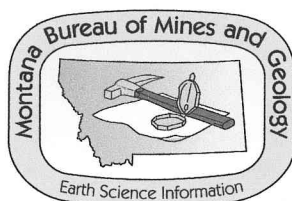


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Abstract

Flushing and a point-of-use (POU) ion exchange unit were tested as means to reduce copper and lead concentrations, that are above the recommended levels, in two public water supplies. Elevated copper and lead levels are attributed to the reaction of the source water with plumbing materials. Flushing was effective at a sink that was located upstream in the distribution system. It was ineffective at a water fountain located at the far end of the distribution system. These results indicate that the success of flushing may depend on the outlet location in the building, which relates to the distribution system length and the residence time of water in contact with plumbing materials. The ion exchange unit was capable of removing copper in drinking water; however, at breakthrough, elevated copper concentrations exceeded the action level. Frequent replacement of the cartridge or an automatically-regenerating ion exchange unit would be necessary to ensure that drinking water standards are met.

Introduction

The Lead and Copper Rule, established by the Federal Safe Drinking Water Act, sets limits for lead and copper at the tap in public water supplies. These limits, referred to as “action levels,” are 15 $\mu\text{g/l}$ and 1300 $\mu\text{g/l}$ for lead and copper, respectively. Continuing exceedances of copper and lead at the 90th percentile necessitates water treatment.^{1,2,3}

Plumbing materials consisting of copper and galvanized steel, and lead-based solder may react with corrosive water and result in dissolution of these constituents into the water supply. Calcium, alkalinity, pH, carbon dioxide, sulfate, chloride, dissolved oxygen, silica, temperature, and dissolved solids are some of the chemical constituents that influence the water corrosivity.⁵ Treatment technologies to control the effects of copper and lead corrosion are often expensive and technically burdensome for small public water systems. This study investigates two methods, flushing and a point-of-use device (POU), as a means to reduce copper and lead concentrations at the tap in small public water supplies.

A school and trailer home were used to test the ability of flushing and an ion exchange POU device to reduce copper and/or lead present in the drinking water. These were adjacent systems located in the town of Florence, Montana. Corrosivity of the source water in Florence is attributable to low pH and a moderate dissolved inorganic carbon level. Flushing was investigated at two water fountains and a sink at a K – 12 school, and an ion exchange unit was installed at a third school drinking water fountain and in a trailer home located across from the school.

Flushing

Flushing of water mains is used by many water utilities to control distribution system corrosion, remediate taste and odor problems, remove sediment, or reduce microbial growth.⁷ Although flushing is not currently an approved technology for lead and copper control for public water systems, the EPA does recommend flushing in individual homes if the water at a particular faucet has not been used for six hours or

longer.⁸ There is a lack of information regarding the use of flushing to reduce elevated copper and lead in small public water supply systems. A study at 50 schools in New Jersey indicated that lead levels were elevated by lunchtime after flushing the water fountains for 10 minutes in the morning.⁹ The authors of that study concluded that flushing once a day might be inadequate to consistently reduce lead concentrations in drinking water and suggested periodic flushing of 5 to 10 minutes every 2 to 3 hours.

The present study provides information on the implementation of a flushing program at the Florence-Carlton School.

Florence-Carlton School water supply. The Florence-Carlton School is a non-community non-transient water supply that serves about 950 students in grades K - 12 and 100 staff members. Water is used mainly for gym facilities, drinking water fountains, and two kitchen sinks.

The source water for the school is obtained from two wells, completed to depths of about 40 and 80 feet below ground surface in alluvial fan deposits. The sands and gravels denoted on the driller's log are locally derived granitic deposits. Water is plumbed into the school and stored in a 500-gallon tank prior to distribution.

The source water for the school was sampled at the upstream end of the distribution system after the flow from both wells was combined. The school's source water was a calcium bicarbonate water type with low total dissolved solids (less than 150 mg/l). Copper and lead were present at extremely low levels. The ground water is corrosive to the school's water distribution system and has resulted in elevated concentrations of copper/lead at the drinking water outlets. The influence of plumbing

materials on water quality is illustrated by the higher concentrations of copper and lead present at the sink/fountains when compared to the source water:

	PH	Copper ($\mu\text{g/l}$)	Lead ($\mu\text{g/l}$)
Source Water*	5.9 - 6.5	3 - 17	<2 - 4
Sink/fountains+	6.2 - 6.5	614 - 3690	<2 - 24

* based on 2 analyses + based on 14 analyses

Flushing system. The water fountains are referred to as *fountain 1* and the *gym fountain*. The initial timed flushing sequences for the fountains and sink were based on preliminary testing to determine the needed flush length and cycle frequency.

Because of the low water pressure at fountain 1 (0.2 gallons per minute (gpm)), it was instrumented to flush continuously. The cyclic flushing sequence at the gym fountain was initially set as a 4-minute flush followed by 10 minutes off. The initial flushing sequence at the sink was a 4-minute flush then 2 hours off.

The flushing system timers were Grainger's model 1XC66 2 hour with 2 minute on/off increments. The timer initiated flushing through a 1/4-inch, 110-volt solenoid valve that controlled flow from the branch of the tee installed between the fixture stop and the drinking water fountain or sink. A schematic of the flushing system is shown in figure 1. Flush water was passed through 1/4-inch tubing to the drain. The flush apparatus was out of view of passersby. The sink and gym fountains were flushed at a rate of 0.8 gpm.

Water sampling scheme. Water samples at the sink and the gym fountains were collected weekly for a period of 7 months (34 samples at each location). Fountain 1 was tested for a 4-month period (13 samples). At the sink and the gym fountain, water samples were collected prior to the start of a flush, representing water that has the longest

residence within the distribution system. Therefore, these samples would most likely contain the highest concentrations of copper and/or lead. Samples were analyzed for copper, lead, specific conductance, and pH.

Additionally, 20 samples were collected immediately after a flush at the gym fountain, and 13 after-flush samples were collected at the sink. These samples were obtained to determine the effectiveness of the flush to reduce copper and/or lead in the water.

Analytical results

Fountain 1. Prior to the start of testing, copper concentrations at fountain 1 ranged from 2100 to 3600 $\mu\text{g/l}$, and lead varied from 6 to 24 $\mu\text{g/l}$, both exceeding the respective action levels. The results, shown in figure 2, indicate that flushing consistently reduced copper concentrations to levels below 1000 $\mu\text{g/l}$ and lead concentrations to levels below instrument detection ($<2 \mu\text{g/l}$). On average, copper was reduced from 2840 $\mu\text{g/l}$ to 600 $\mu\text{g/l}$.

Gym Fountain. Figure 3 is a graph of copper concentrations at the gym fountain obtained from samples collected just prior to a flush. The flushing sequence was changed 3 times throughout the testing period in the following order:

- 4-minute flush: 10 minutes off
- 6-minute flush: 8 minutes off
- 6-minute flush: 8 minutes off alternating with an 8-minute flush: 6 minutes off.

Copper concentrations remained elevated in spite of the changes in the flushing sequence. The highest copper was found during low-use periods, either early in the morning or when school was not in session.

Copper concentrations obtained from just before and after a flush show copper decreased between 4 and 66 percent in 12 after-flush samples (figure 4). In eight samples, after-flush copper concentrations were actually greater than the before-flush concentrations. Copper concentrations in these samples increased between 25 and 244 percent.

Sink. The flushing sequence was changed three times before there were consistent copper and lead reductions in the water (figure 5). The inadequacy of the initial 4-minute flush then 2 hours off was compounded with a low-water use period (summer months when school was not in session), resulting in the highest copper and lead concentrations observed during the test. The flush sequence of an 8-minute flush: 52 minutes off resulted in consistently lower copper and lead concentrations even during low use times.

Copper concentrations were lower after a flush when compared to pre-flush samples in 11 out of 13 cases (figure 6). Concentrations decreased between 23 and 63 percent. Copper increased after a flush in 2 samples, by 3 and 83 percent. Lead concentrations were higher after a flush in two samples (figure 7). The increased copper and lead concentrations after the flush were still below the action levels.

Overall flushing results

During the course of the study, the flushing systems functioned without any problems. Continuous flushing at fountain 1 was successful in reducing copper and lead concentrations below the action levels. The flushing sequence at the sink also was adequate to reduce copper/lead in the drinking water. Approximately 288 gallons per day (gpd) were flushed through fountain 1, and 154 gpd through the sink.

