Pollutant Releases from Gutter and Piping Materials into Urban Stormwater Runoff

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ABSTRACT

The primary objective of this research was to examine how different drainage system and tank materials, water characteristics, and exposure time affect contaminants leaching into stormwater runoff. Static leaching tests for eight pipe and gutter materials were conducted over a three month period during which pipe and gutter test materials were immersed in containers with roof runoff water buffered to pH 5 and pH 8. New research was conducted on the same eight gutter and pipe materials using water from Mobile Bay and Black Warrior River in Alabama. In this research, the release of heavy metals is being studied under naturally occurring pH conditions. Water samples were periodically analyzed for a wide range of metallic constituents. As pH decreased, copper concentrations in the copper gutter samples increased. The highest copper release was observed in bay water samples. Galvanized materials resulted in the highest concentrations of zinc. At lower pH conditions, zinc releases from galvanized steel materials increased during the first day of exposure. Zinc releases from galvanized materials were lower in river water samples compared to the bay water samples during short exposure time, however, during long time exposure, zinc concentrations in the river water samples exceeded those in the bay water samples. Galvanized materials were the only source of lead releases.

KEYWORDS: heavy metals, pH, salinity, stormwater.

MATERIALS AND METHODS

The composition of roofing materials and stormwater drainage systems significantly affect the amounts of some pollutants (especially heavy metals) that leach into stormwater. Water chemistry and time of contact also impact the release of contaminants. Long-term static leaching tests were performed for eight different drainage system materials, some of which are also commonly used in water tank construction. During the first series of experiments, eight roof gutter and pipe materials were immersed in containers with roof runoff water buffered to pH 5 and pH 8 for a three month period. These tests investigated the effect of pH and material type on contaminants leaching out of the drainage system materials. The second series of experiments were conducted on the same eight gutter and pipe materials using un-buffered water from Mobile Bay and the Black Warrior River in Alabama. In this recent research, the effect of salinity on the release of heavy metals is being studied under naturally occurring pH conditions. The gutter materials used in the experiments included copper, aluminum, vinyl, and galvanized steel. The pipe materials were concrete, PVC, HDPE, and galvanized corrugated steel. Materials that may also be used in water tank construction are aluminum, galvanized steel, PVC, HDPE, and concrete. All of the drainage system materials were acquired as new specimens from local building material stores.

The pipe and gutter specimens used for the two pH tests were nearly identical. The specimens examined in the natural water tests were also identical. All the gutters and pipes were 30.5 cm long, with the exception of the concrete pipes, which were 15.3 cm long in the first series of the experiments, and in the second series of the tests, a section of the 15.3 cm long section pipe was used. The diameters for concrete, PVC, HDPE, and galvanized steel pipes were 41.2, 15.7, 17.5, 16.4 cm respectively. The diameters of galvanized steel gutters were 15.2 cm. The cross-sectional dimensions of vinyl, aluminum, and copper gutters were 5 by 8, 8.4 by 5.6, and 10.6 by 7.2 cm, respectively. The approximate weight of the PVC, HDPE, and galvanized steel pipes was 1,096, 409, and 8,000 g, respectively. The approximate weight of vinyl, aluminum, galvanized steel, and copper pipes was 100, 79, 704, and 503 g, respectively. The weight of concrete specimens was approximately 22,400 g each in the first testing stage; in the second testing stage, the concrete pipe sections weighed approximately 4,400 g.

During the first series of tests each section of pipe and gutter material was submerged into plastic buckets (16 L) or containers (for concrete materials, 80 L) containing roof runoff water that was adjusted to pH values of 5 and 8. Stormwater from downspouts was used in the gutter material tests and stormwater from parking inlets was used in pipe material experiments. Buffers were prepared utilizing Disodium Phosphate Dihydrate and Potassium Phosphate Monobasic. During the first series of tests the containers were sampled and analyzed at time zero (water with adjusted pH without specimens), 0.5 hr, 1 hr, 27 hrs, 1 month, 2 months, and 3 months for total concentrations of cadmium, chromium, lead, copper, and zinc. Total iron and aluminum and filterable concentrations of lead, copper, zinc, and aluminum were analyzed after 3 months of exposure. Samples were also analyzed for nutrients (ammonia nitrogen, total nitrogen, and nitrate) and COD, and screened using

Microtox toxicity. During the second series of the experiments the containers (14 L) were sampled and analyzed at time zero (un-buffered bay and river waters without pipes), 1 hr, 27 hrs, 1 week, 1 month, 2 months, and 3 months for the total concentrations of lead, copper and zinc, and screened for toxicity. To account for different area surfaces of the pipes and water volumes, mg/L were converted to mg of constituent per surface area of a pipe/gutter. The samples were also analyzed for total iron and aluminum and for filterable concentrations of iron after 3 months of exposure. Also, pH, conductivity, Eh, alkalinity, total and calcium hardness, chloride, and sulfate analysis were also performed during the first and second stages of the tests.

