Garland Avenue Biochar Amended Storm Garden Pollutant Removal Efficacy Effectiveness Study

Interstitial Data Summary Report

September 2023

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Introduction

The urban environment is a source of pollutants that stormwater runoff picks up and ultimately carries with it along its flow path to a receiving water body. Typical pollutants from an urban environment include phosphate and nitrate (nutrients), copper and zinc (heavy metals), pesticides and cleaners (toxic chemicals), car fluids (oils and fuels), and sediment (total suspended solids) that are generated by routine human activities. Without appropriate stormwater management, the pollutants can be transported into the Spokane River and the Spokane Valley-Rathdrum Prairie (SVRP) Aquifer via stormwater runoff. The Spokane River is listed on the U.S. Environmental Protection Agency's (EPA's) 303d list of impaired water bodies for heavy metals and nutrient impacts, and the SVRP Aquifer is the major drinking water source for the region.

Low impact development (LID) methods include the construction of structural best management practices (i.e. bioretention/bioinfiltration facilities) capture and treat stormwater runoff. Bioretention and bioinfiltration facilities (stormwater treatment facilities) are typically comprised plants and engineered soil mixtures that are designed to remove typical urban pollutants from stormwater prior to infiltration or discharge through an outfall. Regional LID guidance and Washington Department of Ecology (Ecology) stormwater manuals prescribe a standard soil mixture of sandy soils and compost for stormwater facility soils for structural best management practices (BMPs). However, recent research has suggested that phosphorus, nitrogen, and copper can leach from the compost component of bioretention soil mixes.

Biochar is a form of charcoal that is the lightweight black residue of carbon and ashes that remains after the pyrolysis of a biomass. It is a carbon-rich material produced from thermal decomposition of biomass at elevated temperatures with little or no oxygen. Biochar biomass originates from a multitude of different feed stocks, such as wood or grass, and its' high surface area and porosity are desirable characteristics for capturing pollutants, similar to activated carbon.

Stormwater treatment facilities (storm gardens) with the inclusion of biochar in the engineered soil were constructed on W. Garland Avenue in the City of Spokane in 2014. Monitoring of the stormwater at the storm gardens began in 2015 in order to study the stormwater treatment potential for urban stormwater pollutants by the biochar soil mix. To determine the treatment potential of the biochar amended soil mix, stormwater is sampled before, and after, it interacts with the engineered soil, and the results are compared in order determine the extent to which pollutants are captured by the soil media.

The Eastern Washington Phase II Municipal Stormwater permit issued by Ecology is the regulatory document that dictates the stormwater management requirements in the City of Spokane. In order to satisfy the conditions of Section S8.A of the 2014 issuance of the permit, the Garland Avenue storm garden site was selected to be an effectiveness study. The Garland Avenue Biochar Amended Storm Garden Pollutant Removal Efficacy effectiveness study Quality Assurance Project Plan (QAPP) was approved by Ecology in March 2019, and stormwater monitoring commenced with the May 2019 sampling event accordingly. Stormwater monitoring for the Garland Avenue Storm Garden effectiveness study will be performed through the spring of 2024.

Project Description

The Garland Avenue Storm Garden effectiveness study site is comprised of a storm garden installed in the public right of way planting strip (area between the curb line and the sidewalk) on W. Garland Avenue near the intersection of N. Belt Street. The storm garden is being monitored to determine the treatment potential of a biochar amended bioretention soil mix for typical urban stormwater runoff pollutants (i.e. sediment, nutrients, heavy metals, diesel range organics, and oil range organics). The location of the study area is shown in Figure 1.

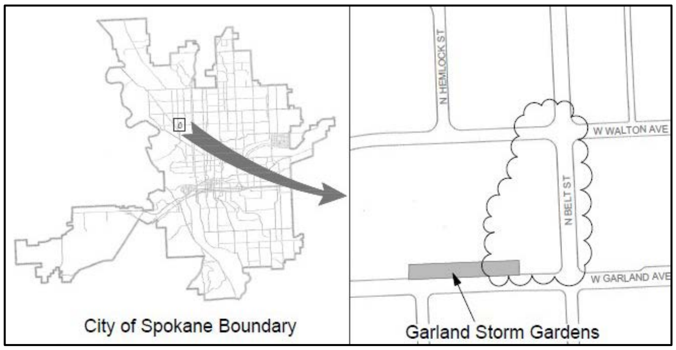

Figure 1. Location map of Garland Avenue Storm

Storm water is conveyed overland via roadway to the storm garden, where samples are collected of the influent prior to infiltrating the storm garden, and of the effluent after it has percolated through the engineered soil. Laboratory analysis of the influent and effluent samples are used to determine the treatment efficiency for each pollutant, as well as to monitor trends of the pollutants over time. Figure 2 displays the location of the storm garden and sampler locations.

Figure 2. Storm garden and sampler location map.

The Garland Avenue storm garden was designed utilizing LID principles and constructed with the inclusion of a wood-based biochar as a component of the engineered bioretention soil mix. The amended engineered soil mix was emplaced over a drain rock underdrain. The underdrain consists of a perforated collection pipe installed the drain rock overlying an impermeable geosynthetic liner. Drought tolerant plant species were planted in the storm garden soils, and bark mulch was used to dress the surface.

Two Vortox liquid samplers were installed at the ground surface in upstream flow path of the storm garden, and in the subsurface downstream of bioretention soil mix layer. Stormwater influent is collected in the shallow sampler prior to interacting with the amended engineered soil, and stormwater effluent that has percolated through the storm garden collects on the lined underdrain, where it is conveyed to a effluent sampler. Figures 3 and 4 provide cross sectional views of the storm garden and sampler installations.

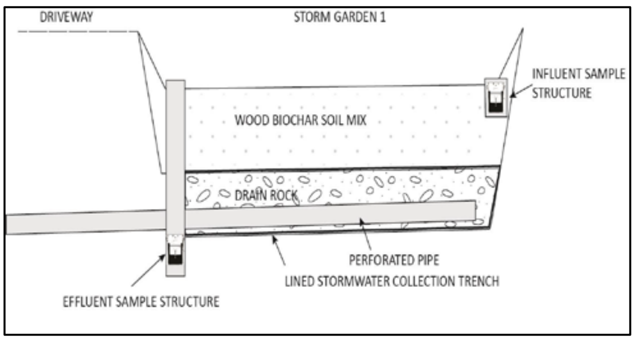

Figure 3. Storm garden cross section.

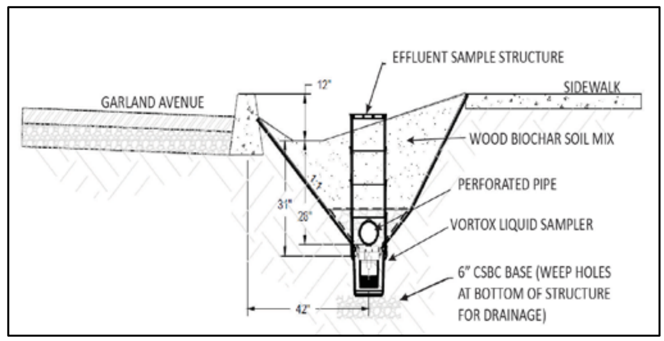

Figure 4. Storm garden effluent cross section.

Additional details and discussion on the of the storm garden construction and stormwater sampling equipment are provided in the Garland Avenue effectiveness study QAPP.

Sample Events

Weather forecasts are monitored daily to identify when a qualifying storm event is likely to occur. The Garland Avenue effectiveness study QAPP defines the qualifying storm event as consisting of a minimum of 0.02 inches of precipitation, with less than 0.05 or 0.025 inches occurring during the preceding antecedent dry period in the wet or dry seasons, respectively. Upon prediction of a qualifying storm event, clean influent and effluent liquid samplers set to collect the first flush runoff are deployed at their respective site locations. Following the storm event, the samplers are retrieved and transported to the Riverside Park Wastewater Reclamation Facility (RPWRF), where the collected influent and effluent are transferred to appropriate sample containers and shipped to an Ecology approved contract laboratory under chain of custody. Analysis is performed to determine the influent and effluent concentrations of total suspended solids, nutrients (NO_2, NO_3, PO_4), total and dissolved heavy metals (As, Ca, Cd, Cu, Mg, Pb, and Zn), diesel range organics, and oil range organics. Additional details and discussion on the sample criteria and process are provided in the Garland Avenue effectiveness study QAPP. Table 1 provides the dates that samples were collected for analysis during qualifying storm events.

2019	2020	2021	2022	2023
May 15	January 22	January 11	March 14	May 4
August 9	May 30	June 15	April 25	June 8
September 27	June 12	August 21		August 29
October 19	October 10	September 18		
December 7	November 5	September 27		
December 19		October 22		

Table 1. Date of qualifying storm events when samples were collected for analysis.

Data Analysis

The influent and effluent pollutant concentrations are used to calculate the pollutant removal efficiency of the bioretention soil amended with biochar for the monitored pollutants. Table 2 contains the list of typical urban stormwater pollutants monitored for this study. Table A-1 and Table A-2 in Appendix A contain the analytical data for the influent and effluent pollutants monitored during the qualifying storm events that were sampled.

Pollutant	Pollutant Form
Sediment	Total suspended solids
Nutrients	Phosphorus as P
	Inorganic Nitrogen (NO_2 + NO_3)
Hydrocarbons	Diesel range organics
	Oil range organics
Total & Dissolved Metals	Arsenic
	Calcium
	Cadmium
	Chromium
	Copper
	Magnesium
	Lead
	Zinc
	Hardness as $CaCO_3$

Table 2. Typical urban stormwater pollutants monitored in this study.

The pollutant removal efficiency for each pollutant (the percent of pollutant retained by the soi) is calculated as percent removal from the in flowing stormwater using the following equation:

$$\text{Pollutant Removal Efficiency (\%)} = \frac{[\text{Pollutant}]_{nf} - [\text{Pollutant}]_{Eff}}{[\text{Pollutant}]_{Inf}} \times 100$$

Where,

$[\text{Pollutant}]_{Inf}$ = Influent pollutant concentration, and

$[\text{Pollutant}]_{Eff}$ = Effluent pollutant concentration.

