APPENDIX II.B - LEAD PILOT RESULTS

DRAFT FOR PUBLIC COMMENTS

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DENVER WATER

Appendix II.B:

DRAFT 2 – Lead Pilot Results

Date:	Revised June 6, 2019 May 15, 2019
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This memo reports data from the two lead service line pilots located at Marston and Moffat treatment plants. These two sites were chosen to represent the South Platte River and the Fraser River which are the two major water supplies to the Denver Water system. Although the Foothills plant produces the most water, it is also located on the South Platte Supply with very similar water quality to Marston. Average and ranges of influent water quality parameters are presented in Table 1.

Table 1. Summary of Influent Water Quality.

Parameter	**Marston Influent** Avg. (range)	**Moffat Influent** Avg. (range)
Temperature (°C)	13 (4-25)	12 (5-21)
pH	7.8 (7.4-9.1)	7.8 (7.2-8.3)
Alkalinity (mg/L as $CaCO_3$)	64 (37-83)	37 (14-70)
Calcium (mg/L)	30 (7-41)	15 (1-36)
Magnesium (mg/L)	7.9 (1.7-10.8)	3.1 (0.3-9.2)
Conductivity (µS/cm)	324 (180-450)	152 (92-330)
Total Chlorine (mg/L)	1.31 (0.03-8.00)	1.38 (0.14-1.78)

Data through March 14, 2019 are included. After this date, pilot operation was modified to begin testing other conditions. These tests are currently underway testing low dose orthophosphate at high pH and transitioning from high pH to orthophosphate should it be necessary in the future.

Each pilot consists of four racks of three whole lead service lines (and one segmented service line not included in sampling). Each pipe was run for three flow and stagnation cycles each day. The flow period was two hours, followed by a 5 hour stagnation period, then a 1 hour sampling period. Feedwater was supplied from the distribution system and piped back to the pilot rigs.

The first rack is the control rack, which has no adjustment to water quality. The second rack tests corrosion control using orthophosphate addition which was started at 3 mg/L as PO_4 and reduced over time. Orthophosphate was dosed as phosphoric acid and the pH was returned to match the existing distribution system of 7.8 with caustic soda. The third rack originally tested silicate addition but was later transitioned to an additional orthophosphate test where the test began at 1 mg/L as PO_4. Only the orthophosphate data are included in this report for Rack 3. The fourth rack uses pH modification for corrosion control. Target pHs of 8.8 and 9.2 were tested using caustic soda as the base. Detailed information on the design and initial operation of the pilots can be found in Denver Water's "Optimal Corrosion Control Treatment Report," dated September 20, 2017.

Summaries of the lead release for each pilot are shown in Figure 1 and Figure 2. Lead was analyzed by the ICP/MS direct method EPA 200.8 with a minimum reporting level of 1 µg/L (ppb). Each pipe was run for a conditioning period to stabilize operation after the disturbance of harvesting the lead service lines. These are indicated by the "pre-treatment" gray box. Lead removal is calculated by dividing the median lead during treatment by the median lead during the pretreatment period for each pipe. The three pipes on each rack were averaged to get the values used in the summary figures. The only data excluded from the analysis were periods where the operational targets could not be maintained (i.e. the orthophosphate dose or pH were out of range). These are noted as upset periods indicated with gray rectangles and are discussed in further detail later.

Both plots show that orthophosphate and high pH reduce lead release, with orthophosphate performing better for lead control. An orthophosphate dose of 2 mg/L appears to be equal in performance to 3 mg/L, assuming dosing starts at 3 mg/L. See Corona Technical Memorandum "Reducing Orthophosphate Dose from 3 mg/L to 2 mg/L does not Result in Increased Lead Release in Denver Water Pilot Study" dated 5/24/2019 for additional information. While testing continues, an orthophosphate dose of 1 mg/L does not appear to result in equivalent reduction.

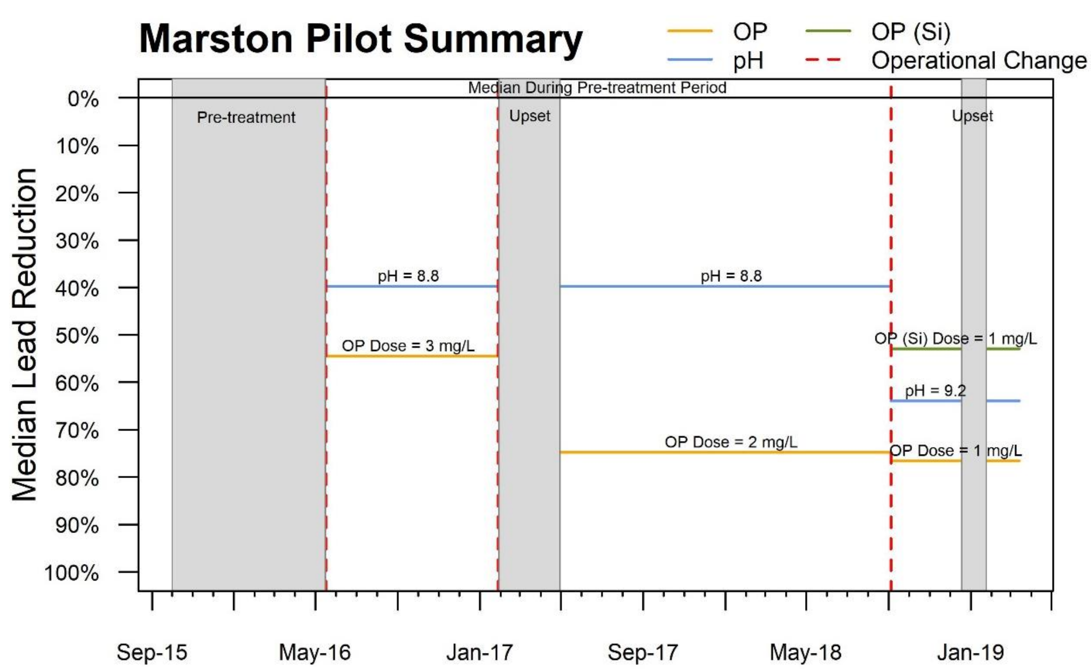

Figure 1: Marston Pilot Summary (orthophosphate doses shown measured as PO_4)

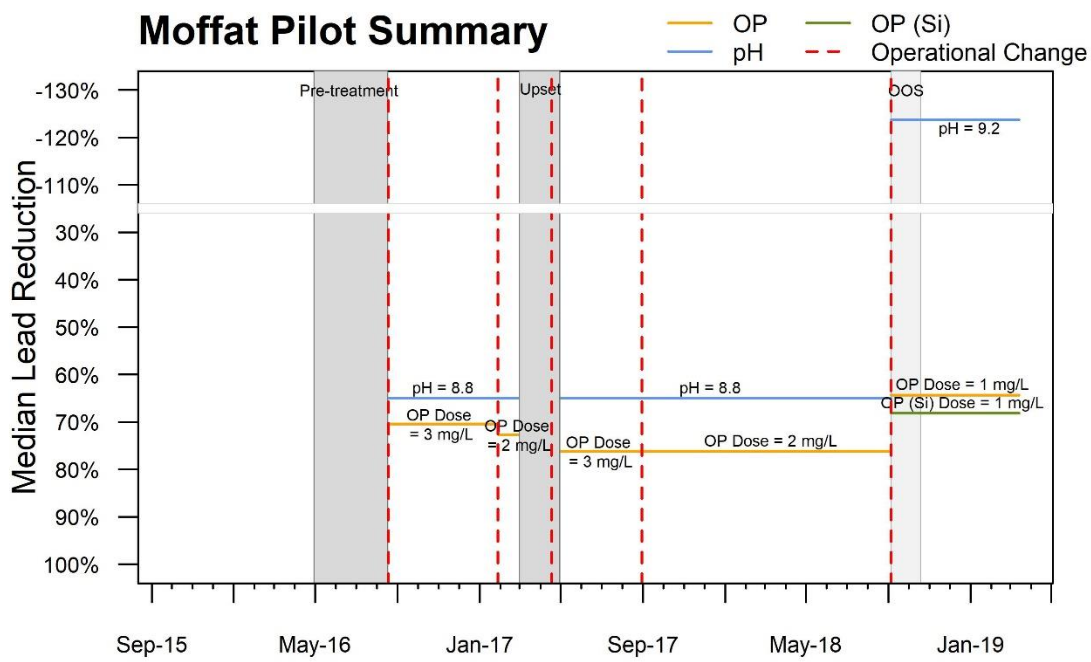

Figure 2: Moffat Pilot Summary (orthophosphate doses shown measured as PO_4)

Time series plots of lead release for all treatment conditions for both pilots are shown in Figure 3 through Figure 12. These plots include all data as distinct points with the y-axis in a log scale for lead data to display all the data and demonstrate the pipe-to-pipe variability. Where appropriate, target orthophosphate dose and target pH are shown with a dashed red line.