Flushing at the gym fountain did not consistently reduce copper in the drinking water. Water was flushed from the system about one half of the time, resulting in a waste of 576 gpd. Forty percent of the samples showed higher copper concentration after a flush when compared to before flush concentrations. Flushing was deemed impractical at this location.

The results indicate that although the source water was the same, the success of flushing was location-dependent. Although the plumbing plans for the school were unavailable, the sink was located closer to the boiler room (where water entered the school) and the gym fountain was located at the downstream end of the plumbing system. The configuration of the plumbing, which includes the amount and makeup of the plumbing materials and the residence time of the water in the system are major factors that influence flushing as a treatment option. Flushing may not have been a reliable method to control copper levels at the gym fountain because of the greater length of the plumbing materials and longer contact time of the water in the system. Residence time of water in the system is determined not only by the flushing sequence, but by how much water is used at each location: a factor that was not measured during this test. Preliminary testing to determine the amount and frequency of a flush is necessary if considering flushing as a treatment option.

Point-of-use ion exchange

Ion exchange units are typically used to soften water by exchanging ions such as sodium for calcium and magnesium. They are often used at the point of entry of water into a building. Dissolved copper and lead have been identified as ions that are readily exchanged by cation resin in the sodium form.¹⁰

Historically, POU devices were not recognized as an acceptable treatment technology for public water supplies by EPA because of several factors:

- Water is only treated at the drinking tap, which has implications in terms of exposure to potential health risks, especially for volatile organic chemicals;
- There is difficulty in monitoring the reliability of treatment performance;¹¹
- This approach is cost prohibitive in larger water systems.¹¹

In 1998, EPA formally removed its prohibition on using POU devices to comply with the Safe Drinking Water Act; however, this pertained to treatment devices that have automatic failure warnings. It was recognized that POU treatment using cation exchange is the least expensive treatment to reduce copper concentrations in communities with less than 30 households.¹²

In this study, POU ion exchange units were tested at two locations, the Florence-Carlton School and the Bitterroot Pines Trailer Court located across from the school. The school's source water was described in the previous section.

Bitterroot Pines Trailer Court water supply. The Bitterroot Pines Trailer Court system is a community public water supply. Source water for the trailer court is obtained from a well of unknown depth and pumped to a 26-gallon pressure tank. The water supplies the needs of 16 trailers and 2 homes. Although the distribution pipes are plastic and galvanized steel, the plumbing materials in the individual homes vary.

The source water is supplied from the same aquifer that supplies the school wells. Similar to the school water, the source water is a calcium bicarbonate type with low total dissolved solids (less than 100 mg/l). Copper and lead concentrations are below instrument detection limits. The source water is corrosive to the plumbing materials as

evidenced by the water quality from the trailer home. Below is a comparison of the source water to water sampled from the trailer home tap:

Trailer Court	pH	Copper ($\mu\text{g/l}$)	Lead ($\mu\text{g/l}$)
Source Water*	6.4 - 6.5	<2	<2
Trailer Home†	5.7 - 6.6	65 – 2584	<2

* based on two analyses † based on 13 analyses

The ion exchange unit was first tested at the trailer home and then at a school water fountain.

Instrumentation. The POU device was an Ametek ion exchange unit typically used to soften water. Unit specifications are as follows:

Functional Structure: organic resin – sulfite – Na^+

Ionic Form: Na^+

Screen Size (U.S. Std. Mesh (Wet)): 20-40

Cartridge Size: $2 \frac{5}{8}$ inch x $9 \frac{3}{4}$ inch

Recommended Flow Rate: 0.5 gallons per minute (gpm)

Based on the hardness of the source water, it was estimated that the capacity of a cartridge should be about 433 gallons before copper breakthrough.

The units were installed under a sink in the trailer home and adjacent to a water fountain at the school. The units were connected to the cold water supply pipe between the cold water supply stop and the faucet. An Alamo water meter (model number V5000) was attached upstream from each ion exchange unit to determine the gallons throughput.

Water sampling scheme. Weekly water samples were collected at sampling taps located just before the POU (influent) and just after the POU (effluent), from the trailer home and school drinking fountain. Samples at the trailer home were analyzed for pH, sodium, alkalinity, bicarbonate, specific conductance, copper, lead, and heterotrophic plate count (HPC). The analyte list was increased at the school fountain to include major cations. Samples were collected during both stagnant and high use periods.

Flow through the unit was recorded weekly. Sampling at the trailer home began on March 11 and was discontinued on June 17, 1998. Testing at the school took place August 25, 1998, through February 19, 1999.

Analytical results

Trailer home. Figures 8 and 9 show influent and effluent copper and sodium concentrations, respectively. Initially, sodium was being exchanged off the column for copper as evidenced by the decreased copper and increased sodium concentrations in the effluent. The unit effectively decreased copper between 58 to 98 percent for about a two-month period. Figure 8 shows copper breakthrough after a two-month period. Copper breakthrough corresponds to a decrease in sodium and a copper increase in the effluent. Breakthrough occurred after about 168 gallons were passed through the unit. The higher effluent copper concentrations suggest that copper was being eluted off the resin.

Because of a leak in the plumbing, a 12-foot length of copper pipe was replaced in the trailer home. The pipe was removed after breakthrough (week of May 24th). The results show that after replacement of the copper pipe with PVC, the influent and effluent copper concentrations were nearly equalized and under 100 $\mu\text{g/l}$.

The HPC results are presented in table 1. HPC was consistently higher in effluent samples suggesting that biofilms may be growing on the resin or perhaps the resin is acting as a filter. A disruption of the column packing, possibly by turning the tap on and passing water through the system, may flush microbes off the resin, resulting in higher effluent HPC.

School Fountain. Influent copper concentrations at the school were generally lower than those measured at the trailer home, which is probably because more frequent use of the school fountain helps to flush some of the copper out of the distribution system. Influent and effluent copper concentrations are shown in figure 10. Prior to breakthrough, copper concentrations were reduced in 14 out of 20 samples by 8 to 84 percent. Seven samples showed a copper increase in the effluent by 4 to over 100 percent. All of these increases occurred when the incoming copper was below 500 $\mu\text{g/l}$.

Copper breakthrough occurred after about five months when approximately 125 gallons of water had passed through the unit. This was shown in the analytical results by increased copper concentrations and decreased sodium concentrations in the effluent (figure 11). Figure 12 shows concentration ratios of calcium, potassium, magnesium, and sodium during the test. Potassium was retained on the column but was eluted off about halfway through the test. Potassium has a lower affinity for exchange when compared to the other ions and therefore has a higher tendency to be eluted back off the column.¹³ Figure 12 shows a gradual breakthrough of this constituent. Magnesium is also initially exchanged on the column. At the point where copper begins to show breakthrough, magnesium retention is decreased until the last sample shows that effluent magnesium concentrations are higher than the influent and that it is being eluted off the column. In

the case of calcium, which is closest in size to the sodium ion, two calcium ions are exchanged for every sodium ion. At breakthrough, the higher effluent copper concentrations indicate that it is probably being exchanged by another ion in the water that has a higher affinity for the resin.

The HPC results for the school fountain are presented in table 2 and do not show the consistent trend identified at the trailer home. The HPC was higher about half the time in the effluent when compared to the influent. In the case where influent HPC is higher, the resin is probably acting as a filter. The flow rate at the school fountain was about 0.4 gpm, less than half the rate at the trailer home. Therefore, disruption in the column packing because of a water surge through the resin is not as likely, and microbes were not flushed through as consistently as they were at the trailer home.

Overall ion exchange results

The ion exchange units successfully removed copper from the drinking water. The major concern was that once the sodium exchange sites became exhausted, the exchange process resulted in elevated copper in the effluent (the chromatographic effect). Breakthrough occurred much earlier than predicted. The flow rate at the tap in the trailer home was about 1 gpm and 0.4 gpm at the school fountain. Differences in the flow rate at the trailer home and school fountain may affect the capacity of the resin and can influence its effective life. Development of a special purpose resin with copper as the preferred ion would postpone the copper breakthrough effect.

