Cu in both water types. New concrete pipes released more dissolved Cr and K into snowmelt compared to other pipe materials. Results show that pipe materials can contribute to changes in dissolved and truly dissolved metal phases in runoff and may contribute to pollutant loads discharging to receiving waters.

MOTS CLÉS

concrete, metals, pipe materials, stormwater, snowmelt

1 INTRODUCTION

Diffuse pollution source control is critical to meeting EU Water Framework Directive (2000) objectives for good surface water quality status, with urban runoff recognized as a major pathway for transporting diffuse pollutants from diverse sources to receiving waters (Müller et al. 2020). To mitigate harmful effects caused by stormwater pollution, the first step is to develop detailed knowledge about the sources of these pollutants. Previous studies have brought together water quality data relating to various urban materials (e.g., roads and roof materials) to estimate pollution generation across urban catchments (e.g., Charters et al. 2021; Müller et al. 2021). In recent decades pollutant release from a wider range of urban materials such as stormwater pipes has gained increased research interest e.g., concrete pipes are reported to change the water chemistry of receiving water bodies by increasing the pH, EC, bicarbonate and calcium concentrations (Grella et al. 2016; Borris et al. 2017; Purdy et al. 2021). Boris et al. (2017) highlighted that both pipe materials and the composition of runoff water play an important role in the release and partitioning of metals between total and dissolved phases during transport. However, the partitioning of metals between total, dissolved (the fraction passing through a 0.45 µm filter) and truly dissolved (fraction passing through 3 kMWCO-ultrafilter) in stormwater after exposure to different pipe materials yet to be evaluated. The present study addresses this gap by evaluating changes in the quality of stormwater and snowmelt runoff on circulation through four common stormwater pipe materials (PVC, galvanised steel, new and old concrete).

2 MATERIALS AND METHODS

New stormwater pipes made of polyvinyl chloride (PVC), galvanised steel (GS) (galvanised corrugated steel pipes and galvanised steel sheets) were purchased from Luleå, Sweden. New concrete pipes were acquired from Skellefteå, Sweden with old concrete pipes (59 years old) provided by Luleå municipality (Sweden) following removal from an urban catchment. Each pipe material was tested in triplicate lengths of 500 mm (diameter; 300-315 mm; new pipes) with old concrete pipes (diameter; 200 mm, length; 2100 mm) adapted to 500mm length sections equivalents by adjusting the position of inlet tubing. The stormwater and snowmelt samples were collected from a site at South Harbor Road (traffic intensity 7,400 vehicles/day) in the center of Luleå (~ 50,000 inhabitants, at latitude of 65° 35' N and longitude of 22° 10' E) in northern Sweden.

The stormwater and snowmelt samples were separately circulated through each pipe section (inclined at a 3% slope) at a flow rate of ~ 960 mL/min using a peristaltic pump (Watson Marlow 520S). 600 mL of each water type was fed into each pipe section at its upstream end, draining into a polypropylene funnel connected through PVC tubing to the peristaltic pump which circulated water back to the upstream end of the pipe. This setup allowed circulation of water through pipe sections continuously for 20 minutes. After the first 20-minute cycle, a second 600 mL water sample was circulated using the same surface of every pipe material section. Before switching to a snowmelt sample, the pipe sections were rotated to provide a new surface for circulation. On observation that particles from stormwater became trapped in GS corrugates during transport (a physical as opposed to a chemical process) galvanised steel sheets were used for the snowmelt circulation experiment.

The initial water (before circulation) and after circulation through every pipe material for each 20-minute run was analysed for pH (330 WTW pH meter, Weilheim, Germany), EC (CO 3100H conductivity meter, VWR, Leuven, Germany) and turbidity (Turbidimeter 2100Q Hach, Loveland, CO, USA). Analyses of metals (total, dissolved and truly dissolved) were undertaken by an accredited commercial laboratory, ALS Scandinavia AB, Luleå (Sweden). The samples for total metals were digested in an autoclave at 120°C for 30 min. Dissolved metals were filtered through 0.45µm PES (Polyethersulfone) filters and for truly dissolved metals the filtrate was directly poured into Sartorius ultrafiltration units (Vivaspin® 20, 3KMWCO) which were then centrifuged at 4000 rpm (Eppendorf, Centrifuge 5804) for 90 min. The concentrations of chromium (Cr), copper (Cu), lead (Pb), and Zinc (Zn) were determined using inductively coupled plasma sector field mass spectrometry (ICP-SFMS) and calcium (Ca), potassium (K), magnesium (Mg) and strontium (Sr) were determined using optical emission spectroscopy (ICP-OES). Results and discussion