The Marston pre-treatment period is shown with a gray rectangle in Figure 3 through Figure 7; during this time no chemical was being added. For the orthophosphate racks, shown in Figure 4 and Figure 5, the orthophosphate dose was started at 3 mg/L and stepped down to 2 mg/L then 1 mg/L. The dose was stepped down to determine whether a lower dose provided equivalent corrosion control to the 3 mg/L dose. The former silica orthophosphate racks stepped directly from no orthophosphate to a dose of 1 mg/L. This condition was selected to determine whether starting with a high dose and lowering the dose was equivalent to starting with a lower dose. The pH racks, shown in Figure 6 and Figure 7, ran with a pH setpoint of 8.8 and increased the setpoint to 9.2. The pH was increased to see whether a higher setpoint would provide further corrosion control.

Marston experienced two upset periods, shown with gray rectangles. Both upsets caused increased lead release. Both upsets were due to several minor electrical faults that prevented the pilot from running correctly as scheduled. As shown in the plots, many of the pipes have not returned to pre-upset conditions. This is especially true for pH pipe 4.

Figure 5 shows the orthophosphate measured in the sample after stagnation. This may not be representative of the applied dose early in the test where pipe scales are forming. Overall, the orthophosphate results indicate it was fed consistently and accurately after the initial range finding.

Figure 7 shows the measured pH in the sample after stagnation. Results indicate a drop in pH of about 0.3 units over the stagnation period.