The total water volumes passed through the POU units were within 25 percent of each other when breakthrough occurred. For this unit to be a viable option for other systems, a water meter could be installed on each unit, and gallons throughput could be

used as an indication when to change the cartridge. However, gallons throughput would have to be initially determined based on testing each source water considered. Another option besides replacing the cartridge would be to regenerate the column with brine as automatic home water-softening units do.

Conclusions

This study indicates that the success of flushing depends on the water outlet location in the building. The shorter the length of the distribution system (potentially less copper tubing), the shorter the residence time of water in contact with the plumbing materials, which results in lower concentrations of copper in the water. Therefore, less flush water is needed to reduce copper/lead levels.

The total cost of equipment and installation of the flushing system was \$458.00. When budgeting a project such as this, the costs of water sampling and the time to ensure the flush sequence is adequate should be factored in. For this study, it took about 50 hours each to establish an adequate flushing sequence at the sink and gym fountain.

Once the flushing system is installed and working, it is essentially maintenance free. In the long term, there is the potential the components may have to be replaced because of the corrosive water. A complicating factor associated with flushing is the water waste – this study indicated that more than 100 gpd from each outlet was wasted. Where water conservation is an issue, flushing may be inappropriate.

Cation exchange was shown to be effective in reducing copper in tap water; however, the cartridges must be changed before copper breakthrough because of the chromatographic effect which results in elevated effluent copper. For ion exchange, initial costs include the ion exchange unit, cartridge, water meter, and installation fees. For this

study, the costs were \$546.00. Maintenance would consist of ongoing, periodic replacement of the cartridge, the replacement frequency depending on the source water.

For POU ion exchange to be a viable option, a pilot test would be necessary. Manufacturers' resin specifications are insufficient to predict copper breakthrough. The pilot study would establish the needed frequency of cartridge replacement. To eliminate the need for a pilot test, an automatically-regenerating POU unit could be installed so that breakthrough is not a concern.

For the conditions encountered during this study, the cost of replacing cartridges at the trailer home would be \$648.00 per year. This cost assumes that the cartridge would be changed every two months or until the established amount of water was passed through the system. The school unit lasted longer because of the lower water demand. Yearly replacement costs at the school fountain would average about \$260.00. For a small home (or a very small system), it may be cheaper to exchange household copper piping for PVC piping, than to maintain a cation-exchange copper removal device.

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Table 1. Heterotrophic plate counts of the influent and effluent residential ion exchange unit.

Date	Influent HPC (cfu/ml) ⁺	Effluent HPC (cfu/ml)
11-Mar-98	200	190
18-Mar-98	TNTC*	TNTC*
25-Mar-98	1585	2850
1-Apr-98	405	4850
8-Apr-98	410	3525
15-Apr-98	1225	1505
22-Apr-98	125	3730
29-Apr-98	290	1460
6-May-98	120	2565
20-May-98	570	2625
27-May-98	1400	3900
3-Jun-98	2400	4800
10-Jun-98	835	1370
17-Jun-98	885	1740

* Too numerous to count

+ Colony forming units per milliliter

Table 2. Heterotrophic plate counts of the influent and effluent at the school fountain.

Date	Influent HPC (cfu/ml)	Effluent HPC (cfu/ml)
2-Sep-98	140	1160
9-Sep-98	9470	2830
16-Sep-98	420	2130
20-Oct-98	4200	5230
26-Oct-98	14800	700
4-Nov-98	2250	2990
10-Nov-98	825	515
18-Nov-98	3290	675
2-Dec-98	1455	2180
9-Dec-98	810	620
15-Dec-98	845	565
6-Jan-99	1990	1970
13-Jan-99	1500	3650
25-Jan-99	920	320
10-Feb-99	395	935

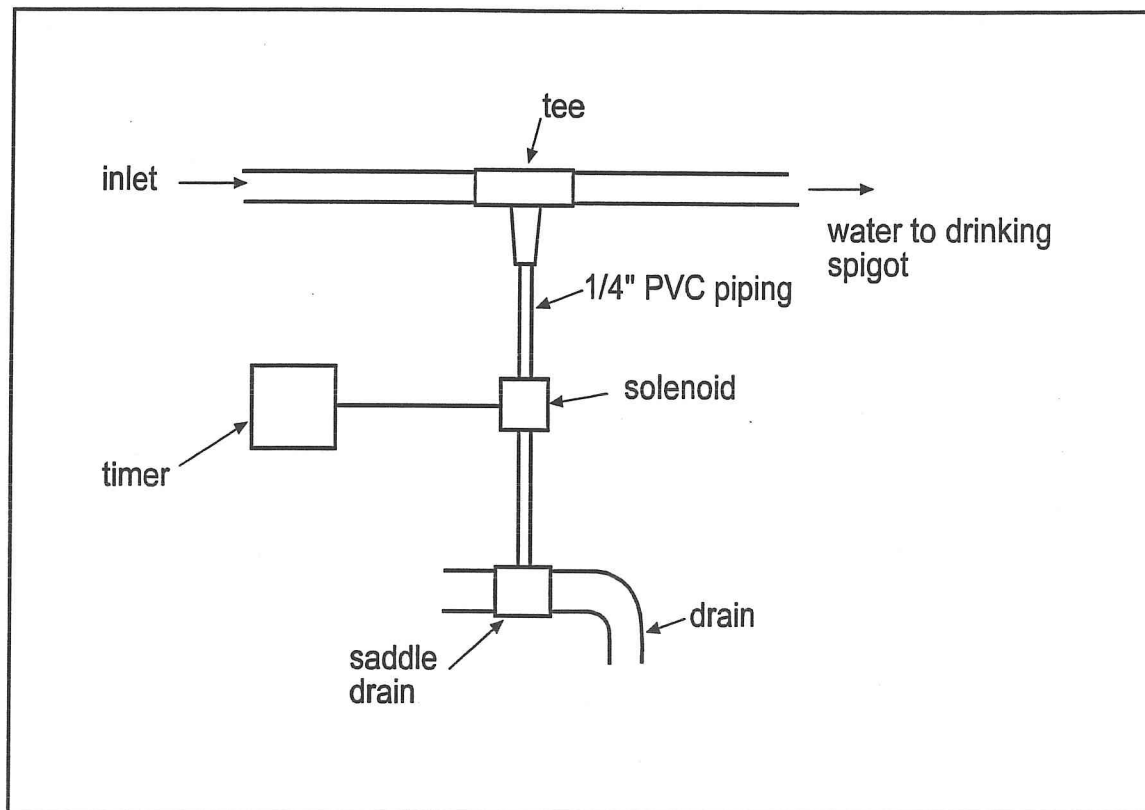


Figure 1. Schematic showing setup of the flushing system.