3 RESULTS AND DISCUSSION

Table 1 presents the effects of different pipe materials on the selected water quality parameters (i.e., pH, EC turbidity). The data is presented as mean concentrations (± standard deviation) of triplicate measurements. The pH in both stormwater and snowmelt showed minor increases after exposure to all pipe materials, with a relatively higher increases in snowmelt water in comparison to stormwater. Minor

changes in pH (i.e., increase by 0.1 unit) was associated with circulation through PVC in both runoff types with little difference between the two cycles. The increase in pH value on exposure to GS for both waters was of a similar magnitude (i.e., up to 0.26-0.33 units after first and second cycle). New concrete pipes led to an increase in pH of 0.26 units in stormwater and 0.38 units in snowmelt while old concrete also increased the pH of circulating waters but to a lesser extent which can be associated to the difference in new and old material surfaces (water reacted to cement components to form hydration products). Grella et al. (2016) reported similar trends in pH after stormwater exposure to new and old concrete pipes. EC was not affected in stormwater and snowmelt by pipe materials except for circulation through new concrete pipes where a 10% increase in EC was observed in stormwater. Turbidity decreases in post circulated waters was greater for old concrete pipes (stormwater, decreased by 26%, snowmelt, decreased by 10 %) than new concrete attributed to surface roughness of old concrete entrapping finer particles. The decrease in turbidity of stormwater after passing through GS was due to the presence of corrugates which were absent in galvanised sheets used for snowmelt water circulation.

Table 1. Overview of pH, EC, and turbidity changes in stormwater and snowmelt before and after circulation through four different pipe materials

Pipes	pH (mean± SD)			EC (µS/cm) (mean ± SD)			Turbidity (FNU) (mean ± SD)			
	S	C1	C2	S	C1	C2	S	C1	C2	
SW	PVC	7.13±0.03	7.19±0.02	7.23±0.04	273±0.6	271±0.6	271±0.6	932±4	883±11	873±12
	GS	7.08±0.05	7.34±0.01	7.41±0.03	278±0.6	277±0.0	277±0.0	1160±51	845±64	829±28
	NC	7.22±0.03	7.46±0.05	7.48±0.09	280±0.6	309±4	299±5	1112±45	909±62	935±42
	OC	7.12±0.01	7.31±0.02	7.32±0.03	282±2.8	289±0.7	283±4	1123±16	822±20	908±23
SM	PVC	7.52±0.06	7.63±0.01	7.65±0.04	892±12	887±17	887±16	2760±232	2610±88	2650±178
	GS	7.44±0.03	7.70±0.04	7.76±0.03	922±3	917±1.0	915±0.6	2670±132	2630±30	2650±101
	NC	7.49±0.06	7.84±0.05	7.87±0.08	920±0.6	946±6.4	925±11	2670±56	2540±137	2490±43
	OC	7.50±0.07	7.73±0.02	7.83±0.01	915±2.8	912±4	908±5	2740±42	2480±14	2510±35

Key: SW=stormwater, SM=snowmelt, SD= standard deviation, S= initial value, C1= after first cycle, C2= after second cycle, PVC=polyvinyl chloride, GS= galvanized steel, NC=new concrete, OC= old concrete

In terms of metals, the partitioning of Cu and Zn between the truly dissolved, dissolved, and total phases in stormwater and snowmelt before and after circulation through pipe materials is shown in Figure 1. The circulation of waters through PVC had a negligible effect on total, dissolved and truly dissolved Cu and Zn concentrations as well as Pb concentrations (data not shown). Whilst exposure to new and old concrete pipes led to decreased total Cu and Zn concentrations in circulating waters, circulation through old concrete pipes increased dissolved and truly dissolved Cu concentrations in snowmelt (dissolved Cu; from 3±0.4 µg/L to 7.2±0.15 µg/L, truly dissolved Cu; 1.6±0 µg/L to 4.3±0.5 µg/L) with this associated with the re-partitioning of Cu from particulate to dissolved forms. An increase in dissolved Cu in semi-synthetic and field-collected stormwater was also reported by Borris et al. 2017. GS pipes led to relatively greater quantities of Zn after the first circulation cycle into stormwater (total Zn; from 507 µg/L to 734 µg/L, dissolved Zn; from 75 µg/L to 249, truly dissolved Zn; from 58 µg/L to 188 µg/L) and snowmelt (total Zn; from 979 µg/L to 1390 µg/L, dissolved Zn; from 14 µg/L to 107, truly dissolved Zn; from 11.8 µg/L to 82.8 µg/L). On circulation through GS pipes, the dissolved Zn to total Zn ratio almost doubled in stormwater and in snowmelt it changed from 1.5% to 8%, with 77-82 % of dissolved Zn present in the truly dissolved fraction. Total Zn concentrations were several folds higher than the Swedish direct stormwater discharge guidelines for total Zn (Alm et al. 2010) and – whilst not directly comparable – truly dissolved Zn concentrations exceeded the UK bioavailable EQS standard for Zn (10.9 µg/L in surface waters) (UK TAG 2013). Pb partitioning was not affected by exposure to any pipe materials, with minor increases in dissolved and truly dissolved Pb associated with PVC and GS pipes. These increases could be due to co-occurrence of Pb (<1%) with Zn in GS pipes and use of Pb compounds as thermal stabilizers in the PVC. Other element concentrations were found to increase in circulating waters (only after contact with concrete pipes) include dissolved and truly dissolved Ca, Cr, Mg, K and Sr. Similarly, levels of increases were reported for Ca and Sr (from < level of detection to 34.6 mg/L and 13.9 mg/L, respectively), in water circulated through concrete pipes (Purdy et al. 2021).