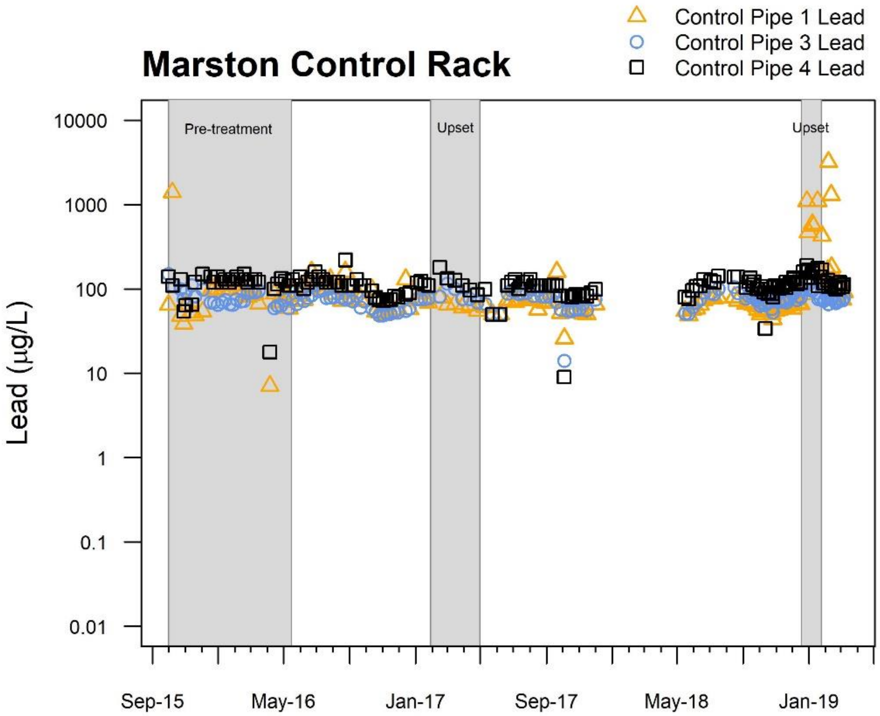

Figure 3: Marston Control Rack - Lead

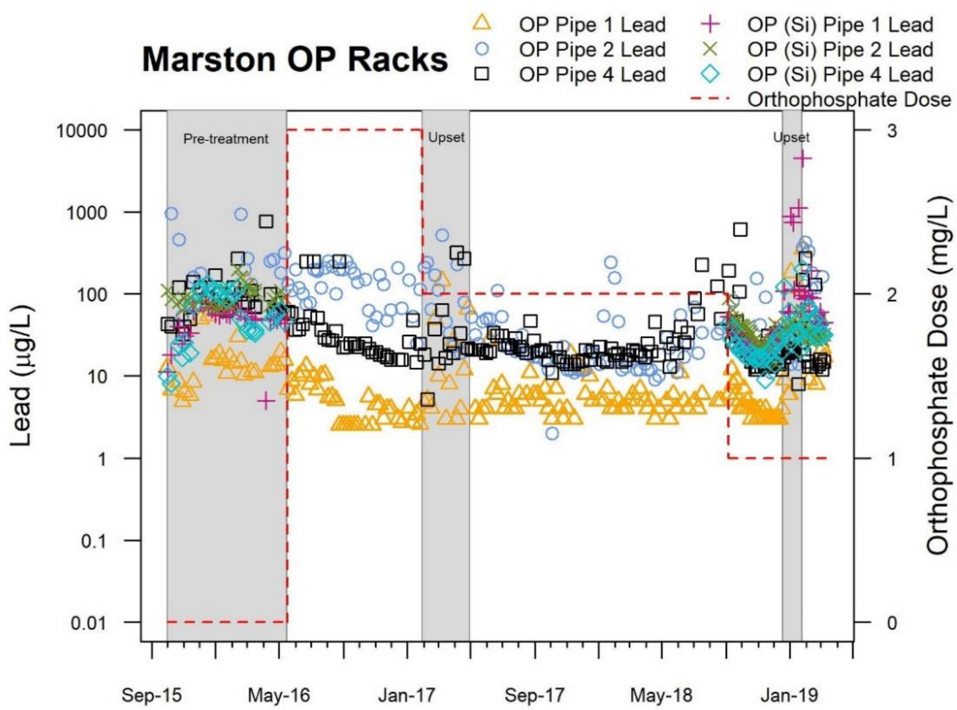

Figure 4: Marston OP Racks - Lead

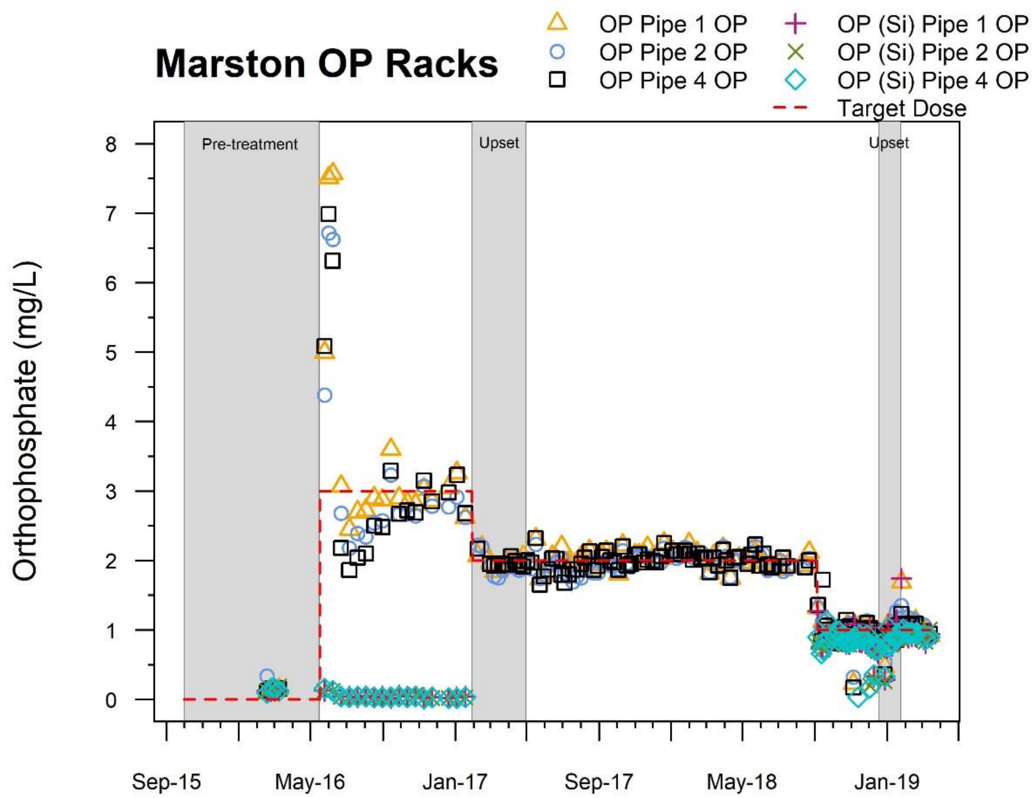

Figure 5: Marston OP Racks - OP Target Dose and Measured Residual

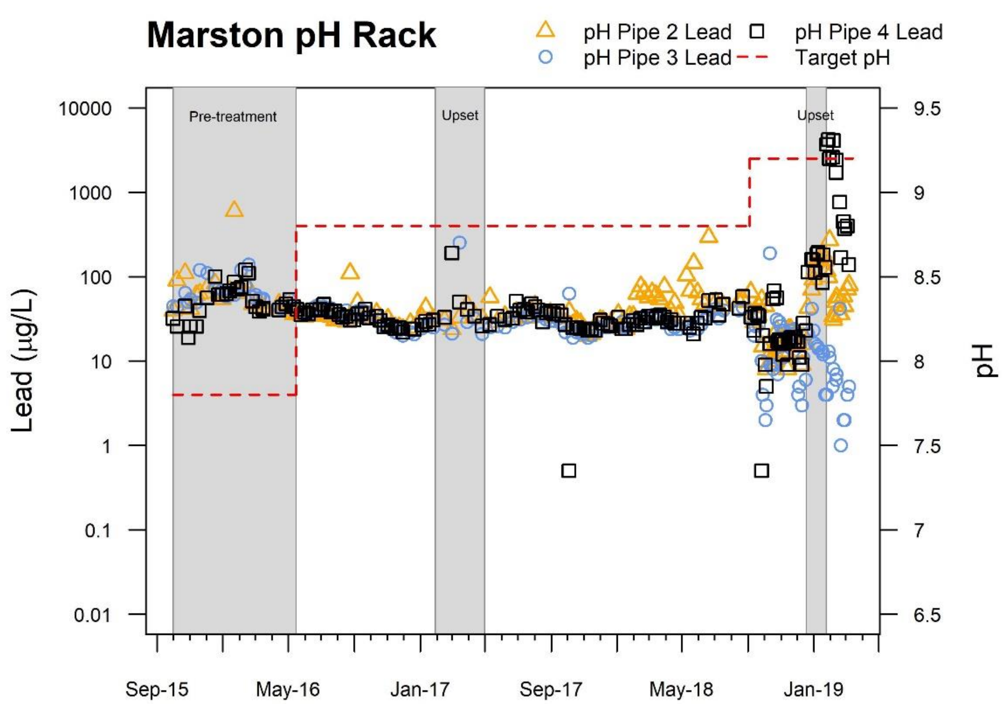

Figure 6: Marston pH Rack - Lead

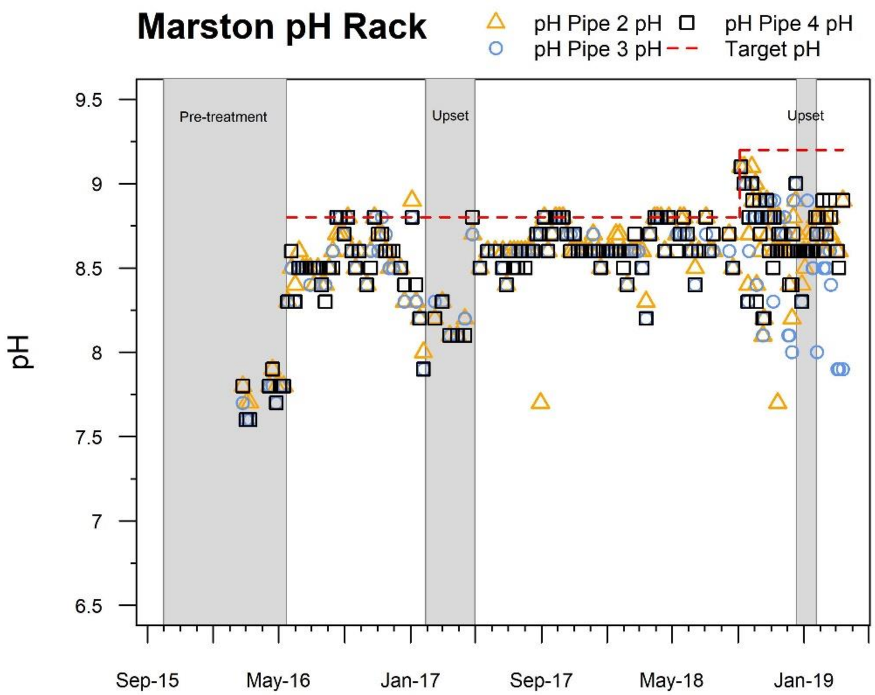

Figure 7: Marston pH Rack - pH

The Moffat pretreatment period is shown with a gray rectangle in Figure 8 through Figure 12. For the orthophosphate rack, dose was stepped down in a similar manner to Marston. The former silica rack and the pH rack were both controlled the same as Marston. Moffat experienced one upset due to a series of pump failures that resulted in the target conditions not being met. The orthophosphate dose was increased back to 3 mg/L to help stabilize lead release. A second area is highlighted in a light gray box when the Moffat plant was out of service. During this time, the pilot was being fed a water from the distribution fed by the Marston plant. The change in water quality caused a large response in lead release. All pipes saw an increase in lead release during the out of service period and some maintained the higher levels when the out of service period ended. Pipe 1 in the pH rack was affected most drastically. Because all operational parameters were maintained during this period and this is a normal occurrence, these data were included in the analysis.

Figure 10 shows the orthophosphate measured in the sample after stagnation. Like the Marston pilot, the orthophosphate results indicate it was fed consistently and accurately after the initial range finding. Figure 12 shows the measured pH in the sample after stagnation. Results also show some drift in pH but pH was more stable than at Marston.