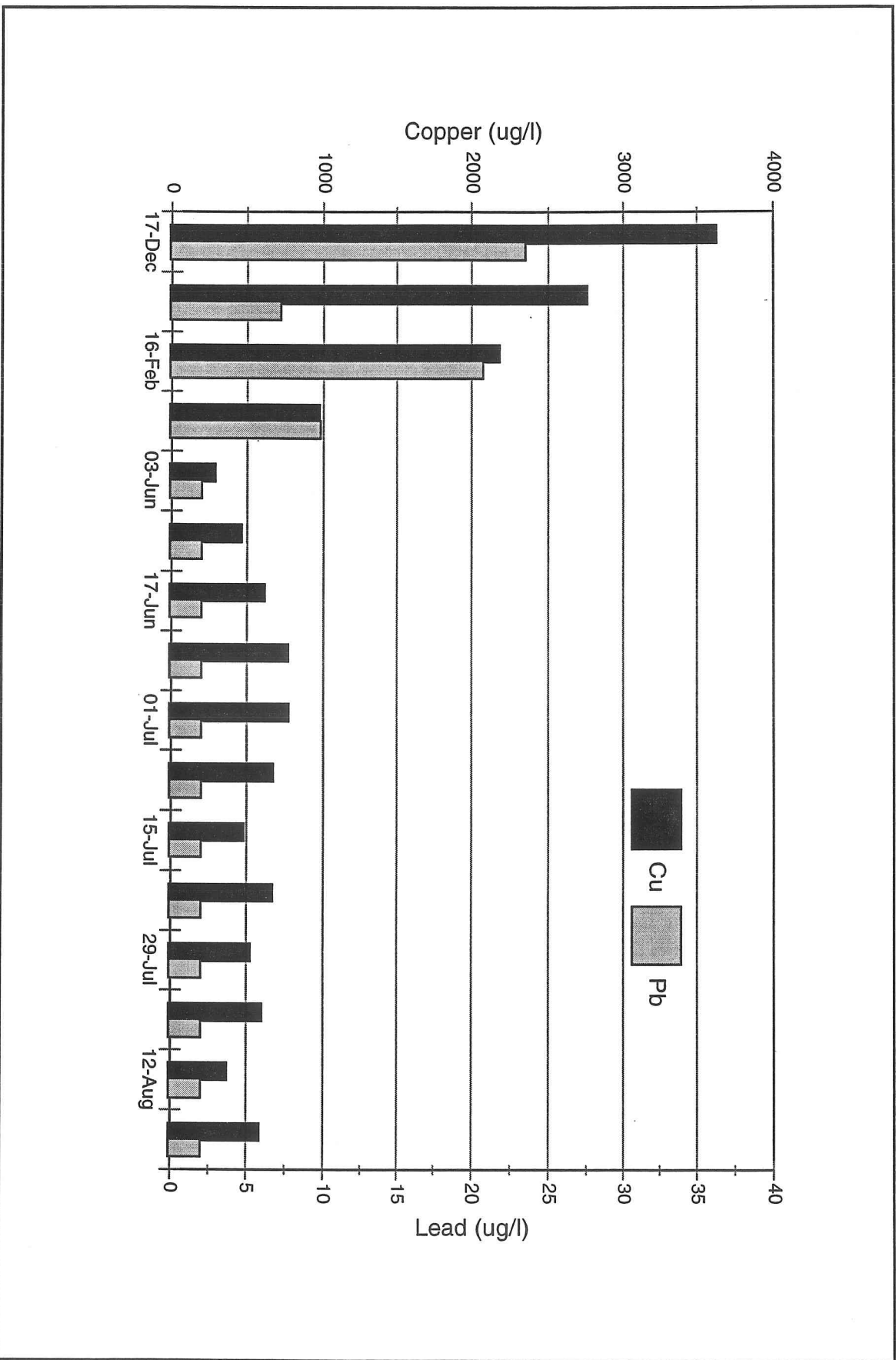


Figure 2. Copper and lead concentrations prior to testing (17-Dec thru 27-May) and after the start of continuous flushing at fountain 1, (03-Jun thru 19-Aug). Instrument detection limit for lead is 2 $\mu\text{g/l}$.

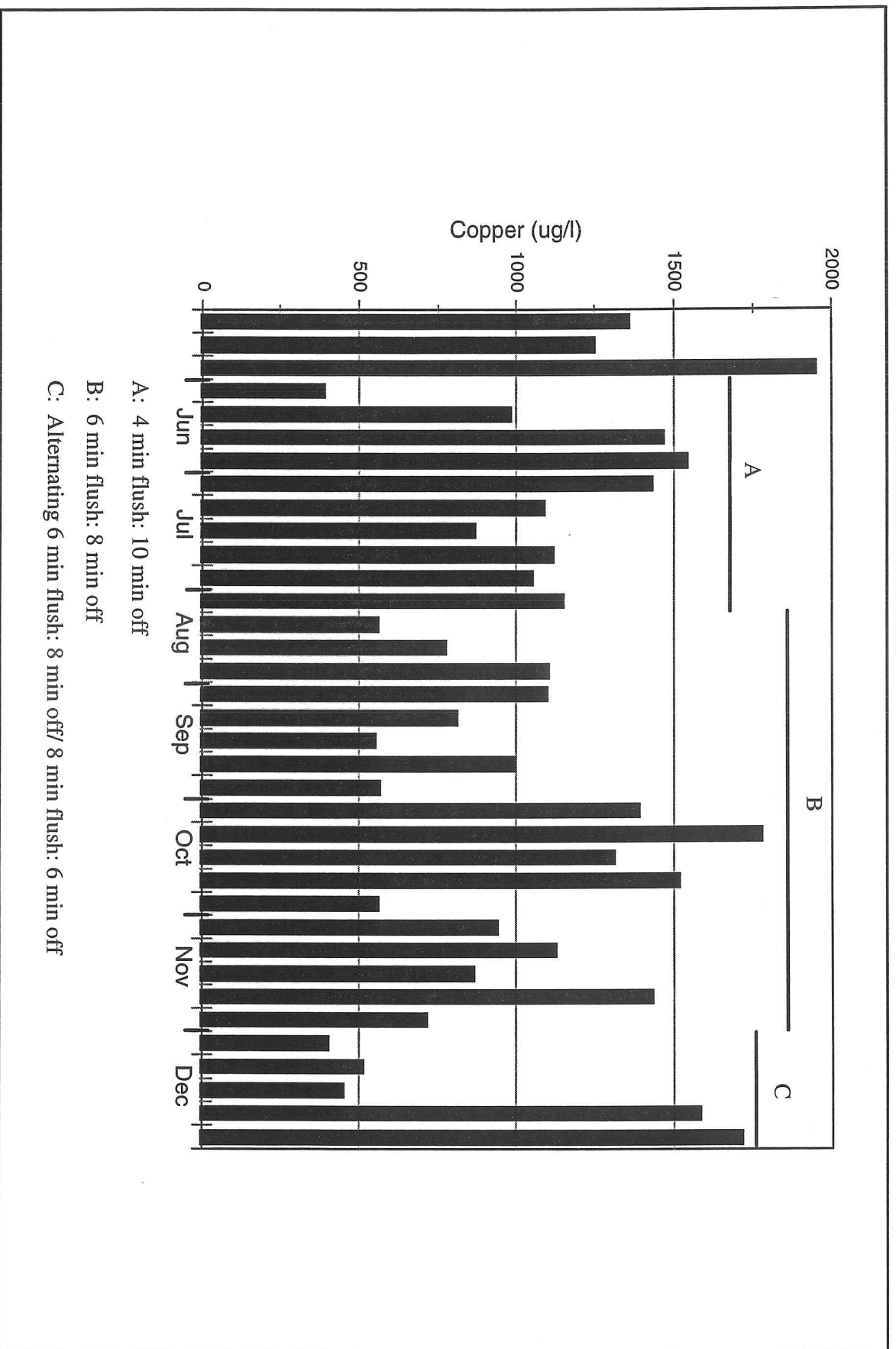


Figure 3. Copper concentrations at the gym fountain prior to a flush.