RESULTS

Figures 1 and 2 show lead, copper, and zinc releases from various pipe and gutter materials. Values below the detection limits were substituted with half of the detection limit for the calculations and the graphs. Detection limits for zinc, copper, and lead concentrations were 20, 20, and 5 μg/L, respectively.

Lead releases. During short exposure times (1hr to 1 week), some elevated lead concentrations were observed from the galvanized materials submerged in bay and river waters. For example, after 27 hrs, a lead concentration of 0.012 mg/L was observed in the bay water containing the galvanized steel pipe section in. During long exposure times (1 month to 3 months), intermittent lead releases were noted only for galvanized steel materials in containers with both bay and river waters; the highest lead concentration was noted for steel gutter section submerged into river water: 0.058 mg/L after 3 months of exposure.

Lead releases from galvanized steel materials under controlled pH conditions were higher than that of under natural bay and river conditions. The highest lead concentrations were observed under controlled pH 8 conditions and were 0.63 mg/L (25 mg/m^2), followed by the lead released under controlled pH 5 conditions of 0.25 mg/L (10 mg/m^2) after 3 months of exposure.

Copper releases. In both bay and river water samples, copper releases were detected only from copper materials. For both types of waters, elevated copper concentrations were noted beginning after 1 hour of exposure. Copper releases were slightly greater for bay water samples compared to containers with river water. In bay water samples, copper concentrations exceeded 2 mg/L after the first day of exposure. Copper leaching from copper materials reached a level of approximately 7 mg/L at pH5 conditions and at pH8, the copper release was less than 1 mg/L after the first day of exposure.

After 3 months of exposure, the highest copper concentrations were found in copper samples in containers with bay water and reached 36 mg/L, compared to 5.5 mg/L in copper samples from containers with river water, 5.1 mg/L in copper samples under pH 5 conditions, and 2.1 mg/L in copper samples under pH 8 conditions.

Zinc releases. During short-term exposures (up to 1 week), zinc was detected for the galvanized steel pipe and gutter materials in both bay and river water samples, as well as for copper gutter materials in bay water samples. Zinc releases for the other materials were observed after 1 or 2 months of exposure. The greatest zinc releases were observed from galvanized materials. The galvanized steel pipes and gutters had very high levels of zinc concentrations (5 to more than 8 mg/L) at the first day of exposure, with greater leaching observed for containers with bay water. However, those concentrations were lower compared to zinc losses from samples under controlled pH 5 conditions (exceeding 14 mg/L) and greater than zinc concentrations from controlled pH 8 tests (exceeding 2 mg/L) after one day of exposure.

After 1 month of exposure, zinc concentrations in river samples surpassed those in bay tests. Long-term exposures (up to 3 months) of galvanized steel materials resulted in zinc concentrations for bay waters that exceeded 70 mg/L and for river samples exceeding 180 mg/L, compared to zinc concentrations from galvanized steel materials for controlled pH 5 conditions that reached 14 mg/L and for controlled pH 8 conditions that reached 90 mg/L.

Copper samples were the second highest source of zinc releases, the highest concentrations were noted in river water samples and were 0.48 mg/L. Zinc releases from plastic and aluminum materials were much lower. No zinc losses were detected from concrete pipes in both bay and river tests.

Generally, under natural bay and river conditions, zinc releases were higher from galvanized steel pipes compared to galvanized gutters, however under controlled pH 5 and pH 8 conditions, zinc losses were greater from galvanized steel gutters compared to galvanized pipes.

Iron concentrations from galvanized steel material were higher at pH 5 than at pH 8 and reached approximately 20 mg/L. Iron releases from galvanized materials in bay and river water samples ranged between 1 to 2 mg/L and were comparable with iron releases under pH 8 conditions. **Aluminum** materials released the highest concentrations of aluminum.