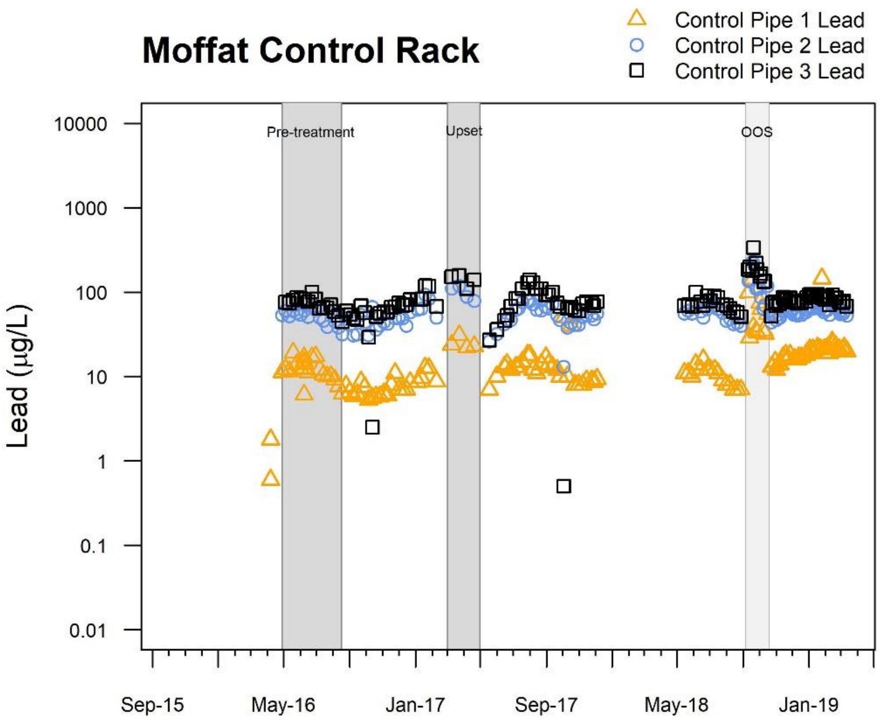

Figure 8: Moffat Control Rack - Lead

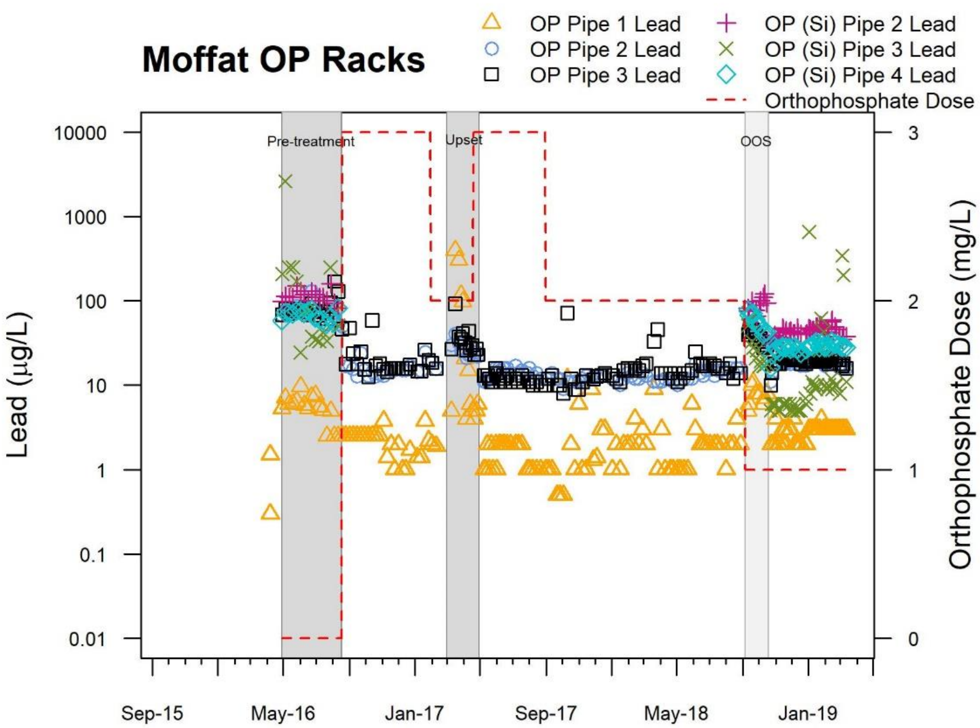

Figure 9: Moffat OP Racks - Lead

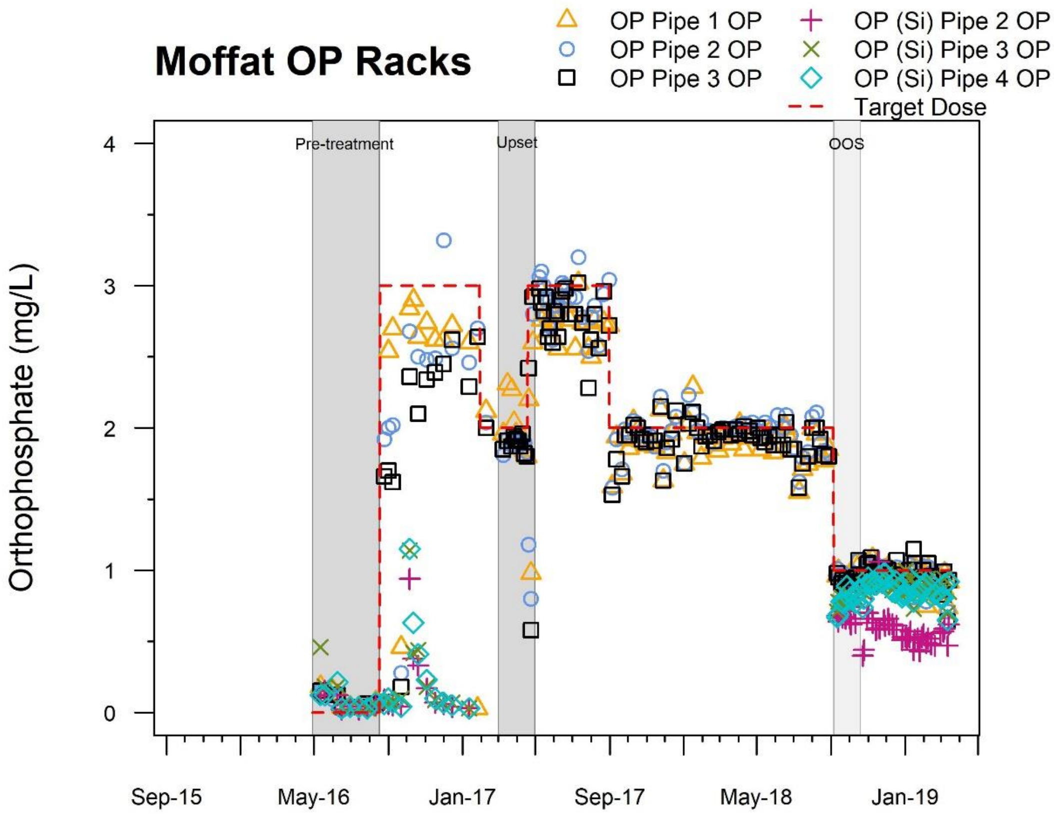

Figure 10: Moffat OP Racks - OP Target Dose and Measured Residual

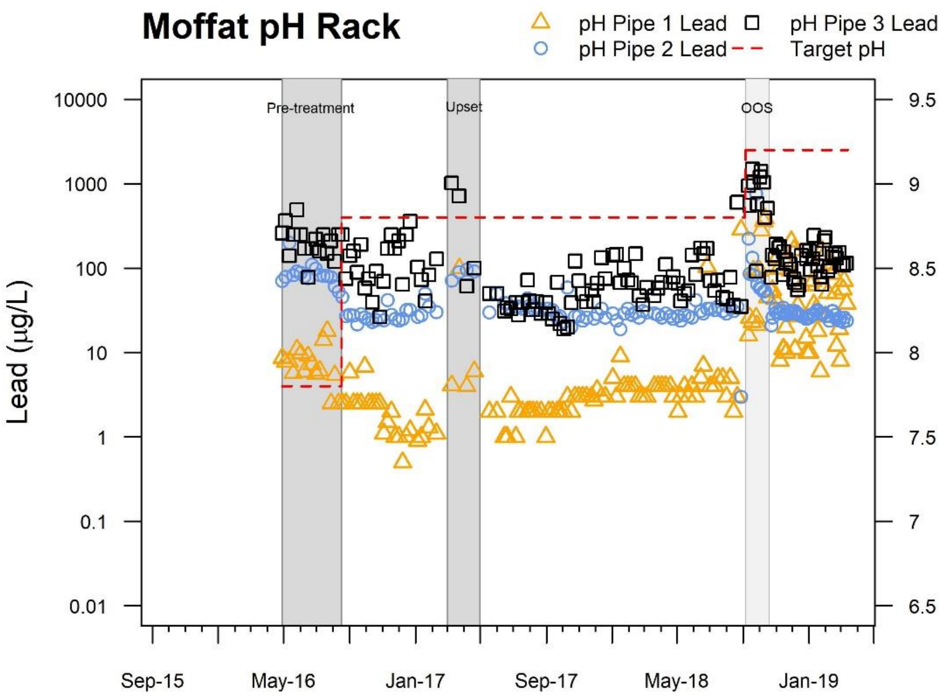

Figure 11: Moffat pH Rack - Lead

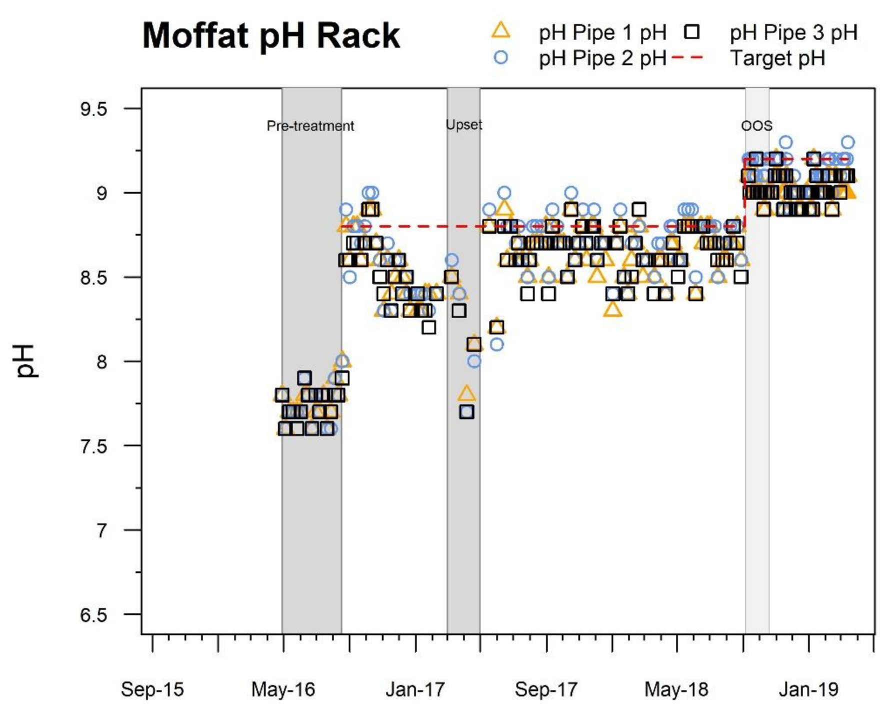

Figure 12: Moffat pH Rack - pH

Box plots of lead release under the different treatment conditions are shown in Figure 13 through Figure 24. The quartiles are shown with horizontal lines; the mean is shown with a diamond. The whiskers represent the 5th and 95th percentile. Dots outside the whiskers show individual data points outside this range. The counts for each range of data are shown below the box. All plots use the same y-axis range of 0 to 250 µg/L. Because of high measurements, not all data are shown. Each treatment condition has a matching control box plot. All control box plots use the same data, but the data are split across the different boxes to match the times at which the corresponding treatment conditions were varied. For example, Figure 13 shows the control rack behavior when the OP rack was at 3 mg/L, 2 mg/L, and 1 mg/L.

The box plots are also divided by individual pipe, each shown in a separate pane, which shows the variability in lead release between different pipes under the same conditions. For example, as shown in Figure 14, OP Pipe 1 has always had low lead release in comparison to the other pipes in the pilot, even during pretreatment. Therefore, plotting individual pipes allows comparison of treatment conditions to pretreatment lead release, with each treatment condition shown as a separate box plot. The matching control plots are shown to account for the variability in pilot feed water affecting lead release.

The upset periods were removed from the calculations for all box plots because target operational conditions were not maintained.