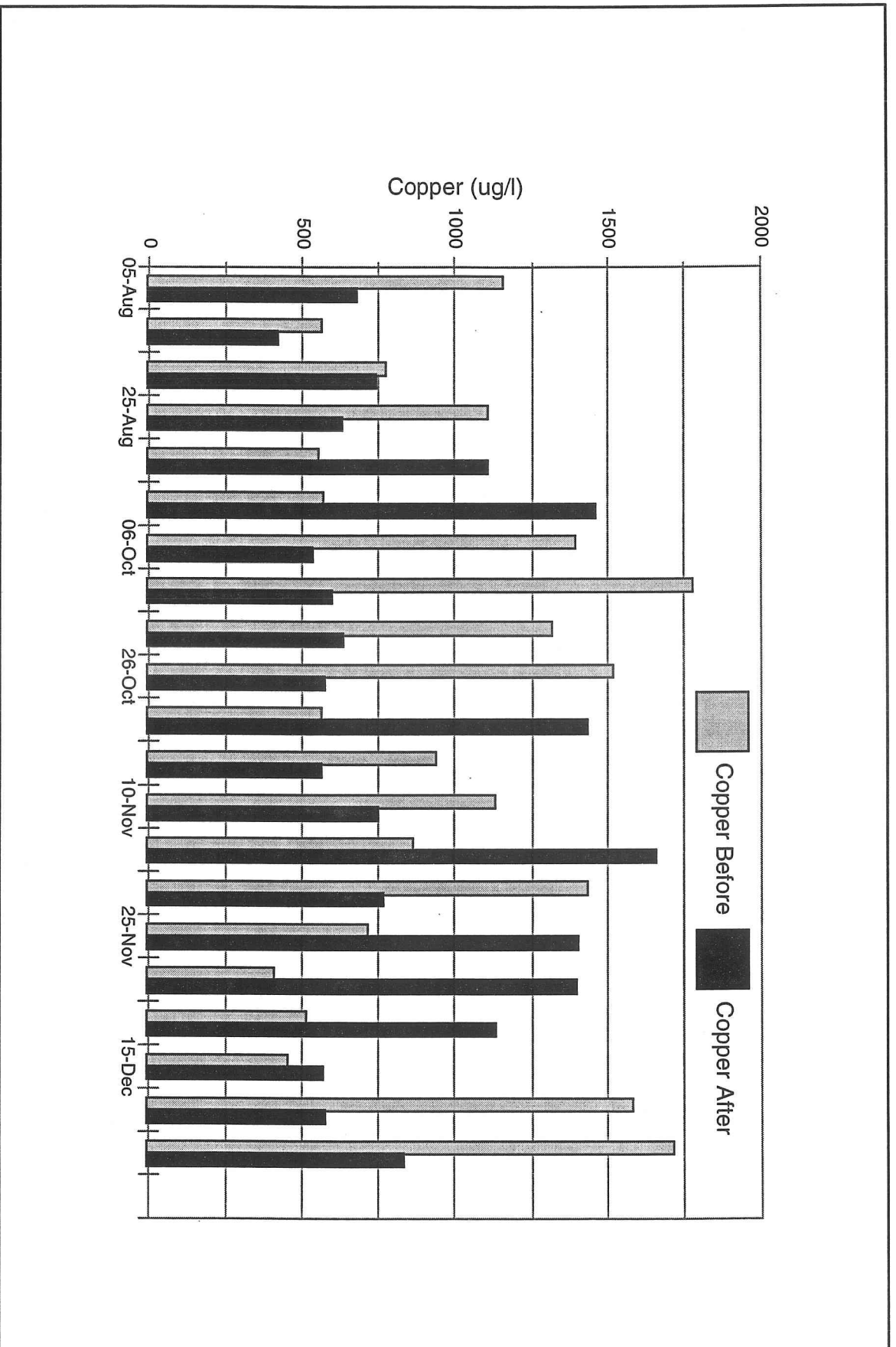


Figure 4. Copper concentrations before and after a flush at the gym fountain.

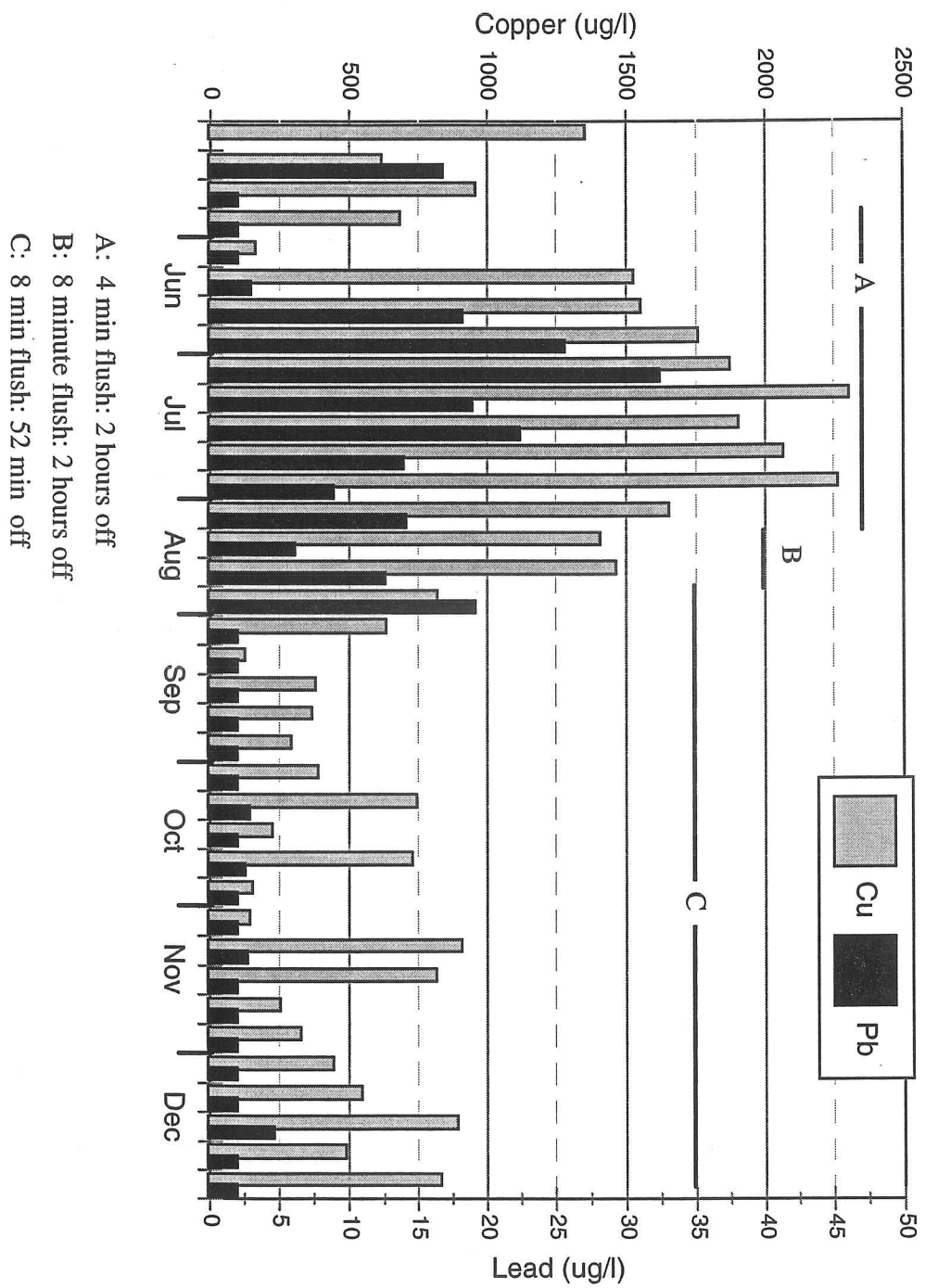


Figure 5. Copper and lead concentrations prior to a flush at the sink. Instrument detection level for lead is 2 $\mu\text{g/l}$.