Percent removals are calculated from the pollutant influent and effluent concentrations for the pollutants listed in Table 2 in order to obtain pollutant specific treatment efficacies for the biochar amended soil. Table A-3 in Appendix A contains the percent removal efficiencies for the pollutants monitored during the qualifying storm events that were sampled. Pollutant removal trend analyses for each monitored pollutant are provided in Appendix B. Percent removals per each qualifying storm event sampled for the monitored pollutants are provided in Appendix C.

Results

Review of the analyses show mixed pollutant retention results that appear to depend on the pollutant and perhaps season. The results seem to vary significantly per event. Between 54 and 73 percent of the events for the concentrations of total metals showed a net decrease (removal), with the exception of total calcium. Of the array of dissolved metals, only zinc had a value that was more than half of the events sampled showing a net decrease in concentration. Dissolved zinc, total suspended solids, and oil range organics demonstrated that greater than 75% of the sample events had a net decrease in pollutant concentrations.

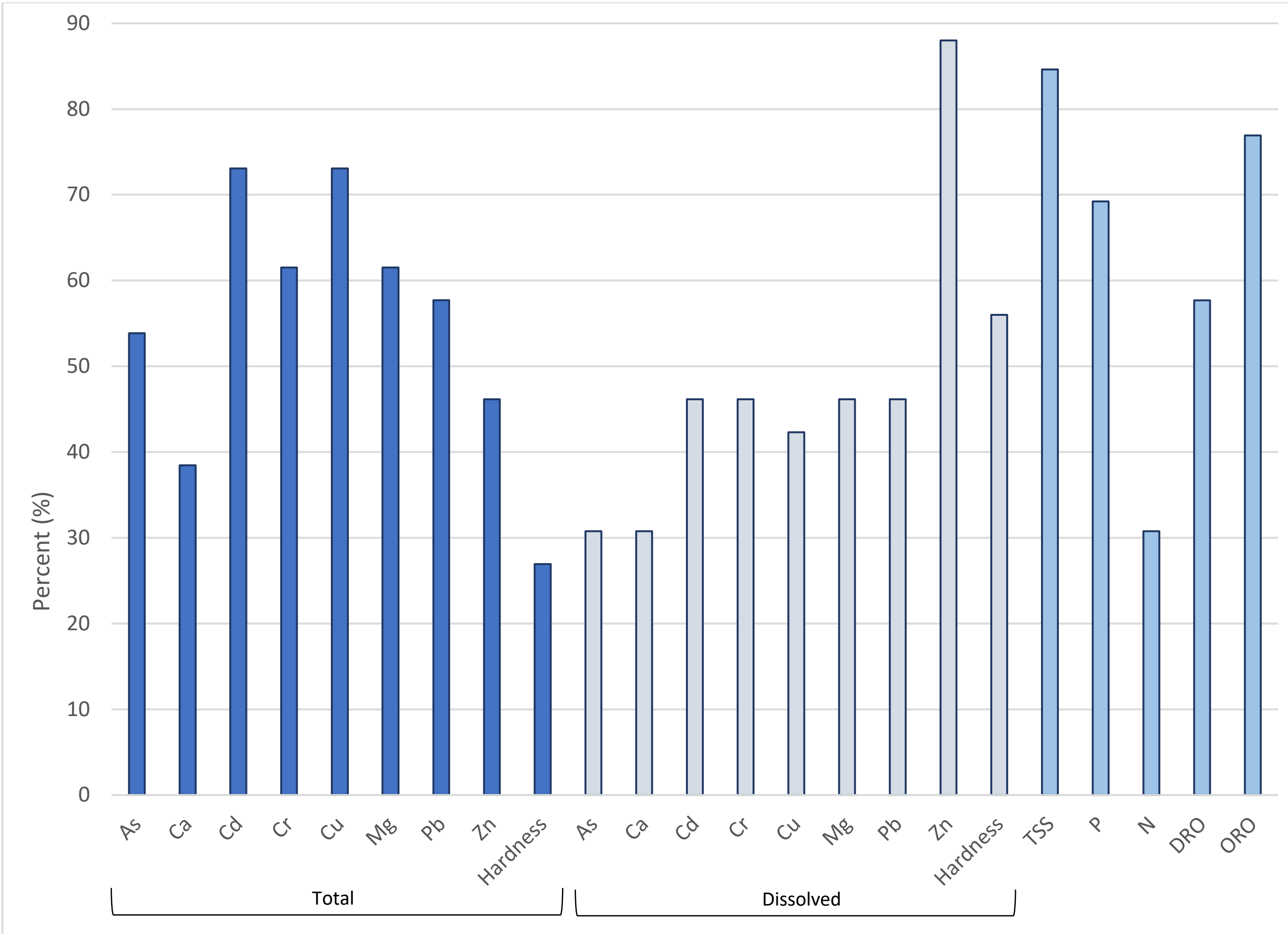

Figure 5. Percent of Events with Net Removal of Pollutant

Path Forward

This study will continue until the spring of 2025, and final determinations will be made on the performance of the Garland Avenue Storm Gardens with biochar amended soil.

Appendix A – Influent and Effluent Data Tables

Table A-1. Table of 2019 – 2023 Influent Pollutant Concentrations

		Total Metals									Dissolved Metals													
	pH (std)	As (mg/L)	Ca (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Mg (mg/L)	Pb (mg/L)	Zn (mg/L)	Hardness (mg/L $CaCO_3$)	As (mg/L)	Ca (mg/L)	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Mg (mg/L)	Pb (mg/L)	Zn (mg/L)	Hardness (mg/L $CaCO_3$)	TSS (mg/L)	P (mg/L)	N (mg/L)	DRO (mg/L)	pH (std)
15-May-2019	6.3	898	2.69	1.191	2.8	6.6	0.00647	13	0.000663	0.0153	0.0886	15.9	0.0617	0.688	97.7	0.00209	7.58	0.000102	0.0024	0.0279	11.7	0.000517	0.14	67.1
09-Aug-2019	6.35	20	0.47	0.2073	3	1.9	0.00172	9.84	0.00006	0.00353	0.0184	6.06	0.0017	0.246	49.5	0.00148	10	0.000067	0.00305	0.0147	6.06	0.000927	0.0926	50
27-Sep-2019	6.86	5	0.185	0.4202	0.41	0.62	0.000404	2.23	0.000032	0.000878	0.00542	1.53	0.00049	0.0219	11.9	0.000372	2.26	0.000026	0.000723	0.00506	1.5	0.000303	0.0151	11.8
19-Oct-2019	6.86	12	0.187	0.5311	0.62	1.2	0.00151	3.73	0.000066	0.00401	0.00867	2.55	0.00235	0.0879	19.8	0.00111	3.75	0.000065	0.0029	0.0072	2.4	0.000996	0.0514	19.2
07-Dec-2019	6.61	20	0.159	0.3398	0.75	0.93	0.000658	3.87	0.000044	0.0039	0.00835	3.26	0.00292	0.0534	23.1	0.000508	3.64	0.000026	0.000667	0.00613	3.05	0.000674	0.0223	21.7
19-Dec-2019	8.62	184	0.633	0.5129	1.9	6.3	0.00423	26.8	0.000256	0.0135	0.0312	79.6	0.0124	0.31	394	0.00214	24	0.000146	0.00352	0.0101	76.6	0.000333	0.0894	375
22-Jan-2020	5.81	317	0.777	0.2084	1.4	8	0.00301	4.05	0.000453	0.012	0.0315	6.94	0.0215	0.265	38.7	0.00063	1.5	0.000012	0.000961	0.00479	4.3	0.000638	0.00502	21.5
30-May-2020	5.67	2036	2.43	1.237	5.1	6.9	0.00688	17.9	0.000999	0.0251	0.139	16.8	0.106	0.857	114	0.00126	10.5	0.000239	0.00334	0.0474	10.6	0.00206	0.317	69.8
12-Jun-2020	6	617	0.966	0.0176	2.2	4.6	0.0105	18	0.000931	0.0401	0.142	14.3	0.158	0.913	104	0.000932	4.49	0.000061	0.00115	0.0102	4.46	0.000338	0.0728	29.6
10-Oct-2020	5.74	31	0.551	3.139	0.97	1.1	0.00233	4.88	0.000246	0.00569	0.0427	3.58	0.0253	0.252	26.9	0.000902	3.27	0.00005	0.00145	0.0136	2.24	0.00115	0.0594	17.4
05-Nov-2020	6.82	112	0.743	0.5892	2.8	5.2	0.00309	10.5	0.000199	0.00774	0.0282	35.7	0.01	0.244	173	0.0022	10.1	0.000086	0.00306	0.017	34.5	0.00054	0.0657	167
11-Jan-2021	7.56	132	0.44	0.5241	1.2	4.9	0.00209	11.2	0.000202	0.00417	0.0237	21.4	0.0112	0.255	116	0.000775	10.6	0.000044	0.000901	0.00602	17.1	0.00028	0.0129	97.2
15-Jun-2021	5.84	380	0.262	0.9462	3.2	4.7	0.00469	22.5	0.000404	0.0122	0.0412	7.64	0.0582	0.411	87.7	0.00127	19.5	0.000178	0.00353	0.0173	5.24	0.00176	0.224	70.4
21-Aug-2021	6.97	59	0.2855	1.123	0.32	0.64	0.00219	16.4	0.000061	0.00302	0.00992	6.97	0.00536	0.0569	69.7	0.00181	15.5	0.00002	0.00146	0.0063	6.41	0.000131	0.00886	65.1
18-Sep-2021	6.95	47	0.252	1.16	0.57	1.2	0.00172	10.4	0.0000895	0.00644	0.0102	4.58	0.00333	0.161	44.7	0.0013	10.9	0.000025	0.00421	0.00665	4.43	0.000275	0.0365	45.5
27-Sep-2021	6.71	64	0.317	0.648	0.76	1.8	0.00112	5.24	0.0000895	0.00815	0.0124	2.09	0.00598	0.104	21.7	0.000651	4.65	0.000016	0.00159	0.00599	1.67	0.000277	0.0127	18.5
22-Oct-2021	6.52	130	0.802	0.014	1.7	2.9	0.00134	8.83	0.0000895	0.00283	0.0181	3.68	0.00801	0.149	37.2	0.000849	8.59	0.000386	0.0012	0.0111	3.16	0.00123	0.0275	34.5
14-Mar-2022	6.66	280	0.825	0.226	1	5.1	0.00258	6.4	0.000296	0.00944	0.0246	7.92	0.0155	0.195	48.6	0.000733	3.79	0.000013	0.001	0.00544	5.65	0.00012	0.0029	32.7
25-Apr-2022	14.5	341	0.921	0.523	2.5	7.4	0.00564	13	0.000477	0.019	0.0829	9.61	0.0637	0.665	72	0.00137	6.24	0.000034	0.00164	0.0145	5.09	0.00071	0.043	36.5
05-May-2022	6.34	1323	2.35	0.615	5.1	15	0.00433	12	0.000589	0.0163	0.0643	7.19	0.0427	0.651	59.5	0.000589	4.62	0.000038	0.0021	0.0111	3.01	0.00029	0.0983	23.9
02-Jun-2022	6.29	52	0.388	0.529	2.1	2.5	0.00134	8.27	0.000072	0.00334	0.0133	4.38	0.00525	0.0795	38.7	0.000984	7.65	0.000025	0.0023	0.00782	3.87	0.000507	0.0109	35.1
29-Sep-2022	6.51	50	0.61	0.737	0.54	0.56	0.00119	5.62	0.000052	0.00178	0.0129	2.88	0.00477	0.117	25.9	0.000994	5.52	0.000026	0.00134	0.0122	2.64	0.000847	0.0629	24.7
03-Nov-2022	7.09	300	0.61	0.3608	0.84	3.7	0.00274	5.76	0.000233	0.0128	0.0339	3.7	0.0512	0.243	29.6	0.000548	2.39	0.000018	0.00433	0.00618	1.67	0.000436	0.005	12.9
10-Apr-2023	7.11	322	1.04	1.10	1.4	3.6	0.00273	7.2	0.000157	0.0065	0.0451	11.2	0.0193	0.188	63.9	0.00117	5.12	0.000037	0.00104	0.00876	9.42	0.00214	0.0129	51.6
04-May-2023	6.02	294	0.977	0.4532	4.9	3.5	0.00152	7.62	0.000064	0.00265	0.0162	9.26	0.00128	0.145	57.2	0.0013	7.84	0.000049	0.00214	0.0116	9.15	0.000392	0.125	57.2
08-Jun-2023	5.88	2278	5.16	1.81	3.4	11	0.00898	27.9	0.000861	0.0324	0.135	16.3	0.109	1.15	137	0.00215	13.4	0.00013	0.00421	0.0198	8.39	0.000674	0.319	68.1