Cadmium and chromium were not detected in any of the samples. The detection limits of cadmium and chromium were 0.005 mg/L and 0.02 mg/L respectively.

Statistical analyses were performed to identify significant trends in the releases of the contaminants from the sample materials as a function of time and pH (for the first series of the experiments) and as a function of time and salinity (for the second series of the experiments); also the unit area release rates from the different pipe and gutter materials were compared.

The results for the first testing stage were described in Ogburn and Pitt (2011), the results for the second series of the experiment are described below.

A Kruskal-Wallis test was used to determine whether the data for 1, 2, and 3 months during the second series of the experiments can be combined together into a single "long term" exposure time as replicates for each of the metals (lead, copper, and zinc), and to determine if the data for 1 hr, and 27 hrs, and 1 week during the second series of the tests can be combined together as replicates for the "short term" exposure times for each of the metals (lead, copper, and zinc). The Kruskal-Wallis test showed that the data can be combined into these groups.

Following the Kruskal-Wallis test, Factorial Analyses were conducted to estimate the effects of two factors: exposure time (the data was sorted into short and long exposure times) and salinity (high and low), as well as the interaction of those factors on the metal release in mg per surface area of the pipes. Next, the P-value (Factorial Effect/Pooled Standard Error Ratio) of the Factorial Analysis was used to determine whether the data can be further combined for each pipe and gutter (according to whether or not there was an effect of salinity, time, and an interaction of those factors).

A Mann-Whitney test was conducted to determine if there is a statistically significant difference between the groups. The Mann-Whitney test was employed because some of the data didn't meet the assumptions of normality and/or equal variance. Group box plots were plotted on a log scale for each metal constituent.

CONCLUSIONS

Figures 3, 4, and 5 show the releases for the combined data groups, and the footnotes summarize the statistical findings. The greatest source of lead and zinc were galvanized steel materials, while copper materials were the most significant source of copper. The highest aluminum concentrations were observed from aluminum materials. Lead, copper and zinc releases were detected during both short and long exposures for controlled pH conditions and for natural bay and river water tests. During short exposure times, copper releases were detected only for copper materials at both low and high pH for controlled pH conditions as well as for bay and river water for un-controlled pH conditions.

ACKNOWLEDGEMENTS

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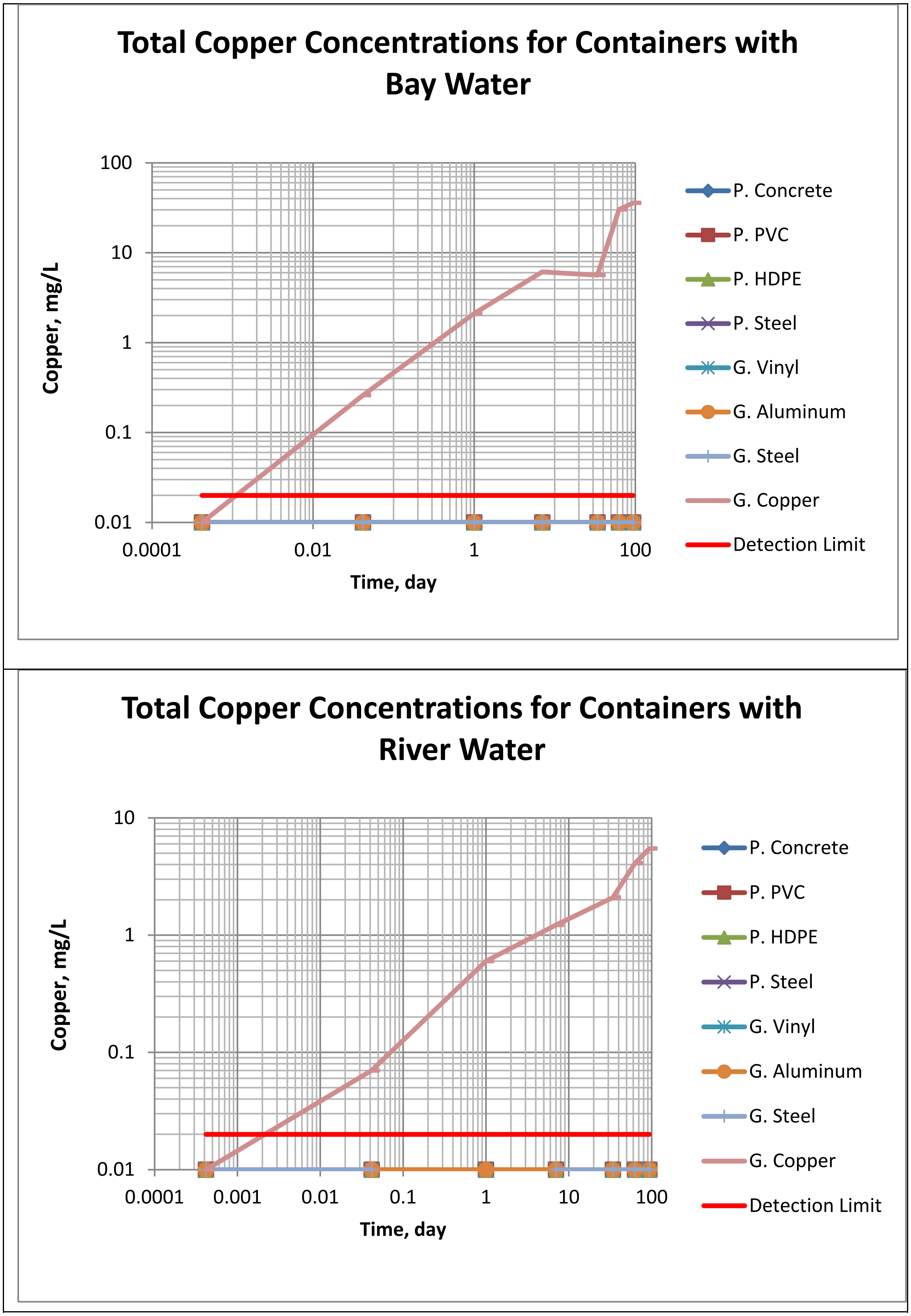