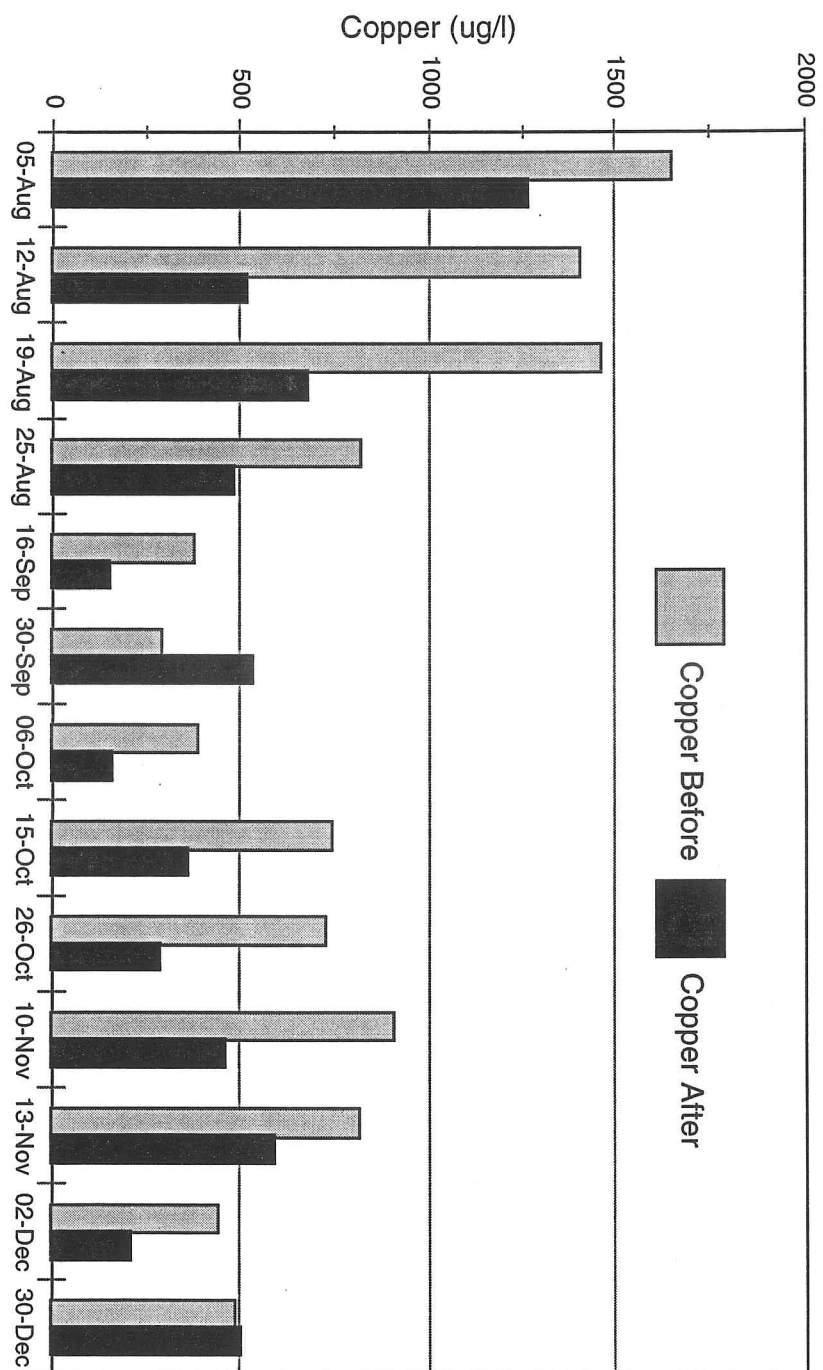


Figure 6. Copper concentrations before and after a flush at the sink.

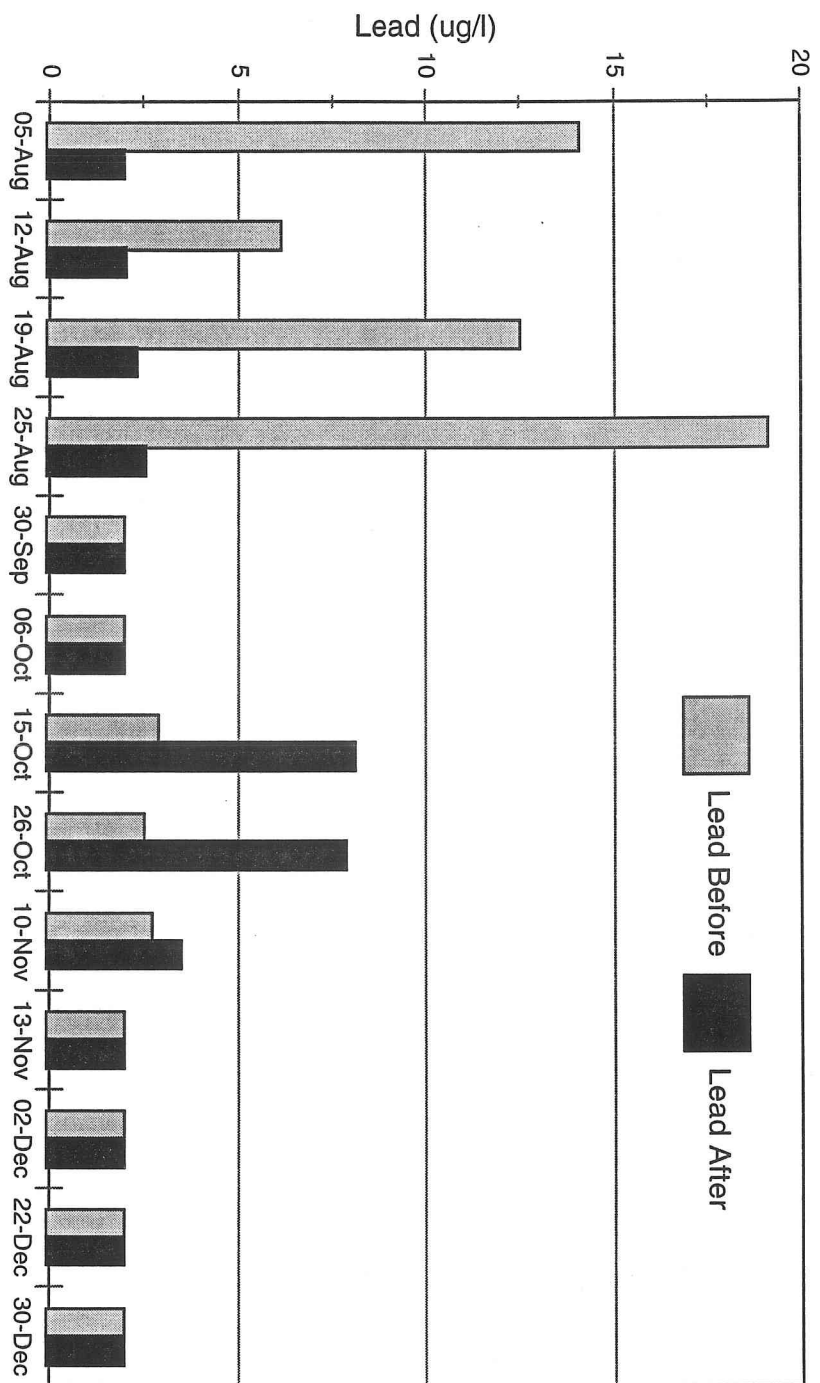


Figure 7. Lead concentrations before and after a flush at the sink.

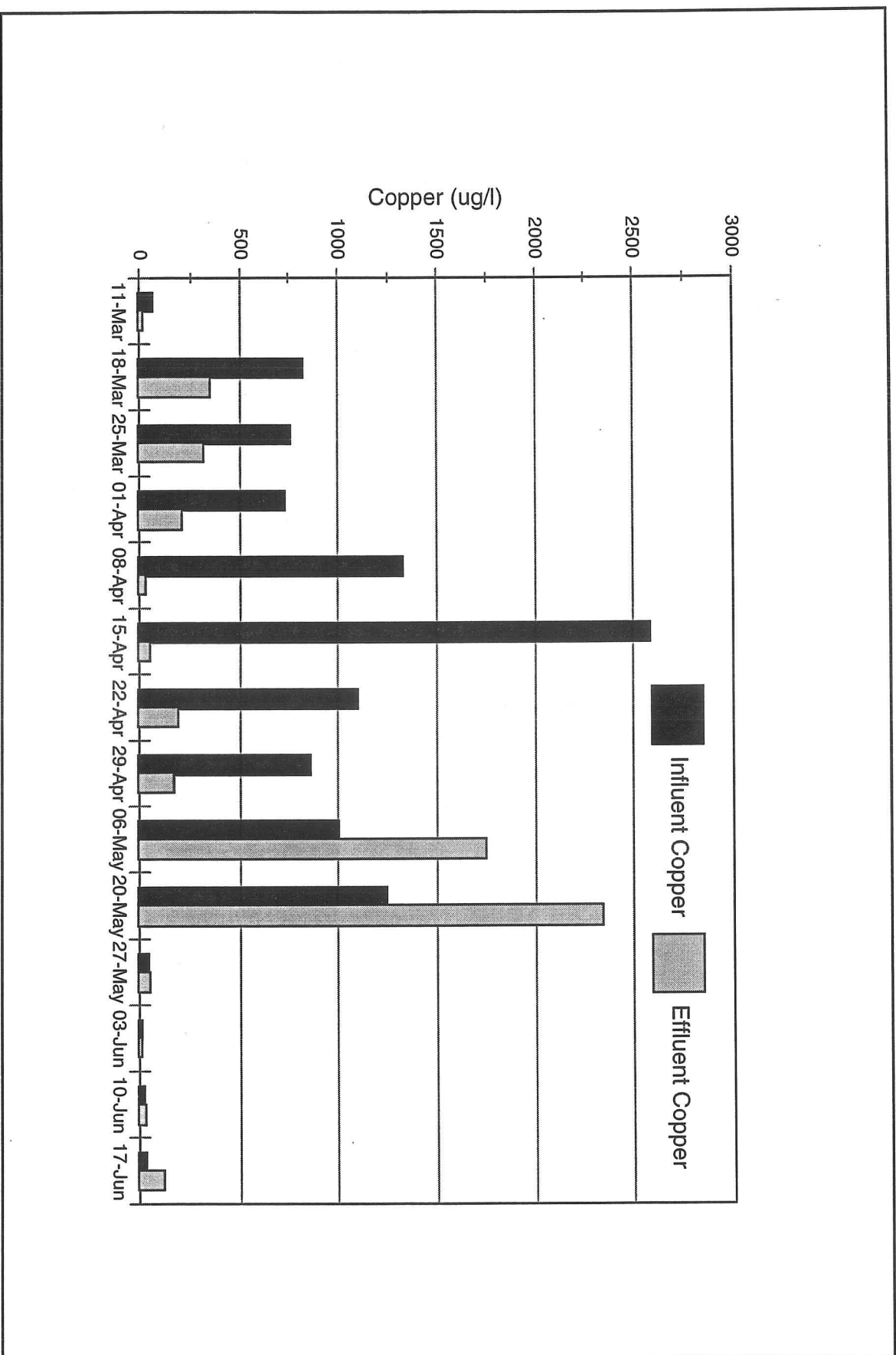


Figure 8. Influent and effluent copper concentrations at the trailer home.