Notes:

As = Arsenic
Ca = Calcium
Cd = Cadmium
Cu = Copper

Cr = Chromium
Mg = Magnesium
Pb = Lead
Zn = Zinc

P = Total Phosphorous
N = Nitrogen, N as NO_3 + NO_2
TSS Total suspended solids

DRO = Diesel range organics
ORO = Oil range organics

Table A-2 . 2019 – 2023 Effluent Pollutant Concentrations

		Total Metals									Dissolved Metals													
	pH (std)	**As** (mg/L)	**Ca** (mg/L)	**Cd** (mg/L)	**Cr** (mg/L)	**Cu** (mg/L)	**Mg** (mg/L)	**Pb** (mg/L)	**As** (mg/L)	**Ca** (mg/L)	**Cd** (mg/L)	**Cr** (mg/L)	**Cu** (mg/L)	**Mg** (mg/L)	**Pb** (mg/L)	**As** (mg/L)	**Ca** (mg/L)	**Cd** (mg/L)	**Cr** (mg/L)	**TSS** (mg/L)	**P** (mg/L)	**N** (mg/L)	**DRO** (mg/L)	**ORO** (mg/L)
15-May-2019	7.15	0.00689	29.1	0.000026	0.00231	0.00585	20.3	0.000211	0.0134	156	0.00669	28.2	0.000042	0.00208	0.00553	19.9	0.000047	0.00686	152	2	0.122	0.3053	0.125	0.21
09-Aug-2019	7.15	0.00689	29.1	0.000026	0.00231	0.00585	20.3	0.000211	0.0134	156	0.00669	28.2	0.000042	0.00208	0.00553	19.9	0.000047	0.00686	152	2	0.122	0.3053	0.125	0.21
27-Sep-2019	7.14	0.00523	21.7	0.000092	0.00624	0.0144	11.3	0.0126	0.0397	101	0.00354	21	0.00003	0.00163	0.00888	10.2	0.00251	0.00606	94.5	71	0.418	4.724	0.125	0.21
19-Oct-2019	7.08	0.00449	13.4	0.000078	0.00293	0.012	9.28	0.00579	0.177	71.8	0.00368	12.8	0.000102	0.00195	0.01	9.17	0.00243	0.0933	69.8	25	0.313	1.9234	0.25	0.59
07-Dec-2019	6.34	0.00459	12.6	0.00006	0.00376	0.0102	9.71	0.00581	0.0481	71.3	0.00311	12.3	0.000034	0.0014	0.0105	10.1	0.00185	0.0174	72.3	39	0.273	1.247	0.13	0.19
19-Dec-2019	6.42	0.00199	19.3	0.000044	0.00434	0.00528	12.7	0.00147	0.0269	100	0.0015	19	0.000026	0.000895	0.00356	12.5	0.000258	0.0086	98.8	14	0.169	0.2927	0.125	0.16
22-Jan-2020	6.85	0.00252	138	0.000099	0.00187	0.00365	138	0.00156	0.0236	914	0.00183	137	0.000091	0.00055	0.00195	135	0.000101	0.0106	897	33	0.081	0.4618	0.125	0.21
30-May-2020	6.72	0.00724	26.6	0.000065	0.0059	0.0124	15.3	0.00596	0.0286	129	0.00724	26.6	0.000065	0.0059	0.0124	15.3	0.00596	0.0286	129	30	0.291	0.548	0.115	0.195
12-Jun-2020	6.76	0.00656	26	0.00056	0.00346	0.0121	13	0.0038	0.0306	118	0.00358	25.8	0.000427	0.000986	0.00803	12.3	0.000943	0.0157	115	13	0.172	0.2221	0.125	0.21
10-Oct-2020	6.5	0.00653	38.3	0.000217	0.0104	0.0255	15.7	0.00473	0.0575	160	0.00406	37.4	0.000142	0.00361	0.0183	14.9	0.000983	0.0141	155	43	0.6	1.0208	0.33	0.21
05-Nov-2020	8.26	0.00148	35.7	0.000139	0.0016	0.00513	62.7	0.000922	0.0275	348	0.00109	36.4	0.000138	0.00102	0.00452	63.5	0.000168	0.0218	352	15	0.083	1.2002	0.125	0.21
11-Jan-2021	6.99	0.00399	16.4	0.000059	0.00233	0.00611	7.71	0.00382	0.0264	72.6	0.00257	16	0.000017	0.000934	0.00302	7.19	0.00119	0.00696	69.5	27	0.29	0.589	0.125	0.21
15-Jun-2021	6.59	0.00979	29.9	0.000147	0.00689	0.0233	15.4	0.0159	0.0805	138	0.00471	28.7	0.000034	0.00143	0.00739	13.3	0.00194	0.0105	126	72	0.899	0.6591	0.125	0.21
21-Aug-2021	7.1	0.00968	11.6	0.000077	0.00511	0.0163	8.89	0.00765	0.0302	65.6	0.00463	10.9	0.000033	0.0021	0.0114	7.52	0.00184	0.00693	58.1	55	0.3455	1.1965	0.12	0.2
18-Sep-2021	6.87	0.00438	18.3	0.000049	0.00213	0.0094	11.2	0.00142	0.0154	91.7	0.00361	17.7	0.000039	0.00111	0.00801	10.9	0.000454	0.00464	89.3	19	0.28	1.67	0.125	0.21
27-Sep-2021	6.58	0.00708	10.2	0.000077	0.0084	0.0136	7.57	0.00499	0.0276	56.6	0.00447	9.46	0.000033	0.00495	0.0101	6.87	0.00172	0.0084	51.9	37	0.279	2.08	0.125	0.21
22-Oct-2021	7.3	0.0223	7.79	0.000181	0.0454	0.025	10.4	0.0189	0.0869	62.2	0.00368	6.53	0.000013	0.00192	0.00817	6.1	0.00154	0.00791	41.4	84	0.459	0.373	0.125	0.21
14-Mar-2022	6.3	0.00304	19.9	0.000086	0.00296	0.00805	18.2	0.00165	0.0338	125	0.00225	19.6	0.000044	0.000849	0.00569	17.5	0.00032	0.00746	121	36	0.16	0.88	0.125	0.21
25-Apr-2022	6.97	0.00606	6.72	0.000087	0.00402	0.0152	5.49	0.0114	0.03	39.4	0.00444	6.35	0.000036	0.00228	0.00972	4.89	0.006	0.0124	36	27	0.353	0.63	0.125	0.21
05-May-2022	6.68	0.00557	3.26	0.000083	0.00495	0.0108	3.68	0.00507	0.027	23.3	0.00419	3.32	0.000028	0.002	0.00847	3.21	0.00244	0.0114	21.5	19	0.266	0.416	0.125	0.44
02-Jun-2022	6.76	0.00484	10.1	0.000046	0.00359	0.01	8.09	0.0046	0.0253	58.6	0.00314	9.44	0.000021	0.0022	0.00759	7.48	0.000923	0.00777	54.4	34	0.182	0.078	0.32	0.82
29-Sep-2022	7.03	0.00368	25.8	0.000187	0.00368	0.0313	16.1	0.00602	0.0955	131	0.0021	24.5	0.000063	0.00138	0.0237	14.6	0.000685	0.0425	0.121	31	0.868	11.45	0.54	0.56
03-Nov-2022	6.56	0.00517	12.2	0.000084	0.00439	0.00811	8.6	0.00345	0.0229	65.8	0.00367	9.96	0.000029	0.00208	0.00635	6.92	0.00161	0.0111	53.4	8	0.163	0.526	1	1.3
10-Apr-2023	6.53	0.00333	3.26	0.000039	0.00205	0.0125	4.98	0.00311	0.0198	28.6	0.00227	3.27	0.000021	0.00132	0.0116	4.39	0.000957	0.009	26.3	30	0.195	2.07	0.125	0.21
04-May-2023	21.2	0.00384	6.96	0.000051	0.00217	0.0113	6.67	0.00231	0.044	44.8	0.00271	6.87	0.000035	0.00147	0.0105	6.2	0.000876	0.0303	42.7	34	0.377	3.68	0.74	0.77
08-Jun-2023	6.42	0.00492	16.6	0.000214	0.0118	0.0289	9.04	0.0205	0.179	78.6	0.00285	14.1	0.000044	0.00533	0.00927	6.47	0.000791	0.0373	61.9	490	1.68	0.104	0.57	1.3