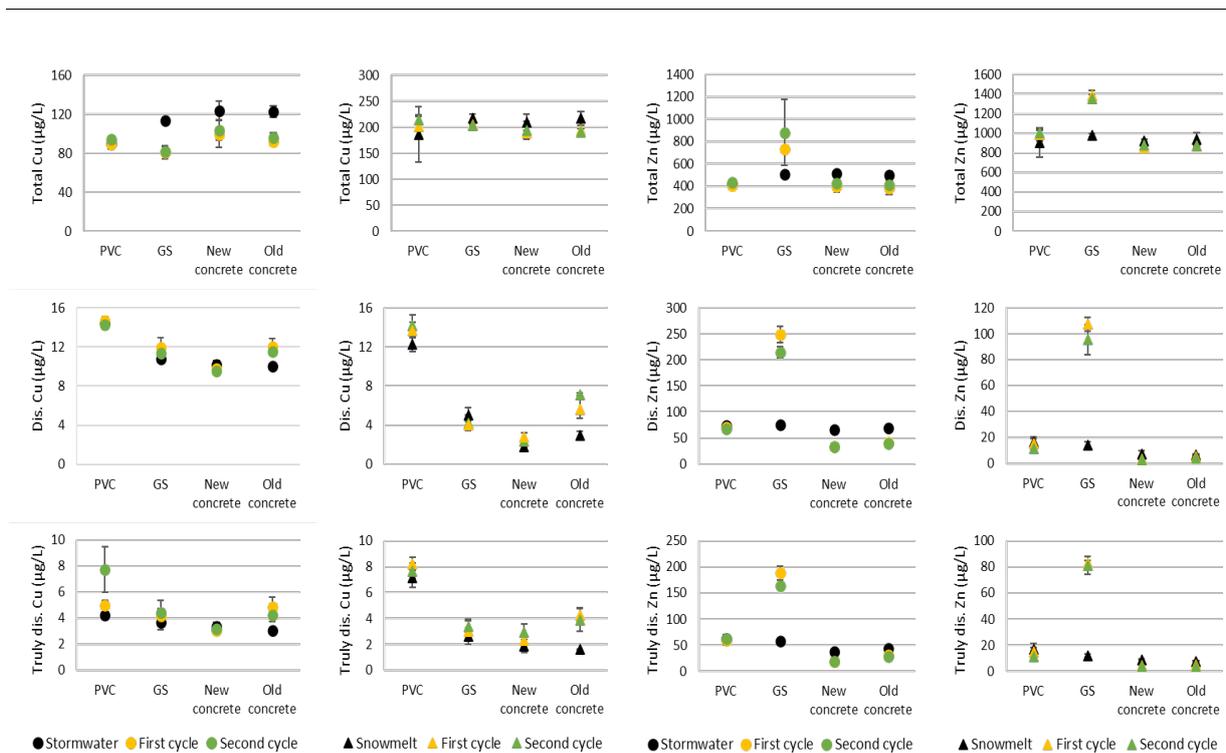


Fig. 1 Changes in total, dissolved and truly dissolved Cu and Zn concentration in stormwater and snowmelt after exposure to pipe materials (black color markers show initial values in stormwater and snowmelt)

4 CONCLUSION

This study characterized changes in the quality of stormwater and snowmelt runoff collected from urban sites on circulation through new (PVC, GS, concrete) and old (concrete) pipes in a short-term laboratory study. The extent of changes in water chemistry was relatively greater for new concrete pipes in terms of increasing pH, EC and dissolved Ca, Cr, Mg, K, and Sr concentrations in comparison to those reported for old concrete, PVC, and GS pipes. The changes in metals (Cu, and Pb) concentrations between total, dissolved and truly dissolved fractions were relatively minor on exposure to all pipe materials. In contrast, exposure to GS increased Zn concentrations (total, dissolved and truly dissolved) by up to several folds in stormwater and snowmelt with Zn mainly present in the truly dissolved and dissolved phases. The results of the study indicate that pipe materials can lead to changes in runoff quality by altering pH and releasing metals ions during transport, potentially exerting further pressure on the aquatic biota of receiving waters.

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