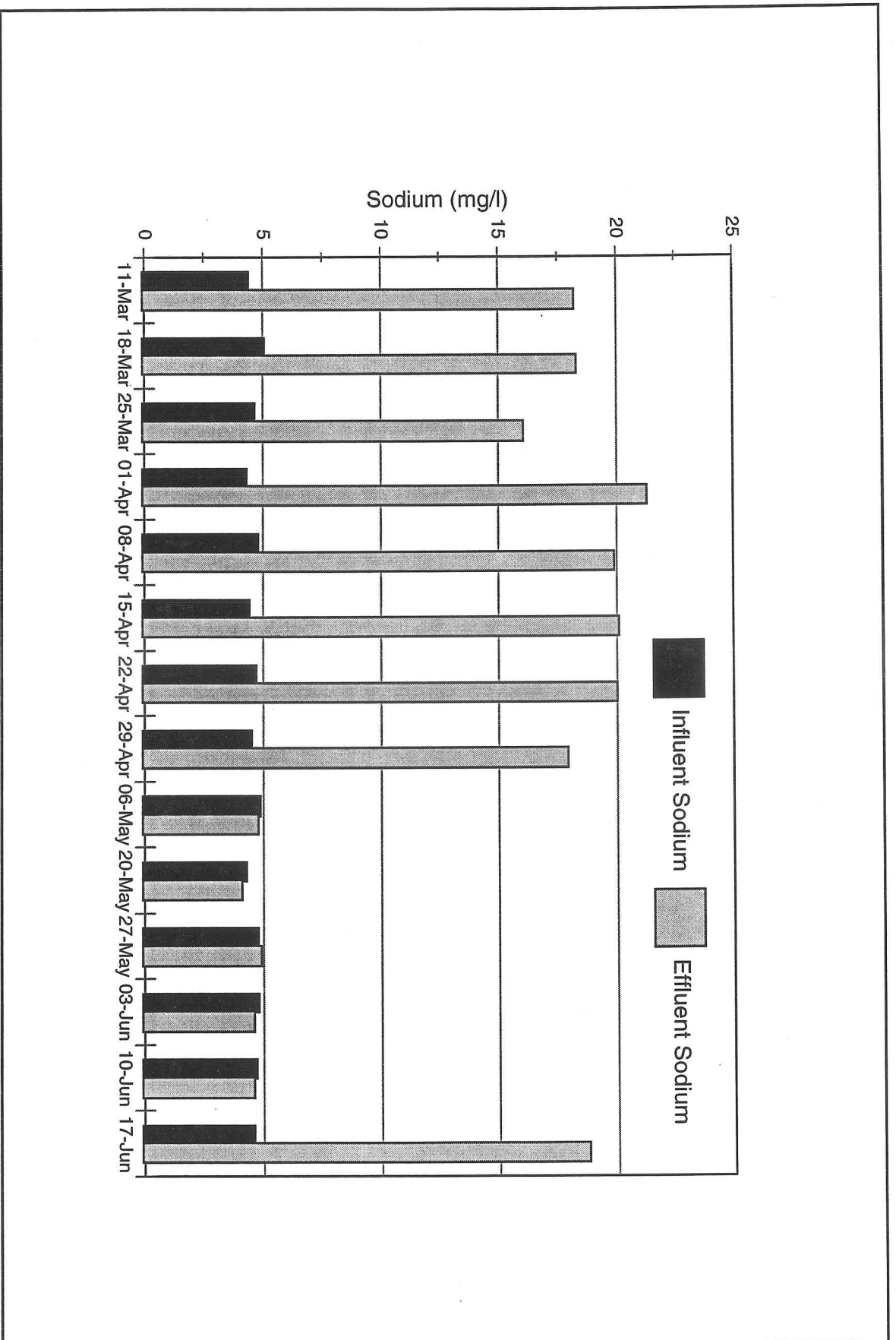


Figure 9. Influent and effluent sodium concentrations at the trailer home.

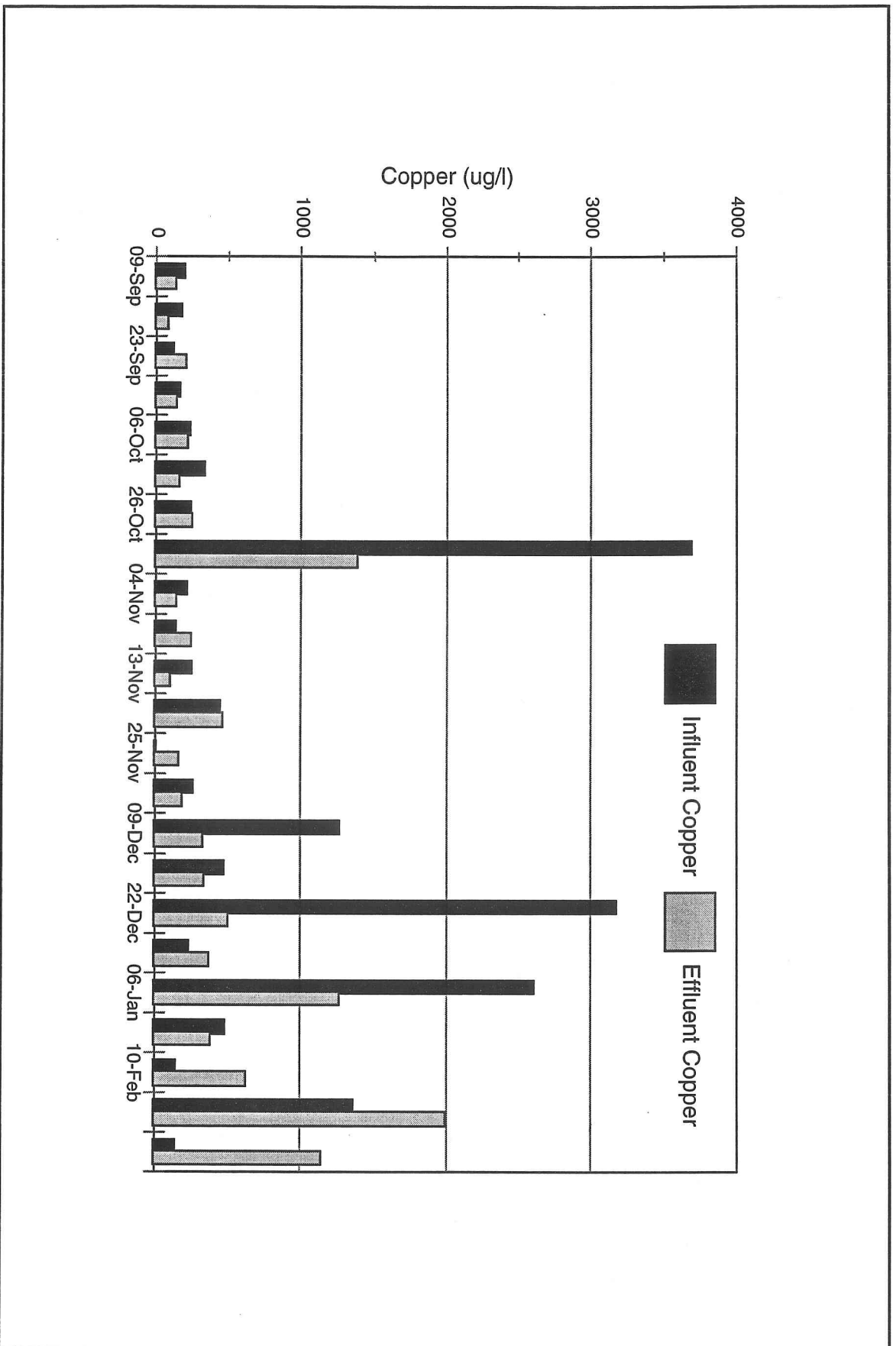


Figure 10. Influent and effluent copper concentrations at the school fountain fitted with the ion exchange unit.