Notes:

As = Arsenic
Ca = Calcium
Cd = Cadmium
Cu = Copper
Cr = Chromium
Mg = Magnesium
Pb = Lead
Zn = Zinc
P = Phosphorous as P
N = Nitrogen, NO_3 + NO_2 as N
TSS = Total suspended solids
DRO = Diesel range organics
ORO = Oil range organics

Table A-3 . Pollutant removal efficiencies from 2019 - 2023

Date	Total									Dissolved									TSS	P	N	DRO	ORO
	As	Ca	Cd	Cr	Cu	Mg	Pb	Zn	Hardness	As	Ca	Cd	Cr	Cu	Mg	Pb	Zn	Hardness					
15-May-2019	-6	-124	96	85	93	-28	100	98	-60	-220	-272	59	13	80	-70	91	95	-127	100	95	74	96	97
09-Aug-2019	-301	-196	57	35	68	-235	88	95	-215	-352	-182	37	32	62	-228	95	93	-204	90	74	-47	96	89
27-Sep-2019	-1195	-873	-188	-611	-166	-639	-2471	-81	-749	-852	-829	-15	-125	-75	-580	-728	60	-701	-1320	-126	-1024	70	66
19-Oct-2019	-197	-259	-18	27	-38	-264	-146	-101	-263	-232	-241	-57	33	-39	-282	-144	-82	-264	-108	-67	-262	60	51
07-Dec-2019	-598	-226	-36	4	-22	-198	-99	10	-209	-512	-238	-31	-110	-71	-231	-174	22	-233	-95	-72	-267	83	80
19-Dec-2019	53	28	83	68	83	84	88	91	75	30	21	82	75	65	84	23	90	74	92	73	43	93	97
22-Jan-2020	16	-3307	78	84	88	-1888	93	91	-2262	-190	-9033	-658	43	59	-3040	84	-111	-4072	90	90	-122	91	97
30-May-2020	-5	-49	93	76	91	9	94	97	-13	-475	-153	73	-77	74	-44	-189	91	-85	99	88	56	98	97
12-Jun-2020	38	-44	40	91	91	9	98	97	-13	-284	-475	-600	14	21	-176	-179	78	-289	98	82	-1162	94	95
10-Oct-2020	-180	-685	12	-83	40	-339	81	77	-495	-350	-1044	-184	-149	-35	-565	15	76	-791	-39	-9	67	66	81
05-Nov-2020	52	-240	30	79	82	-76	91	89	-101	50	-260	-60	67	73	-84	69	67	-111	87	89	-104	96	96
11-Jan-2021	-91	-46	71	44	74	64	66	90	37	-232	-51	61	-4	50	58	-325	46	28	80	34	-12	90	96
15-Jun-2021	-109	-33	64	44	43	-102	73	80	-57	-271	-47	81	59	57	-154	-10	95	-79	81	-243	30	96	96
21-Aug-2021	-342	29	-26	-69	-64	-28	-43	47	6	-156	30	-65	-44	-81	-17	-1305	22	11	7	-21	-7	63	69
18-Sep-2021	45	67	8	-145	57	90	-105	-178	-62	-56	74	-20	-146	-65	87	-96	78	83	60	-11	-44	-155	-76
27-Sep-2021	14	-3	-10	-262	17	73	-161	-587	-103	-106	-211	-69	-311	-521	34	-181	84	88	42	12	-221	-532	-95
22-Oct-2021	-102	-1504	-38	-183	-136	42	-67	-333	24	97	-60	26	-93	-25	71	-20	93	93	35	43	-2564	-1564	12
14-Mar-2022	71	69	67	-130	89	83	-157	-207	-417	-238	15	-5	-210	-167	-157	-270	88	96	87	81	-289	-18	-211
25-Apr-2022	82	79	82	43	82	95	45	-224	-2	-6	-39	33	4	-745	71	1	95	97	92	62	-20	-7	48
05-May-2022	86	70	83	49	88	96	61	-611	28	26	5	24	-7	-741	88	10	98	97	99	89	32	-29	73
02-Jun-2022	36	-7	25	-85	12	68	-51	-219	-23	16	4	3	-93	-82	29	-55	85	67	35	53	85	-261	-22
29-Sep-2022	-260	-107	-143	-459	-26	18	-406	-111	-344	-142	-3	-94	-453	19	32	100	0	0	38	-42	-1454	-209	-359
03-Nov-2022	64	66	76	-132	93	91	-122	-570	-317	-61	52	-3	-314	-269	-122	-314	-19	65	97	73	-46	-89	-112
10-Apr-2023	75	68	72	56	84	89	55	-94	36	43	-27	-32	53	55	30	49	91	94	91	81	-88	-22	55
04-May-2023	20	18	30	28	-80	70	22	-108	12	29	31	9	32	-123	76	25	85	78	88	61	-712	-153	9
08-Jun-2023	75	64	79	45	81	84	43	-33	-5	66	-27	53	23	-17	88	9	83	88	78	67	94	45	41

Notes: Green cells represent percent reduction values greater than zero

As = Arsenic
Ca = Calcium
Cd = Cadmium
Cu = Copper
Cr = Chromium
Mg = Magnesium
Pb = Lead
Zn = Zinc
P =Total Phosphorous
N = Nitrogen, N as $NO_3 + NO_2$
DRO = Diesel range organics
ORO = Oil range organics

Appendix B – Percent Removal Trend Analysis

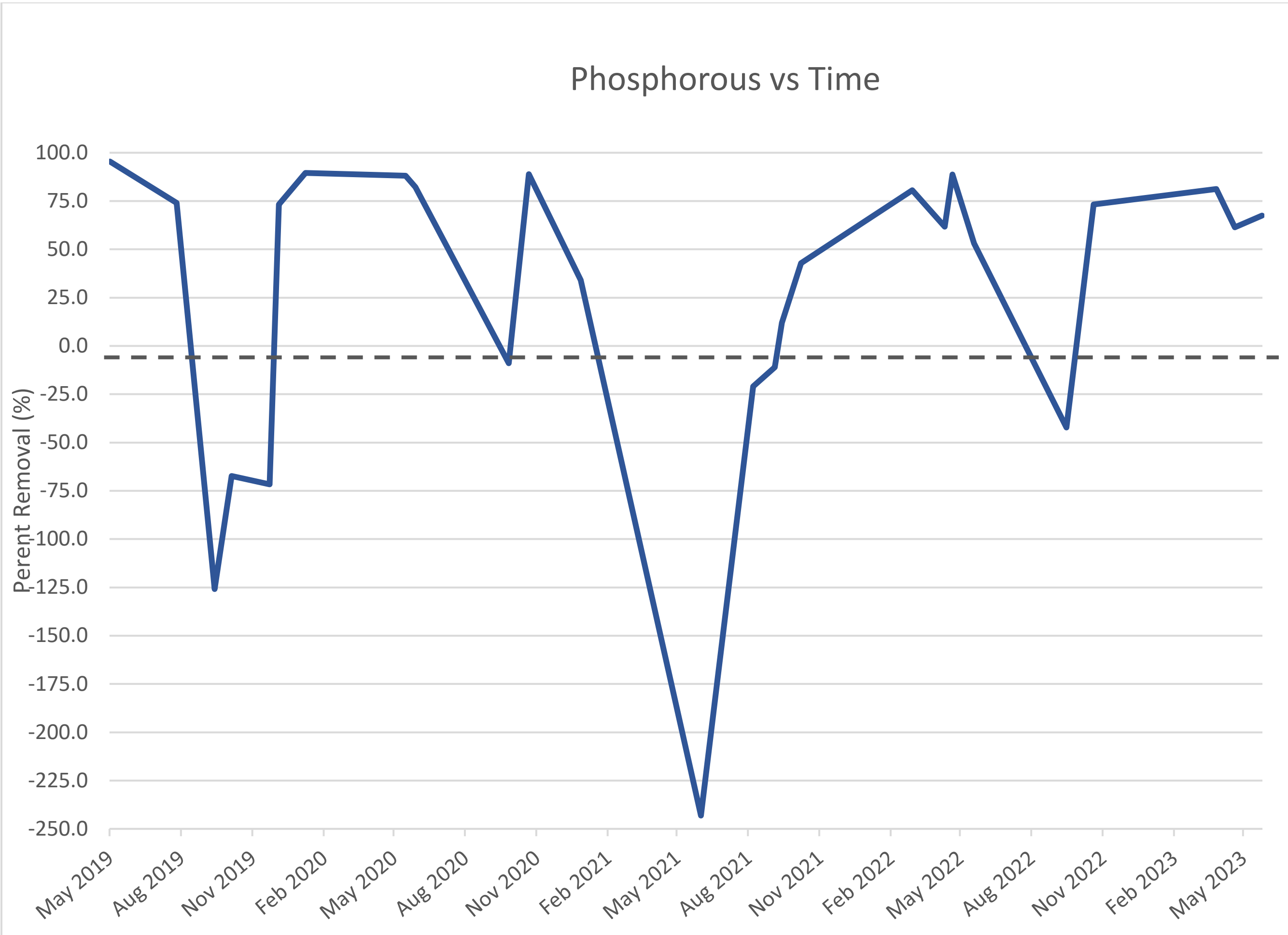

Figure B-1. Percent removal phosphorous .