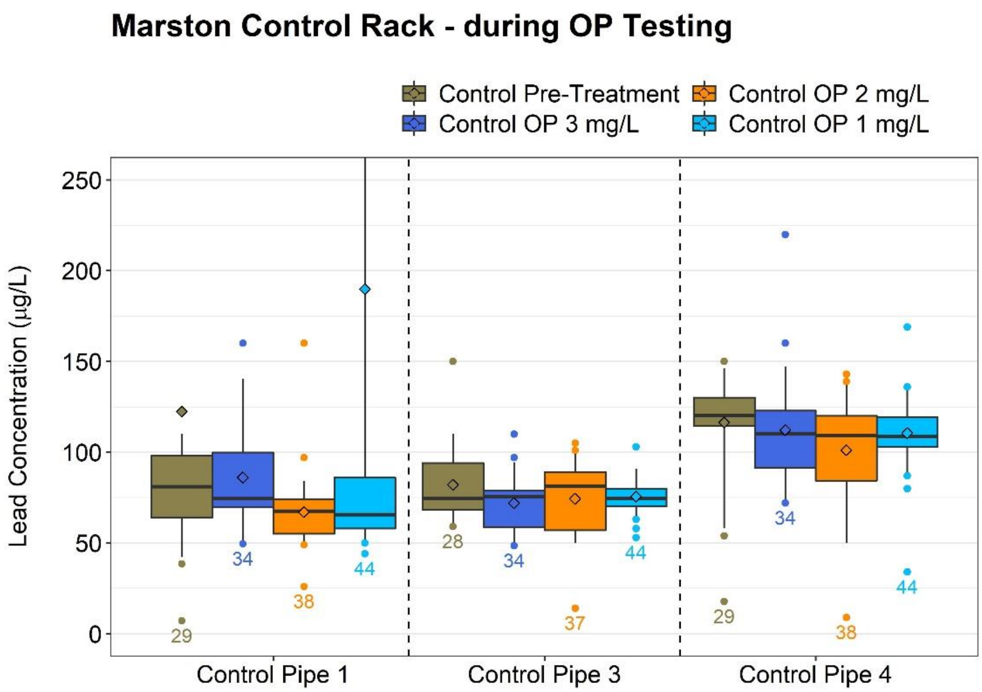

Figure 13: Marston Control Rack - Matching OP Rack

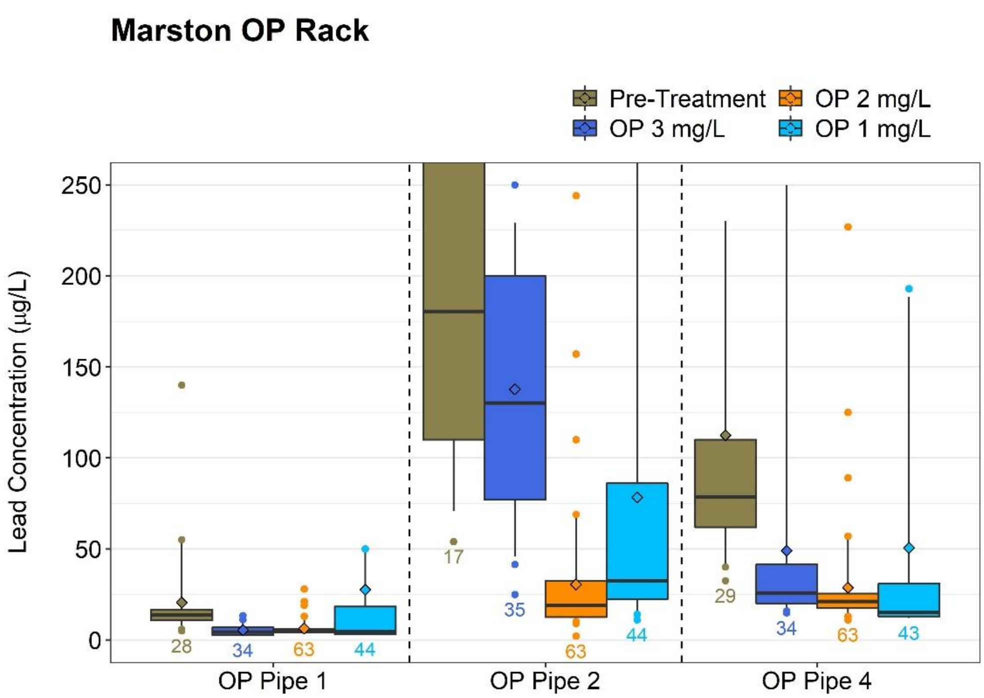

Figure 14: Marston OP Rack

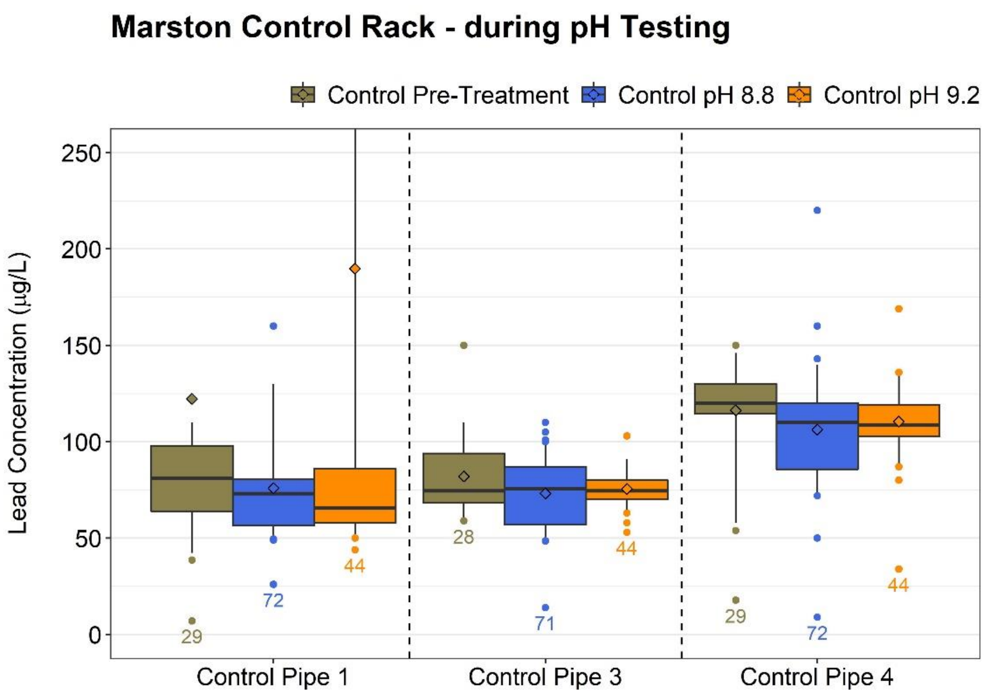

Figure 15: Marston Control Rack - Matching pH Rack

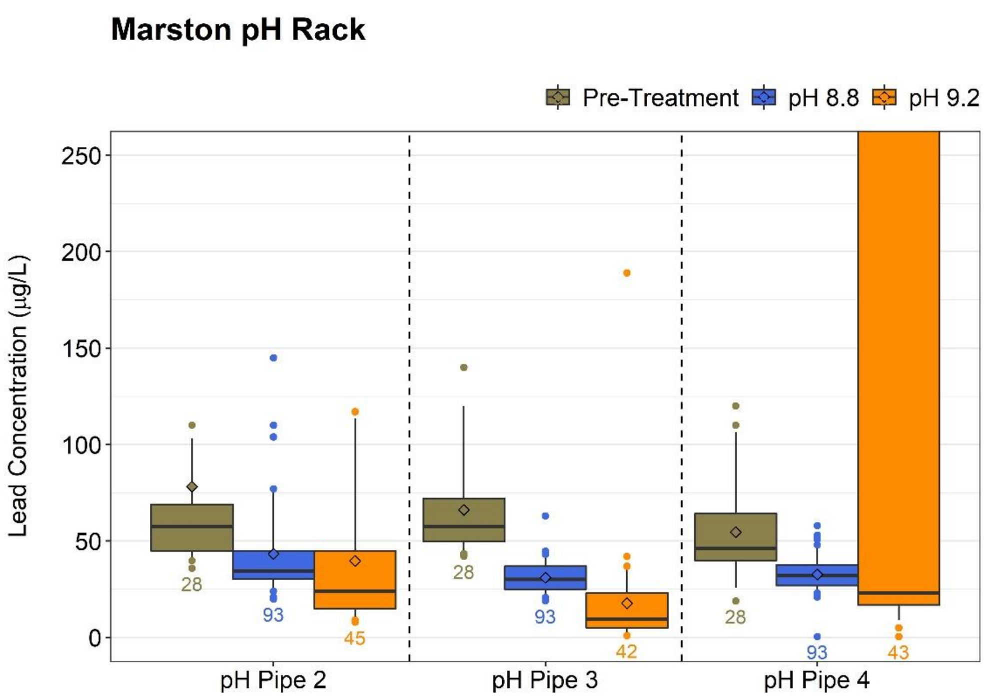

Figure 16: Marston pH Rack