Figure 1. **Copper Releases for Containers with Bay and River Waters.**

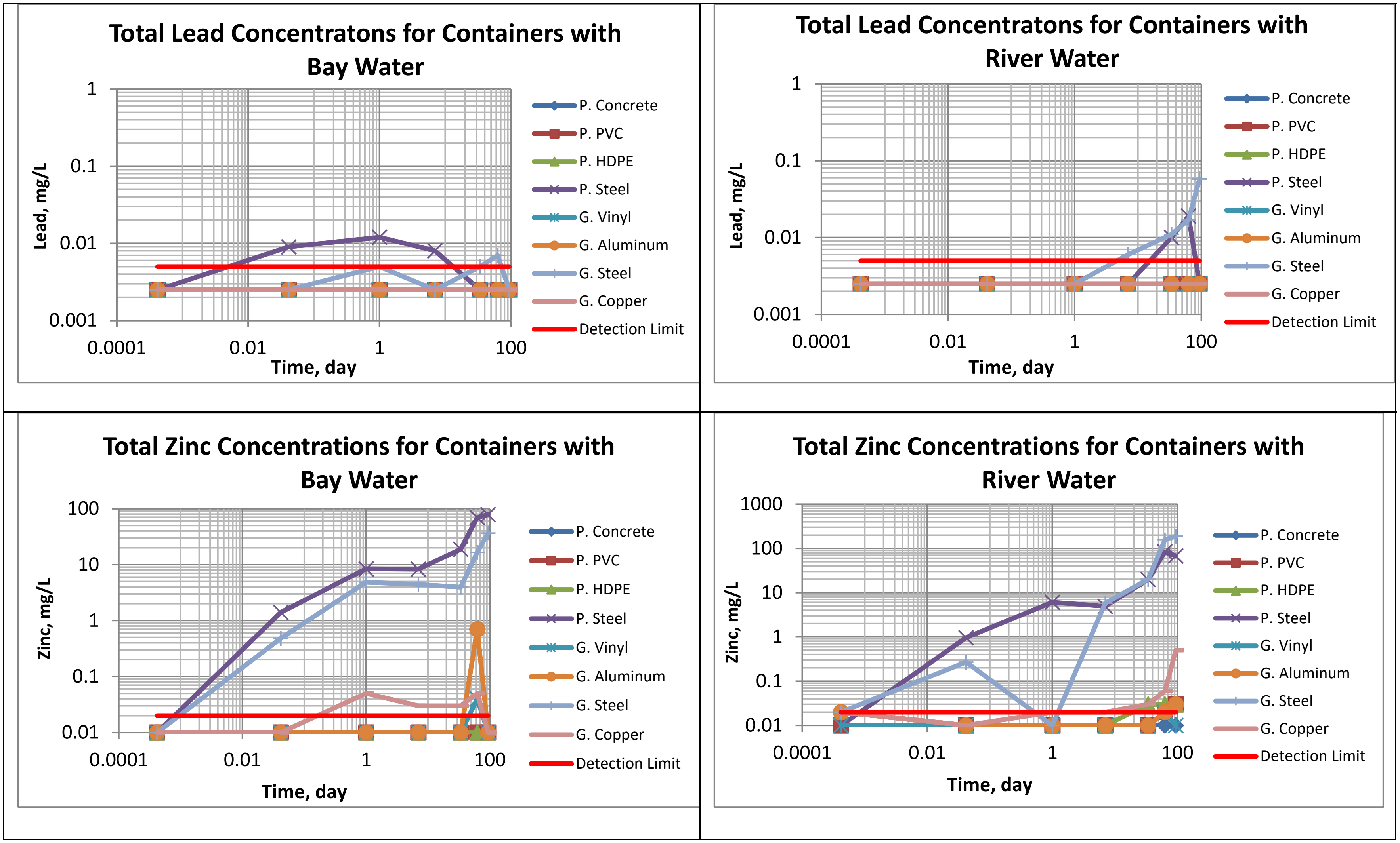

Figure 2. Lead and Zinc Releases for Containers with Bay and River Waters.