Figure B-2. Percent removal TSS .

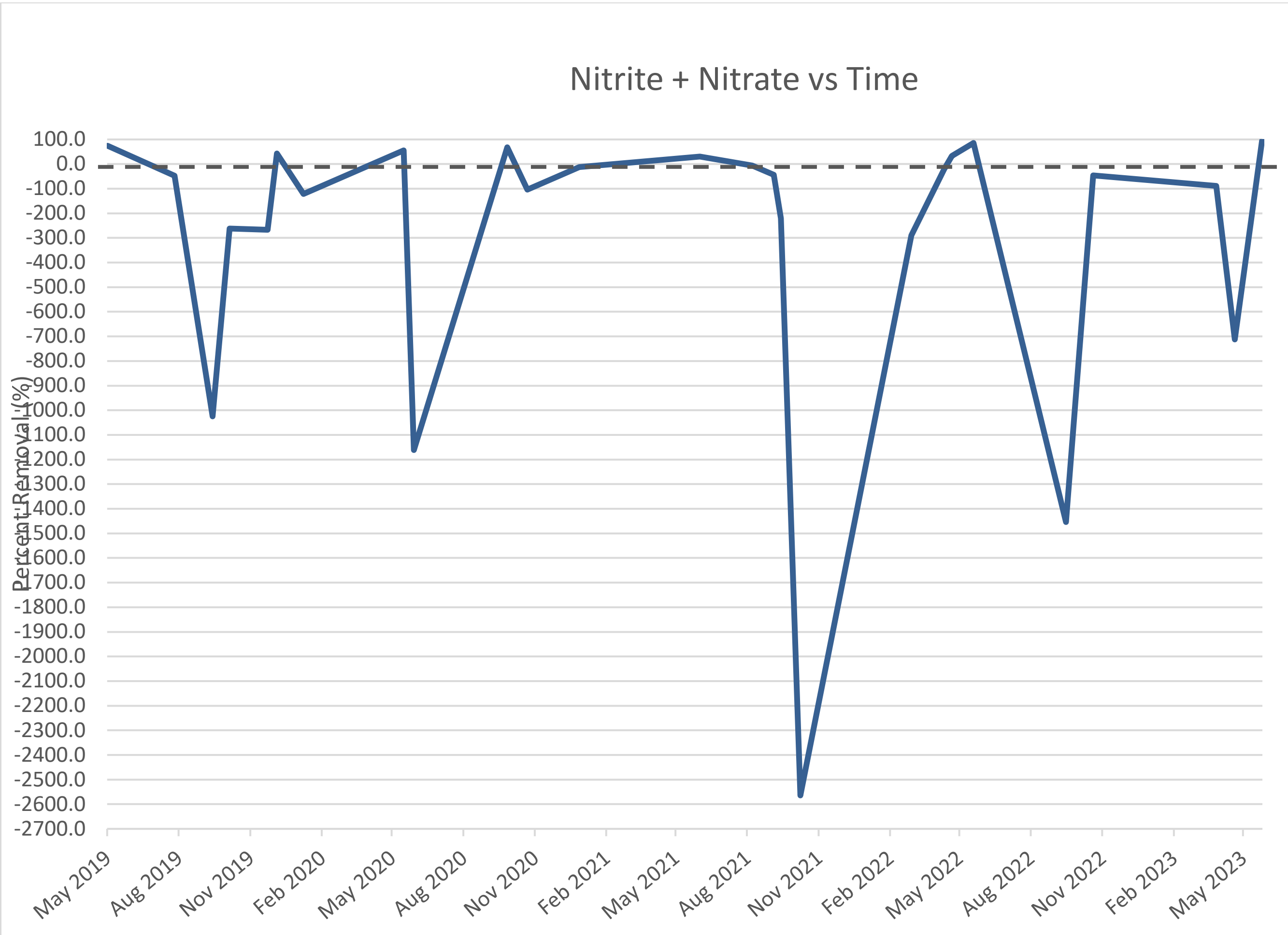

Figure B-3. Percent removal nitrogen .

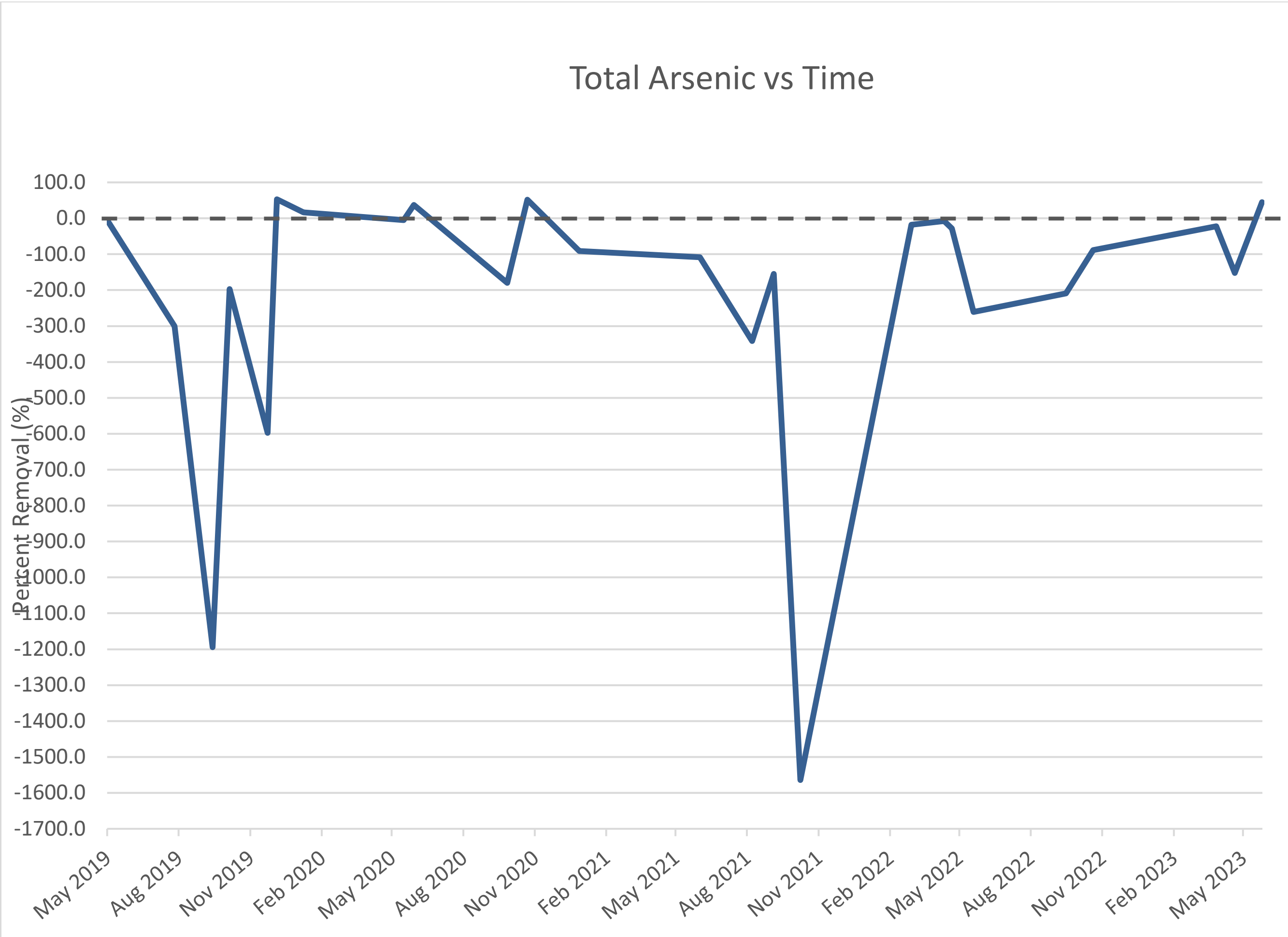

Figure B-4. Percent removal total arsenic.