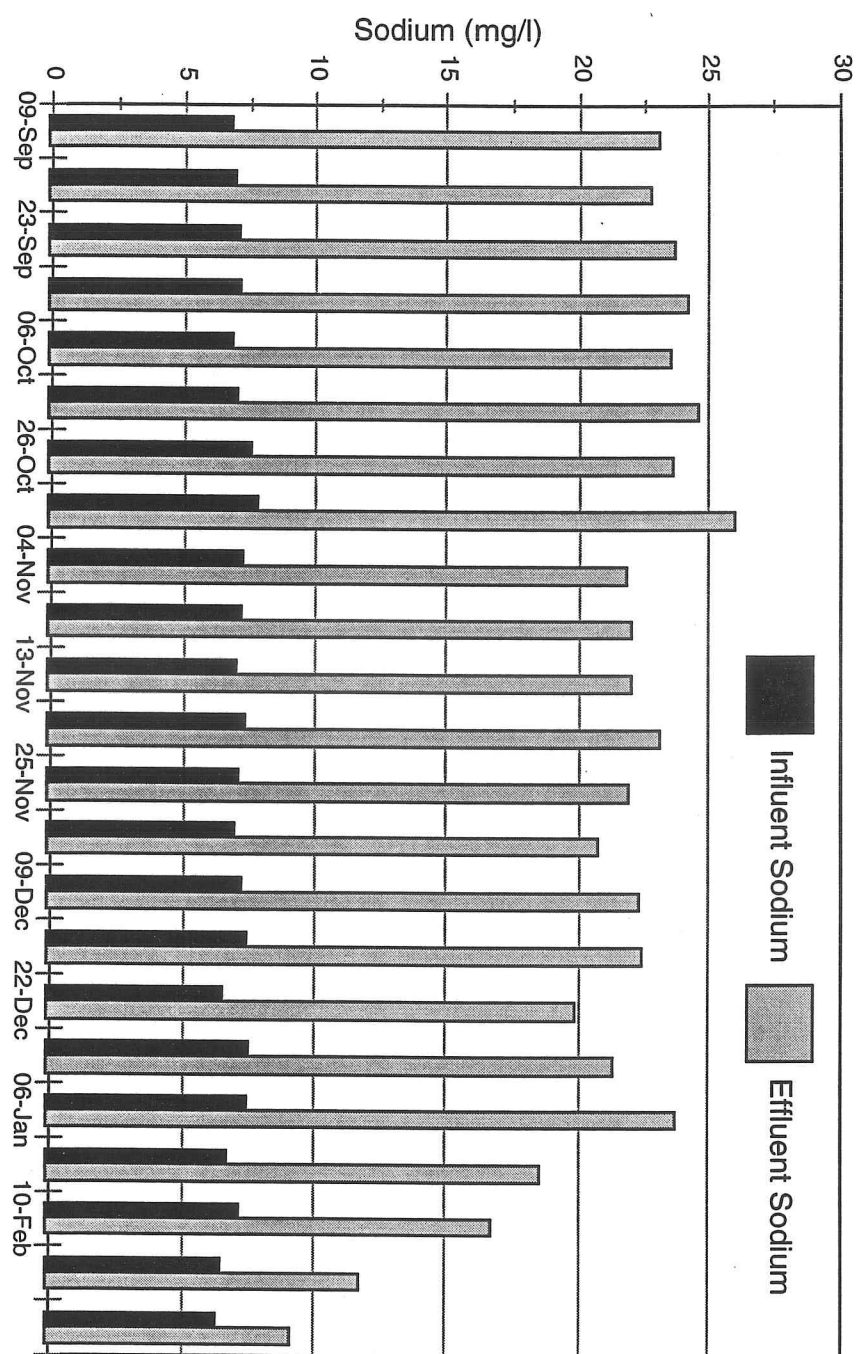


Figure 11. Influent and effluent sodium concentration at the school fountain fitted with the ion exchange unit.

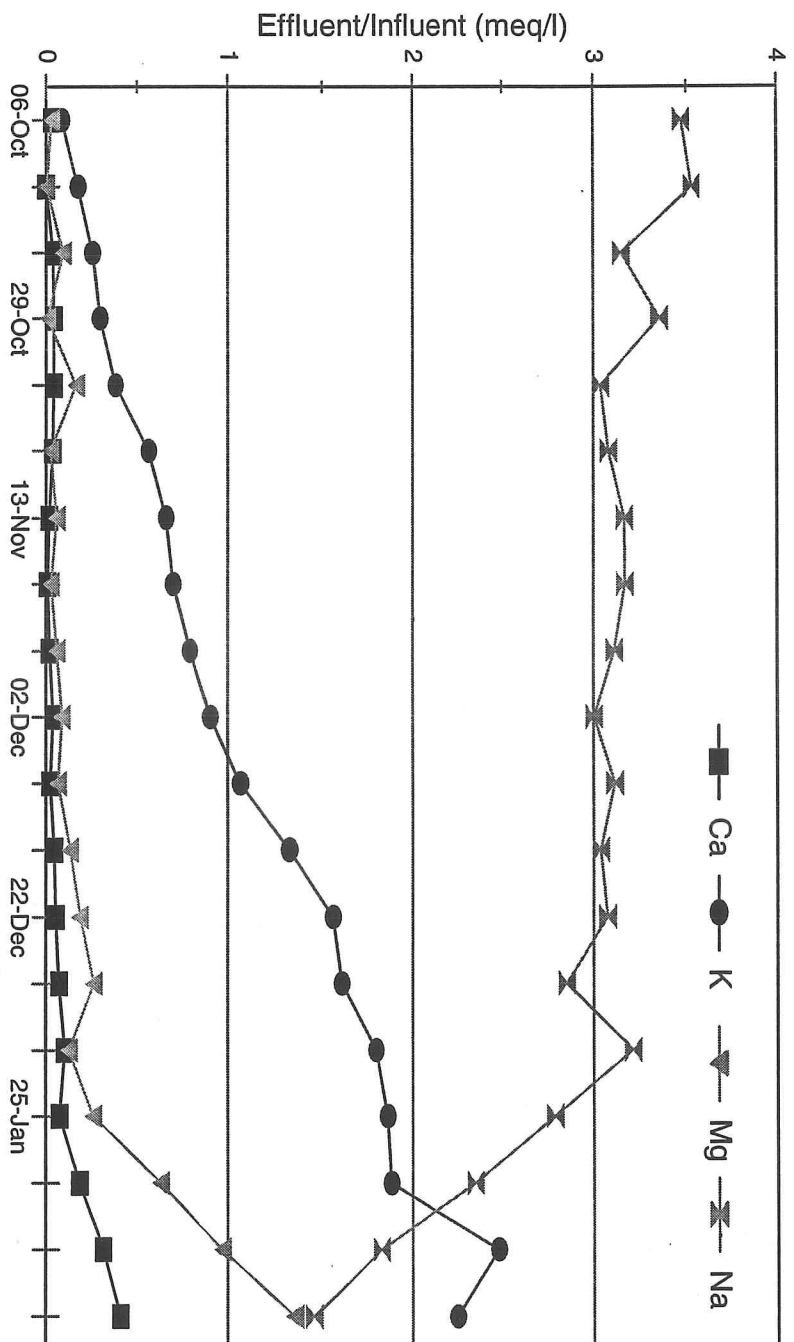


Figure 12. Ratio of effluent to influent calcium, potassium, magnesium and sodium concentrations at the school fountain.