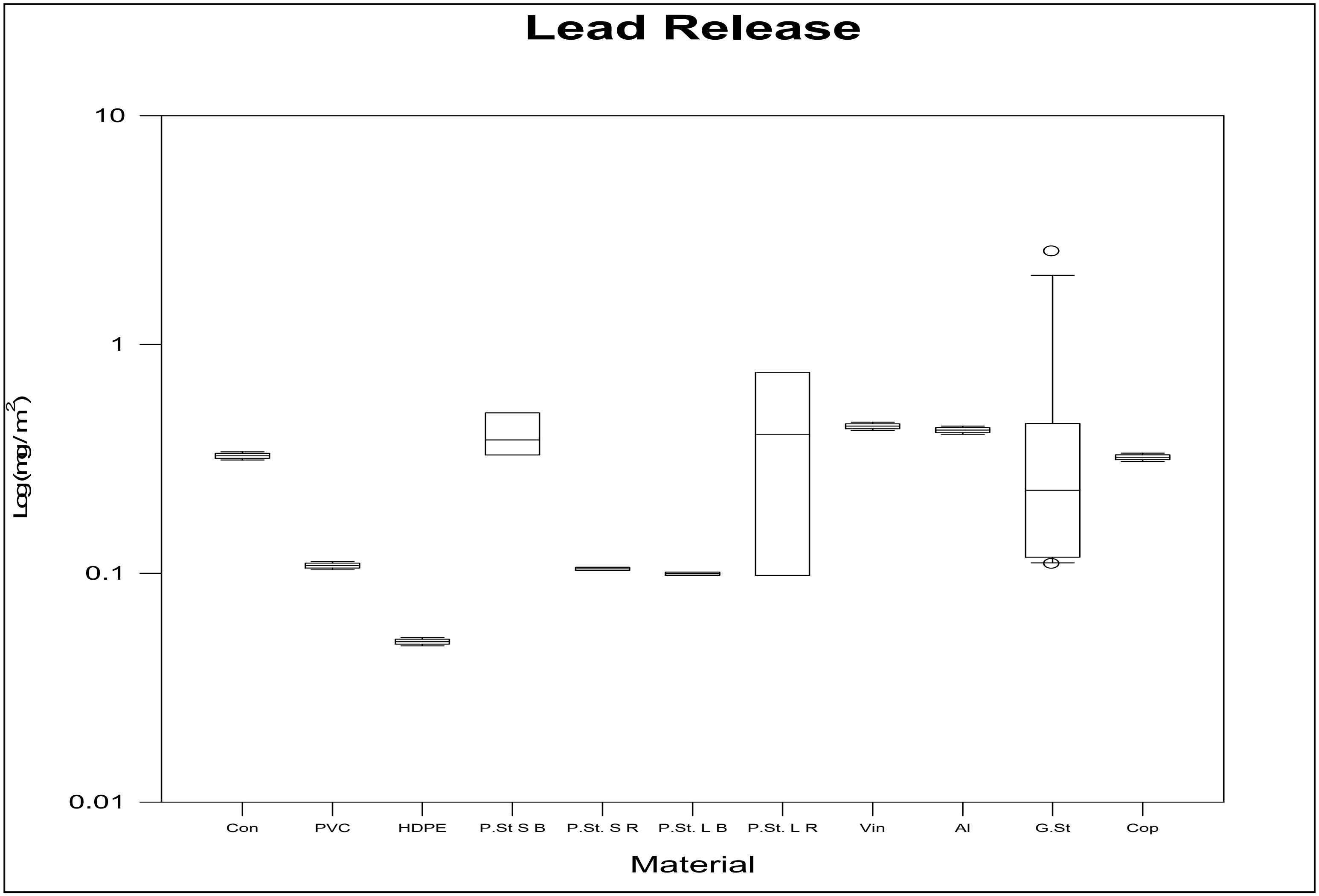

Figure 3.Group Box Plots for Lead Release in mg/m^2 for Different Pipe and Gutter Materials.