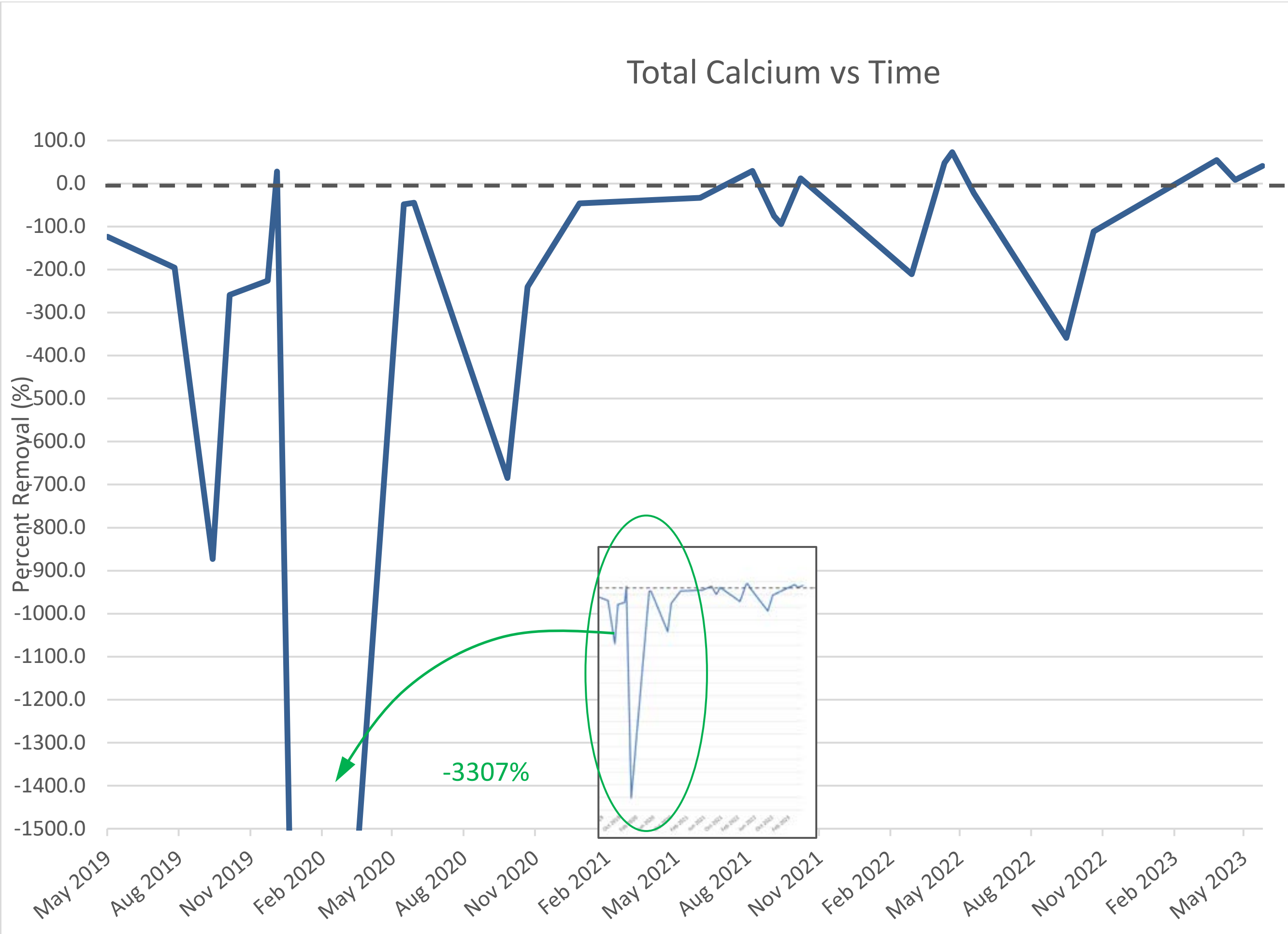

Figure B-5. Percent removal total calcium.

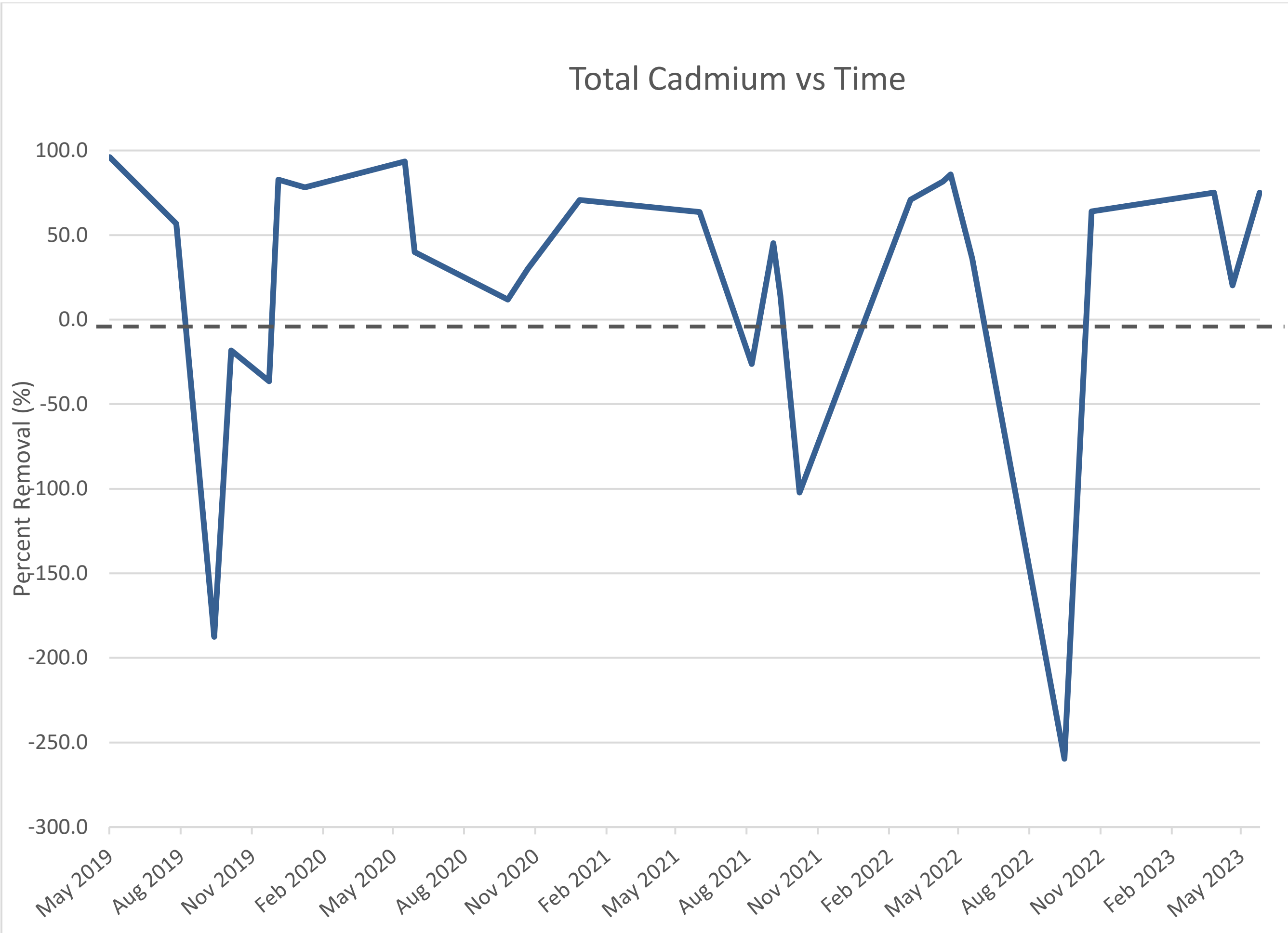

Figure B-6. Percent removal total cadmium .

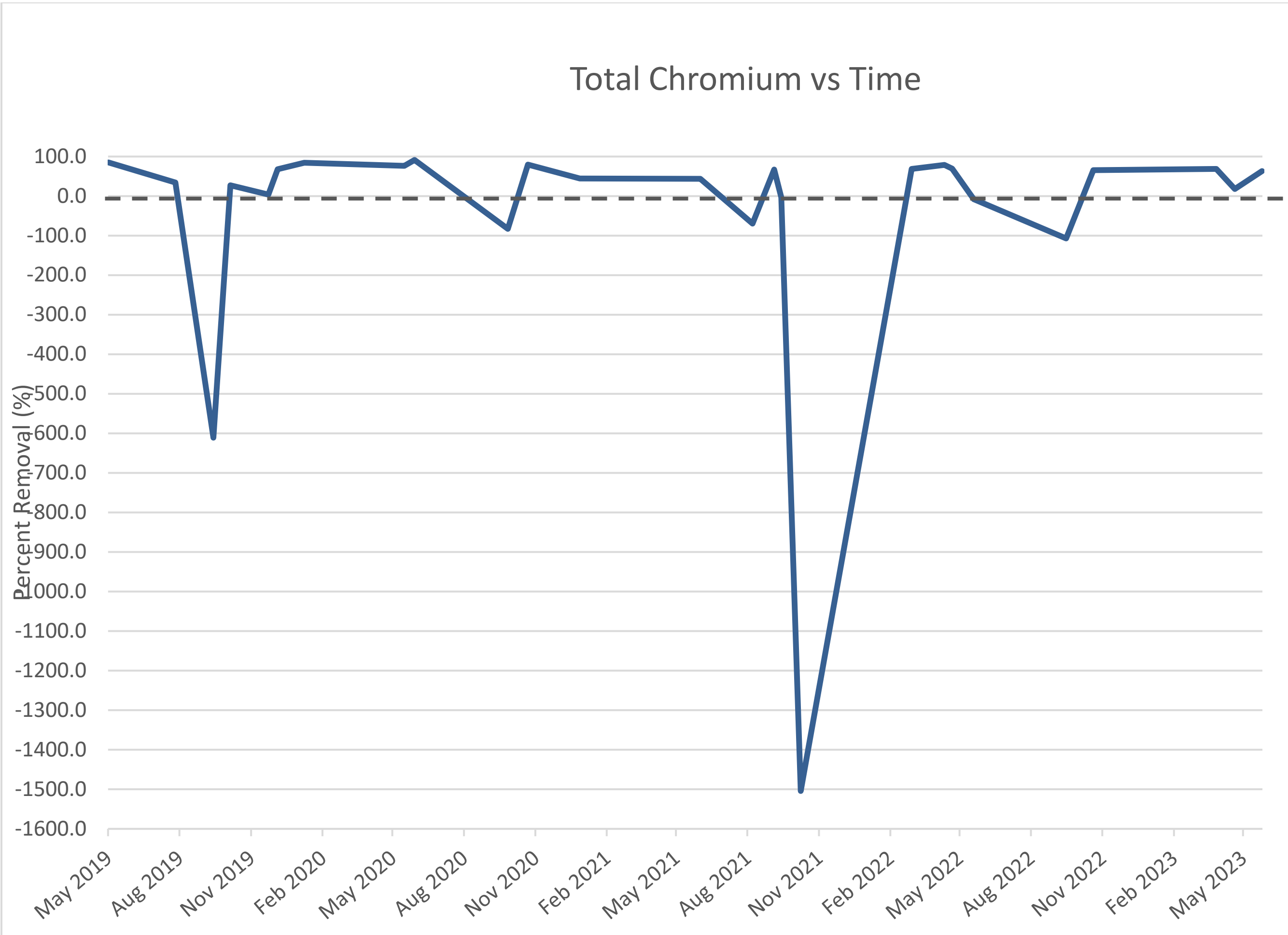

Figure B-7. Percent removal total chromium .