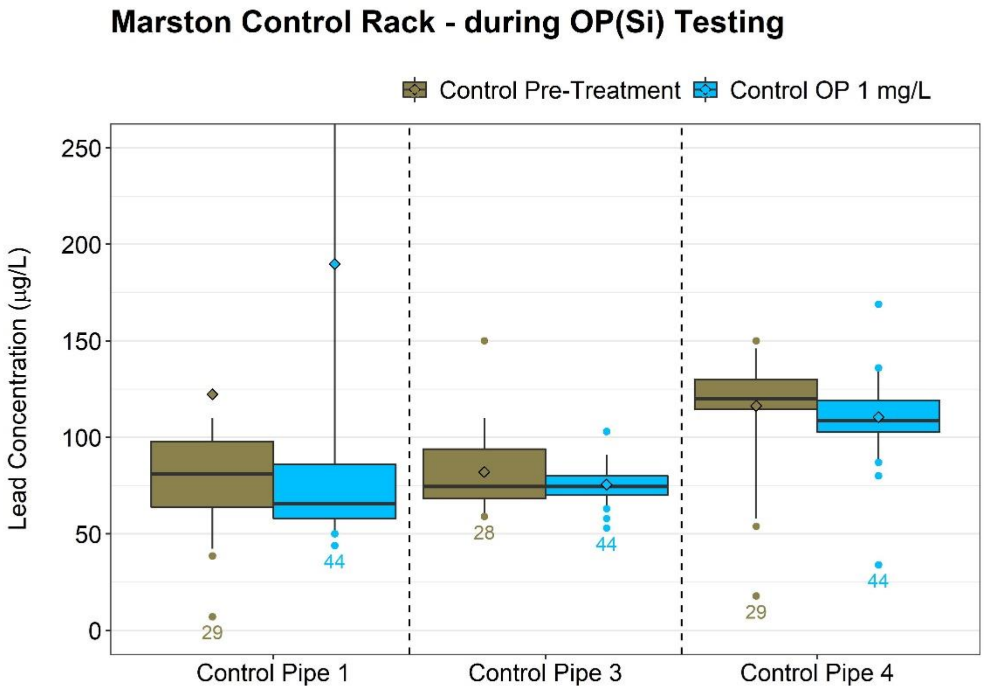

Figure 17: Marston Control Rack - Matching (Si) OP Rack

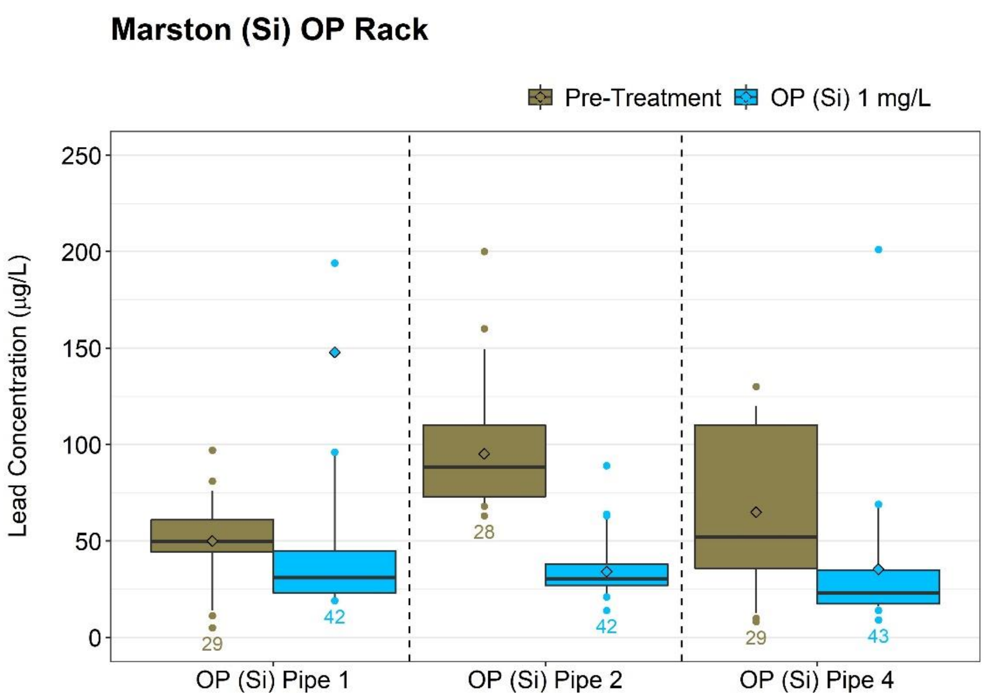

Figure 18: Marston (Si) OP Rack

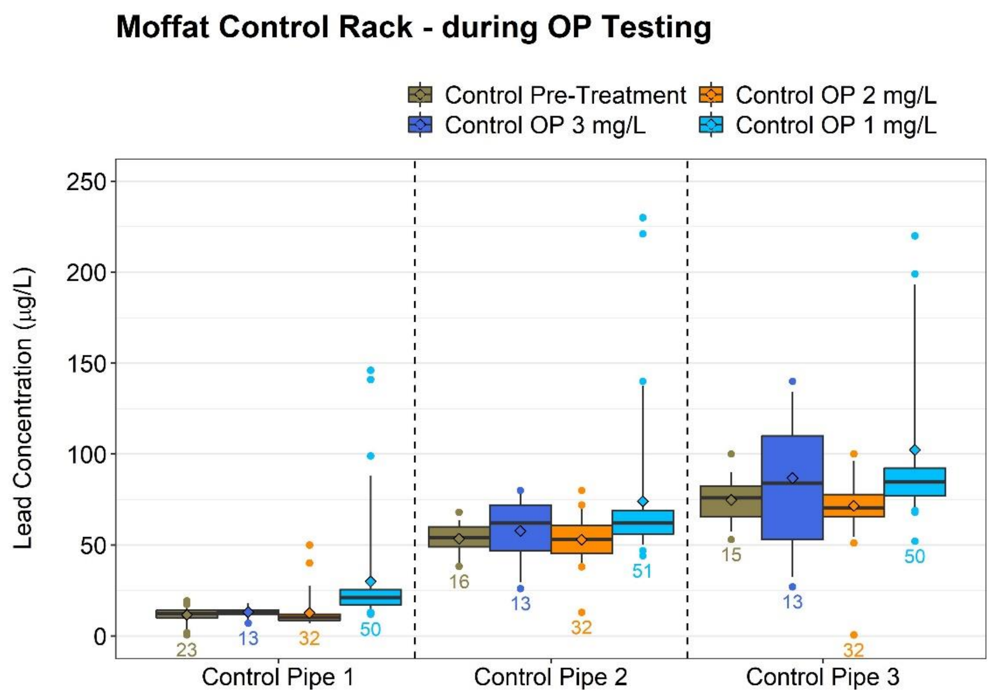

Figure 19: Moffat Control Rack - Matching OP Rack

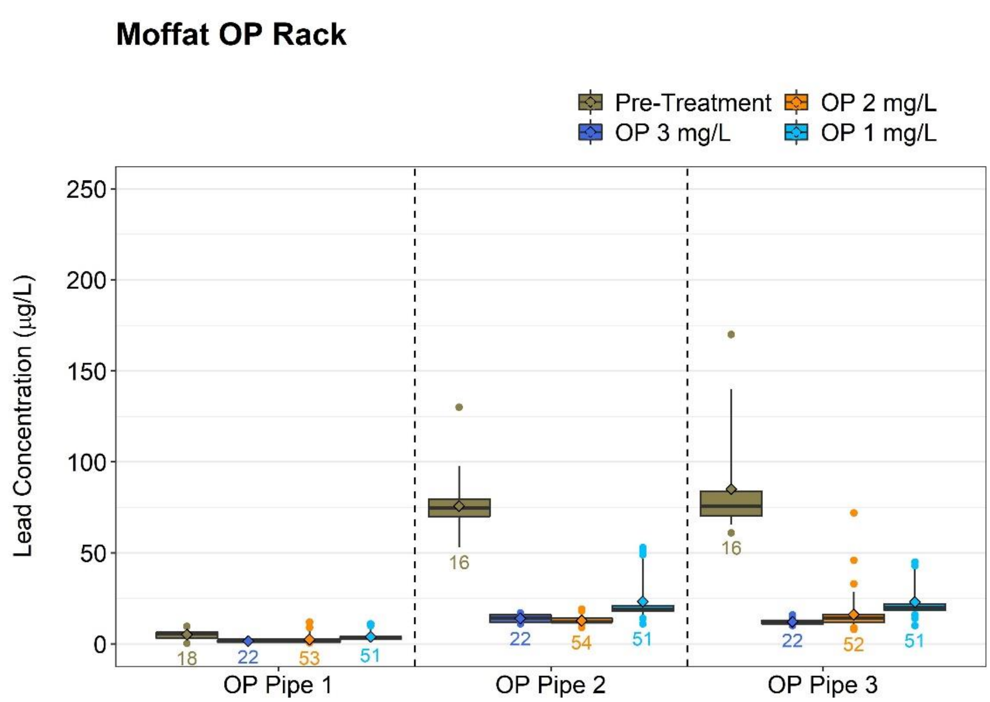

Figure 20: Moffat OP Rack