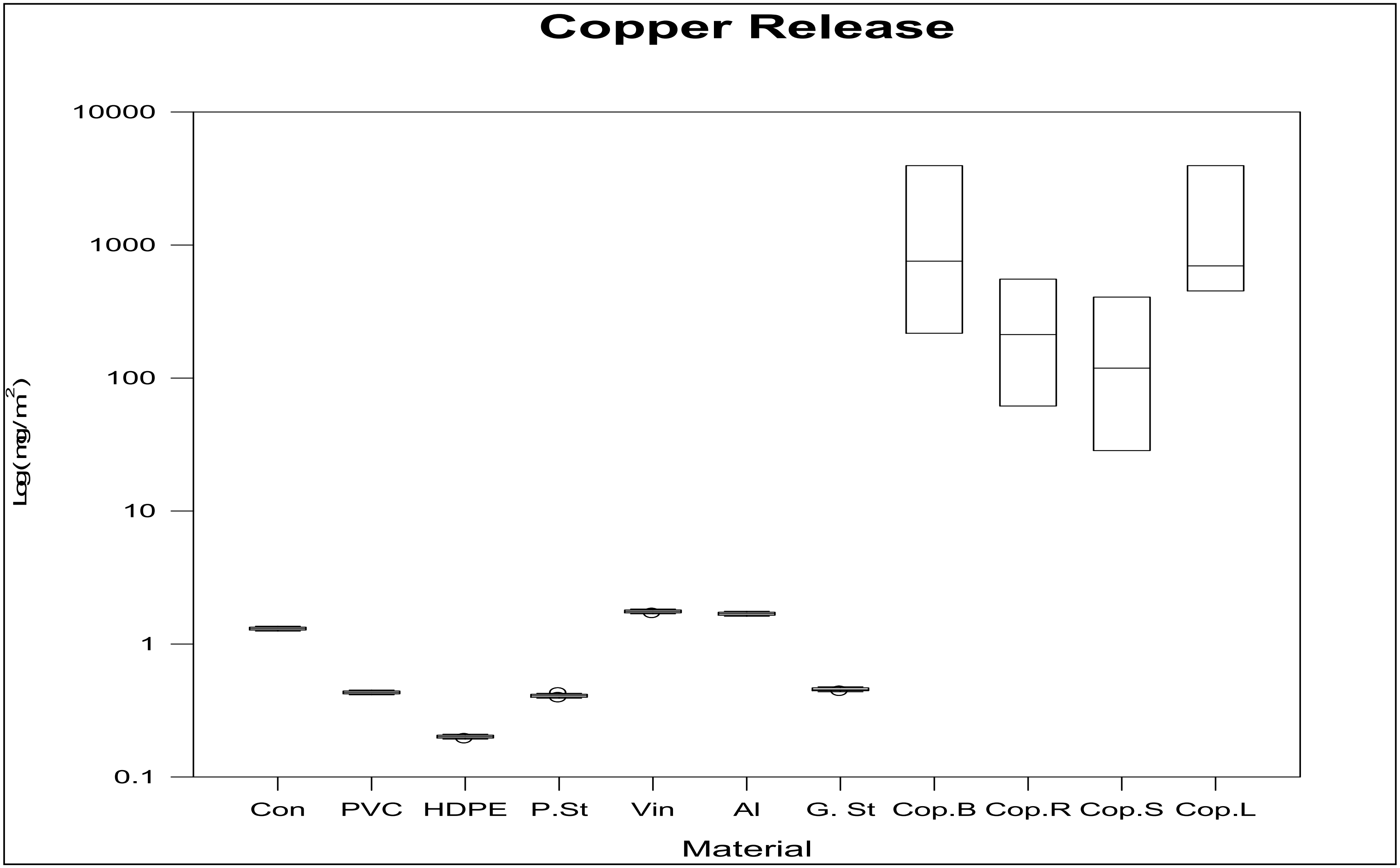

Figure 4.Group Box Plots for Copper Release in mg/m^2 for Different Pipe and Gutter Materials.