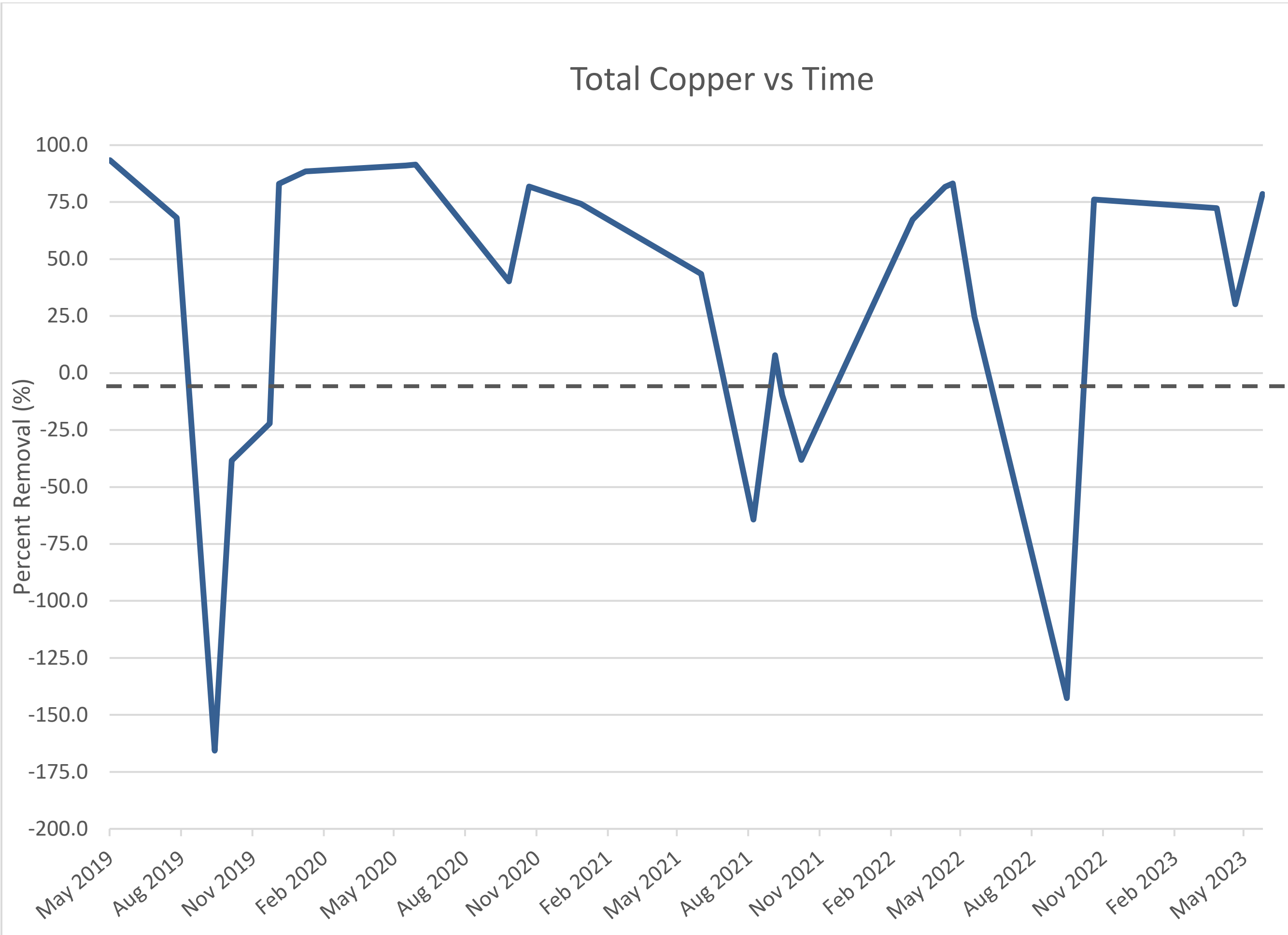

Figure B-8. Percent removal total copper .

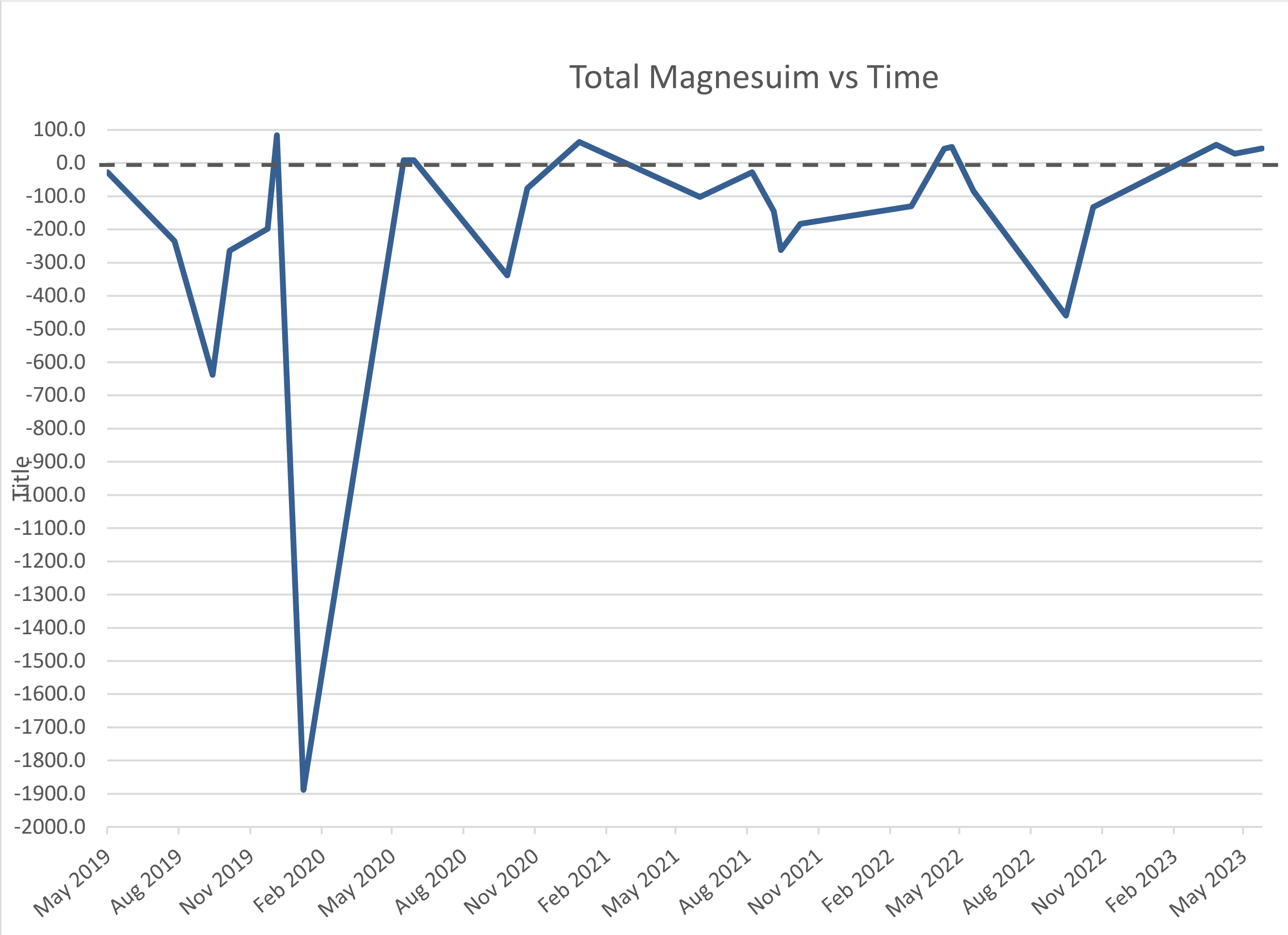

Figure B-9. Percent removal total magnesium .

Figure B-10. Percent removal total lead.