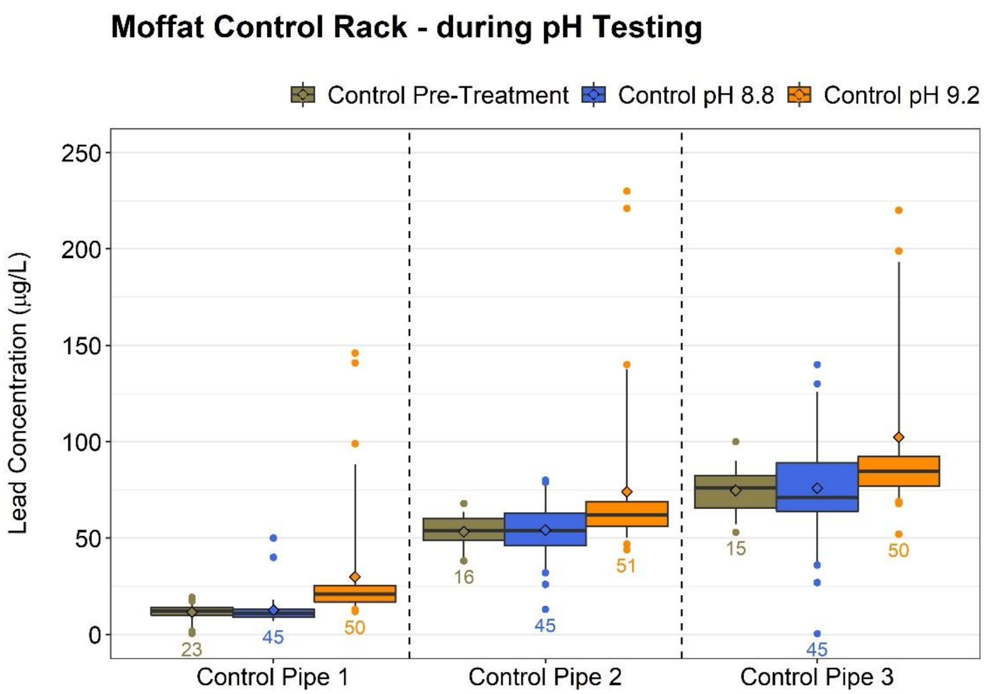

Figure 21: Moffat Control Rack - Matching pH Rack

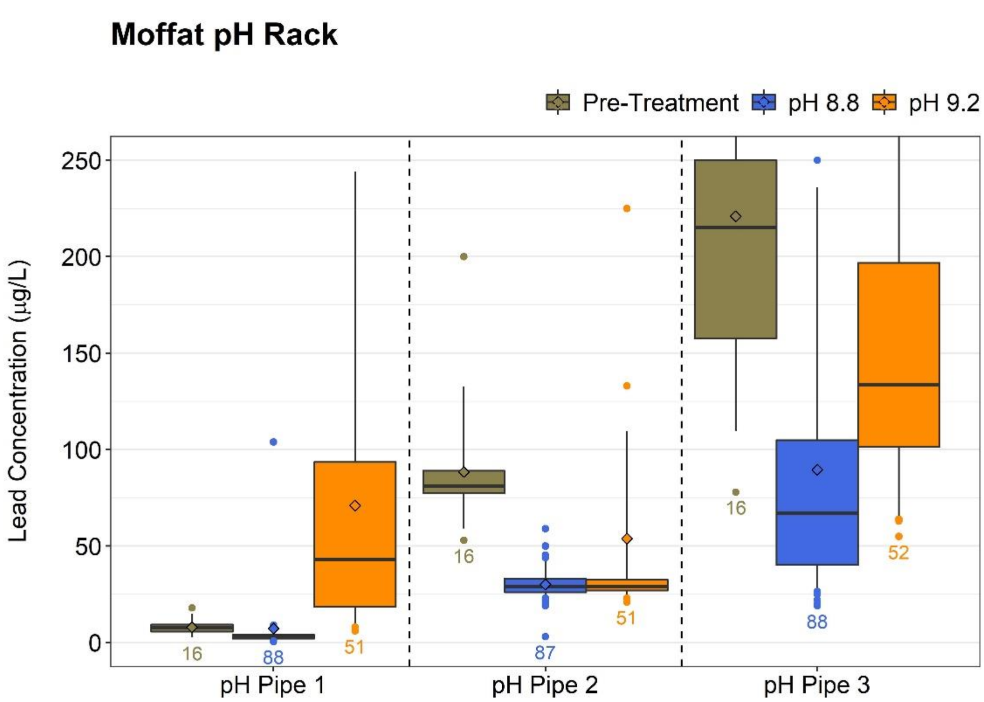

Figure 22: Moffat pH Rack

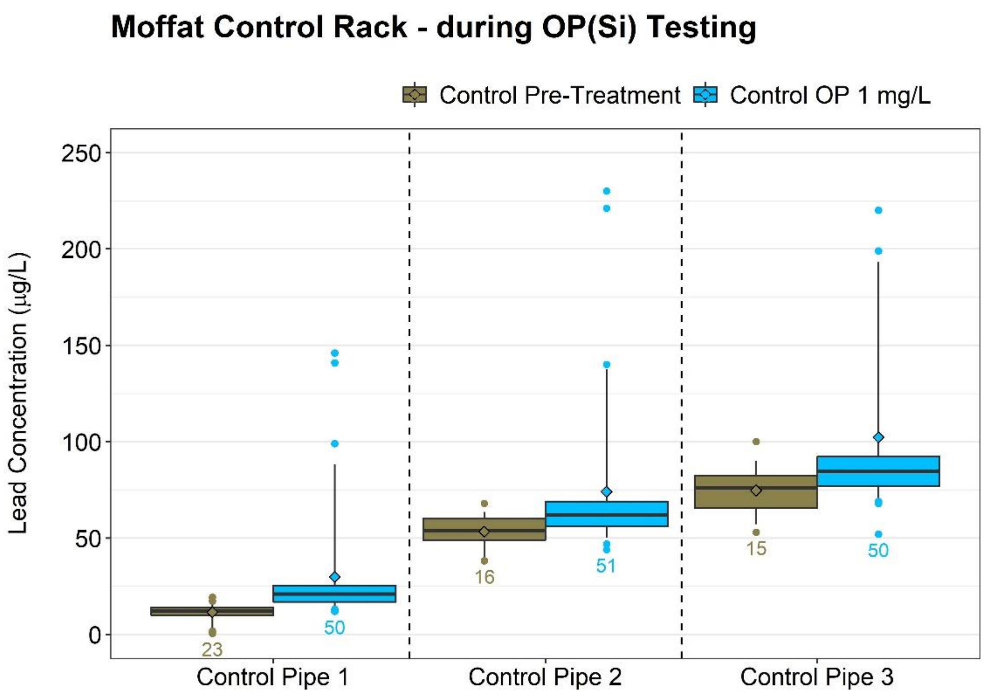

Figure 23: Moffat Control Rack - Matching (Si) OP Rack

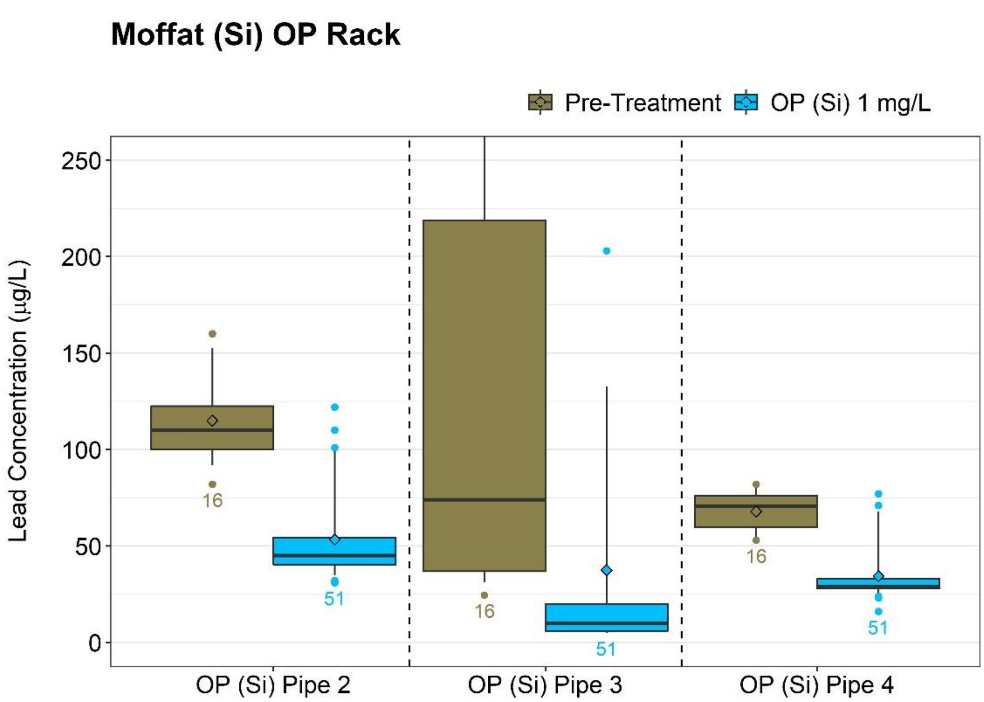

Figure 24: Moffat (Si) OP Rack