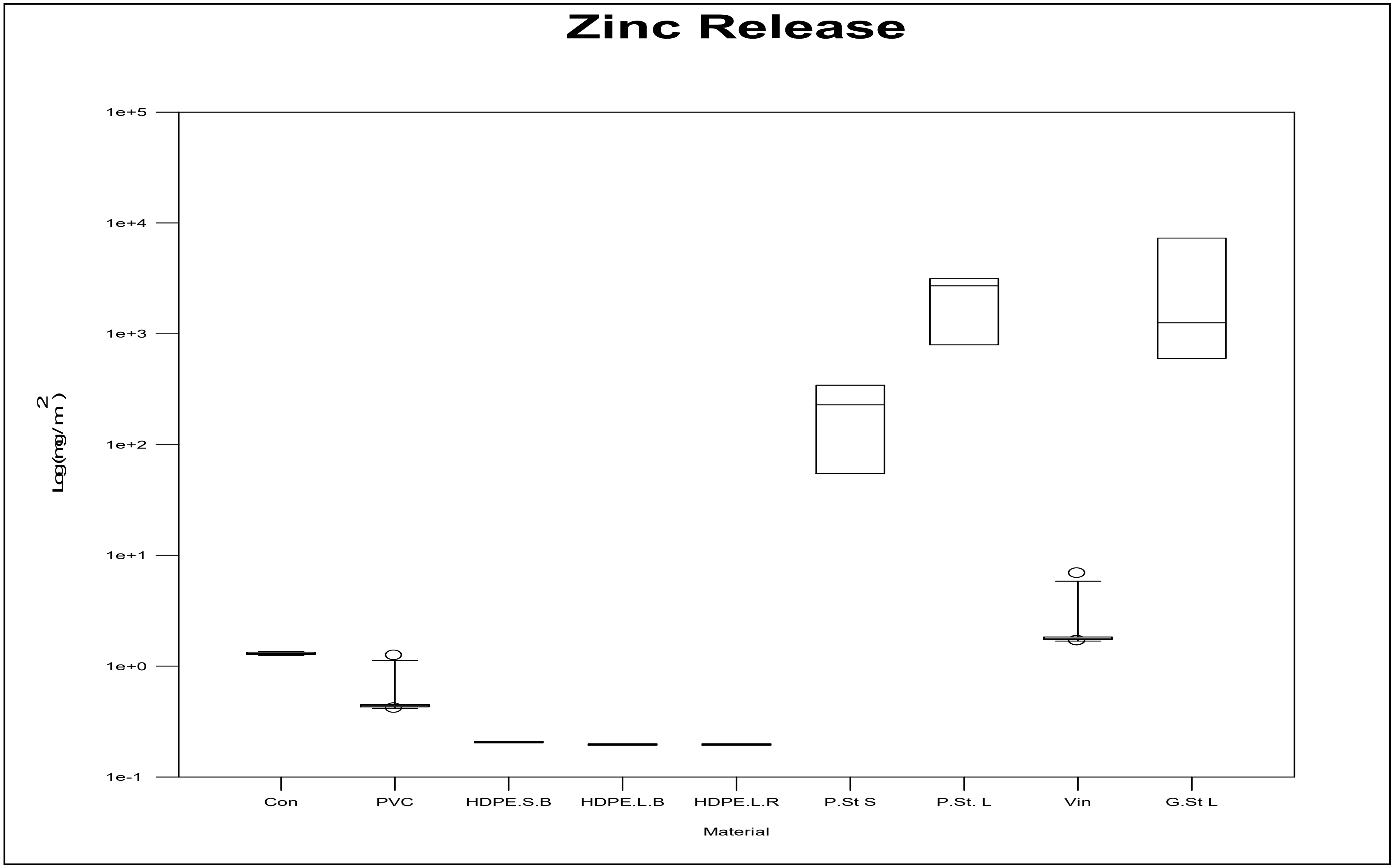

Figure 5.Group Box Plots for Zinc Release in mg/m^2 for Different Pipe and Gutter Materials.

Footnote for Fig. 3:

Values below detection limit (DL) were substituted with the half of detection limit value. For Lead DL = 0.005 mg/L. Lead was not detected for Concrete, PVC, HDPE pipes, as well as for steel pipe during long exposure time in bay water samples and during short exposure time in river water samples. Also, lead was not detected for vinyl, aluminum gutter, copper gutters.

Con = Concrete pipe, all data combined (short and long exposure times, both bay and river waters)
PVC = PVC pipe, all data combined (short and long exposure times, both bay and river waters)
HDPE = HDPE pipe, all data combined (short and long exposure times, both bay and river waters)
P. St. S B = Steel pipe during short exposure time, bay water
P. St. S R = Steel pipe during short exposure time, river water
P. St. L B = Steel pipe during long exposure time, bay water
P. St. L R = Steel pipe during long exposure time, river water
Vin = Vinyl gutter, all data combined (short and long exposure times, both bay and river waters)
Al = Aluminum gutter, all data combined (short and long exposure times, both bay and river waters)
G. St = Steel gutter, all data combined (short and long time exposure, both bay and river waters)
Cop = Copper gutter, all data combined (short and long exposure times, both bay and river waters)

Footnote for Fig. 4:

Values below detection limit (DL) were substituted with the half of detection limit value. For Copper DL = 0.02 mg/L. Copper was not detected for concrete, PVC, HDPE, and steel pipes, and for vinyl, aluminum, and steel gutters.

Con = Concrete pipe, all data combined (short and long exposure times, both bay and river waters)
PVC = PVC pipe, all data combined (short and long exposure times, both bay and river waters)
HDPE = HDPE, all data combined (short and long exposure times, both bay and river waters)
P.St = Steel pipe, all data combined (short and long exposure times, both bay and river waters)
Vin = Vinyl gutter, all data combined (short and long exposure times, both bay and river waters)
Al = Aluminum gutter, all data combined (short and long exposure times, both bay and river waters)
G.St = Steel gutter, all data combined (short and long exposure times, both bay and river waters)
Cop.B = Copper gutter, bay water (short and long exposure times are combined)
Cop.R = Copper gutter, river water (short and long exposure times are combined)
Cop.S = Copper gutter, short exposure time (bay and river waters are combined)

Cop.L = Copper gutter, long exposure time (bay and river waters are combined)

Footnote for Fig. 5:

Values below detection limit (DL) were substituted with the half of detection limit value. For Zinc DL = 0.02 mg/L. Data for HDPE pipe submerged into river water during short exposure times, for aluminum pipe, for galvanized steel pipe during short exposure times (both bay and river waters combined), and for copper pipe are not plotted because of some negative and zero values.

Con = Concrete pipe, all data combined (short and long exposure times, both bay and river waters)
PVC = PVC pipe, all data combined (short and long exposure time, both bay and river waters)
HDPE S B = HDPE pipe, short exposure time, bay water
HDPE S R = HDPE pipe, short exposure time, river water
HDPE L B = HDPE pipe, long exposure time, bay water
HDPE L R = HDPE pipe, long exposure time, river water
P.St S = Steel pipe, short exposure time, both bay and river waters combined
P.St L = Steel pipe, long exposure times, both bay and river waters combined
Vin = Vinyl gutter, all data combined (short and long exposure times, both bay and river waters)
Al = Aluminum gutter, all data combined (short and long exposure times, both bay and river waters)
G. St S = Steel gutter, short exposure times, both bay and river waters combined
G. St L= Steel gutter, long exposure times, both bay and river waters combined
Cop = Copper gutter, all data combined (short and long exposure times, both bay and river waters).