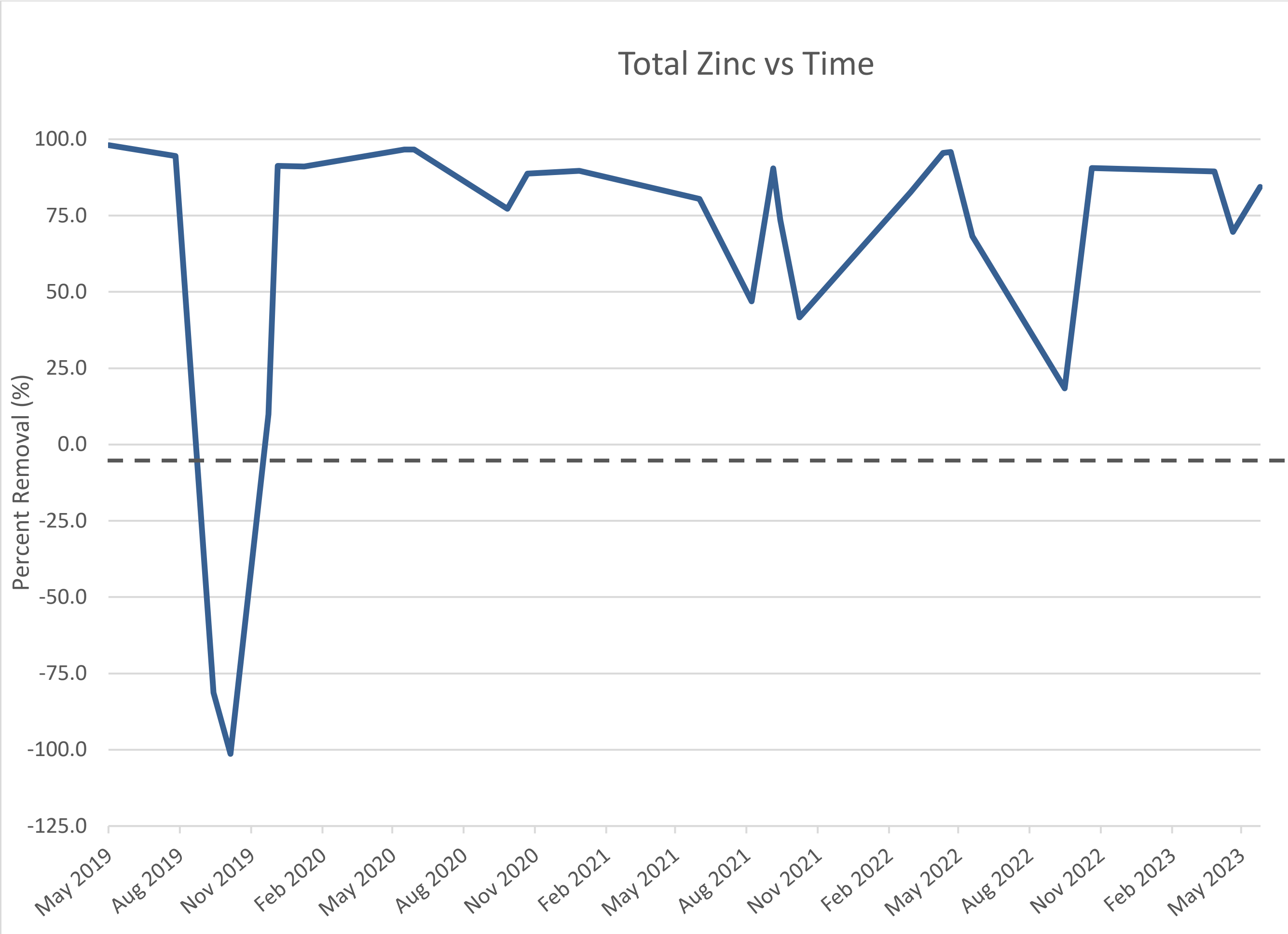

Figure B-11. Percent removal total zinc .

Figure B-12. Percent removal total hardness.

Appendix C– Percent Removal Bar Graphs

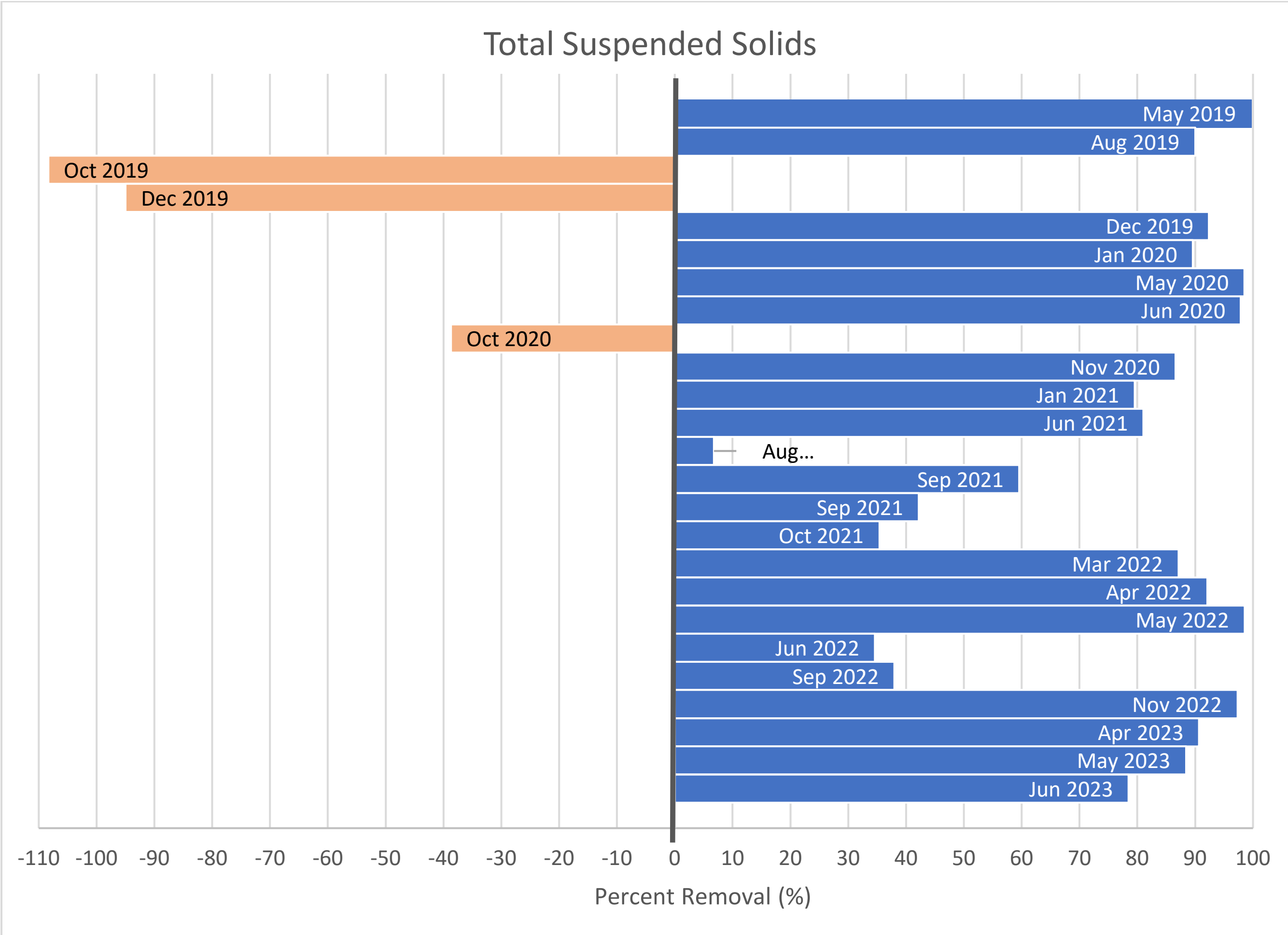

Figure C-1. Percent removal TSS .

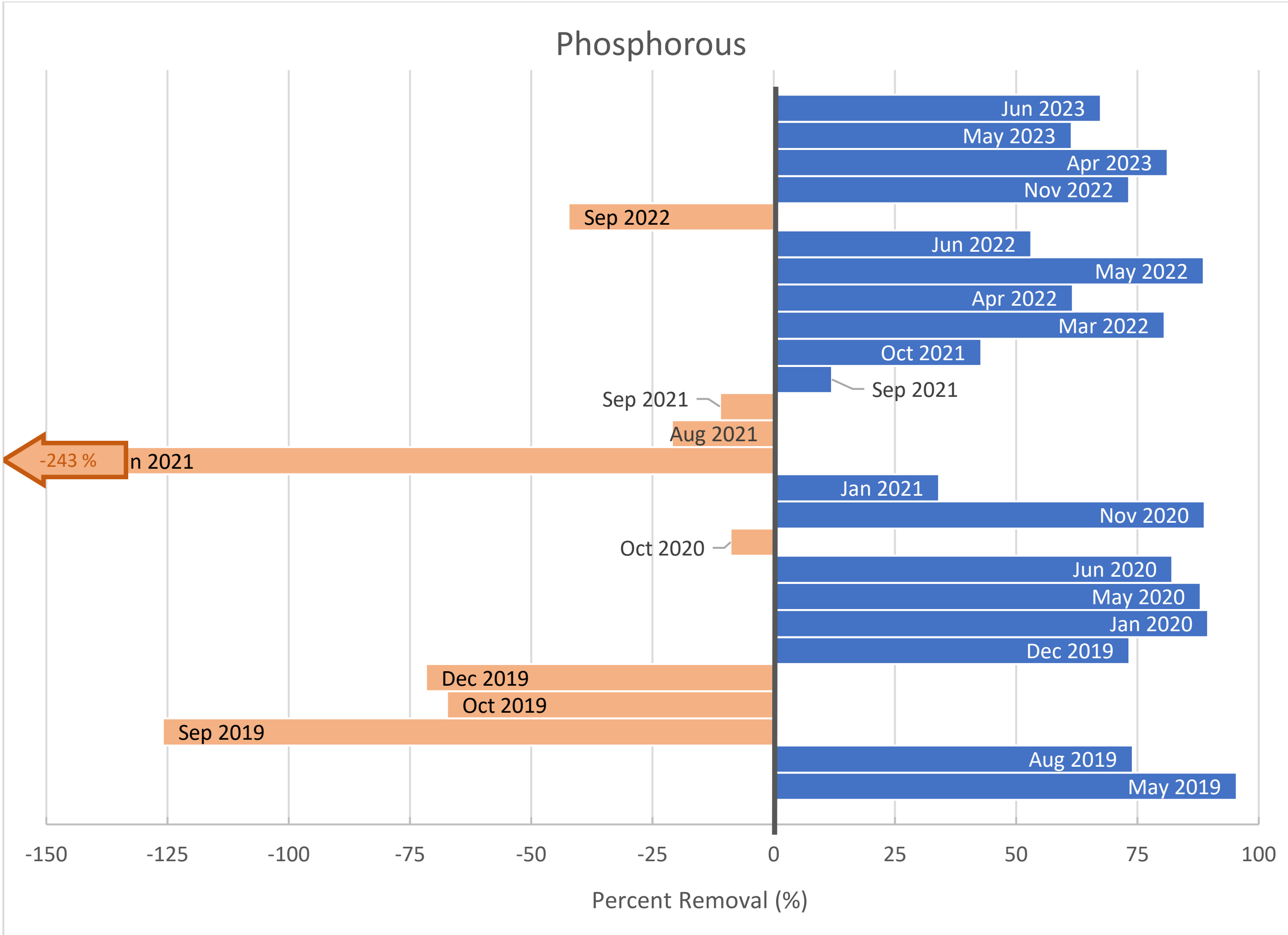

Figure C-2. Percent removal phosphorous.

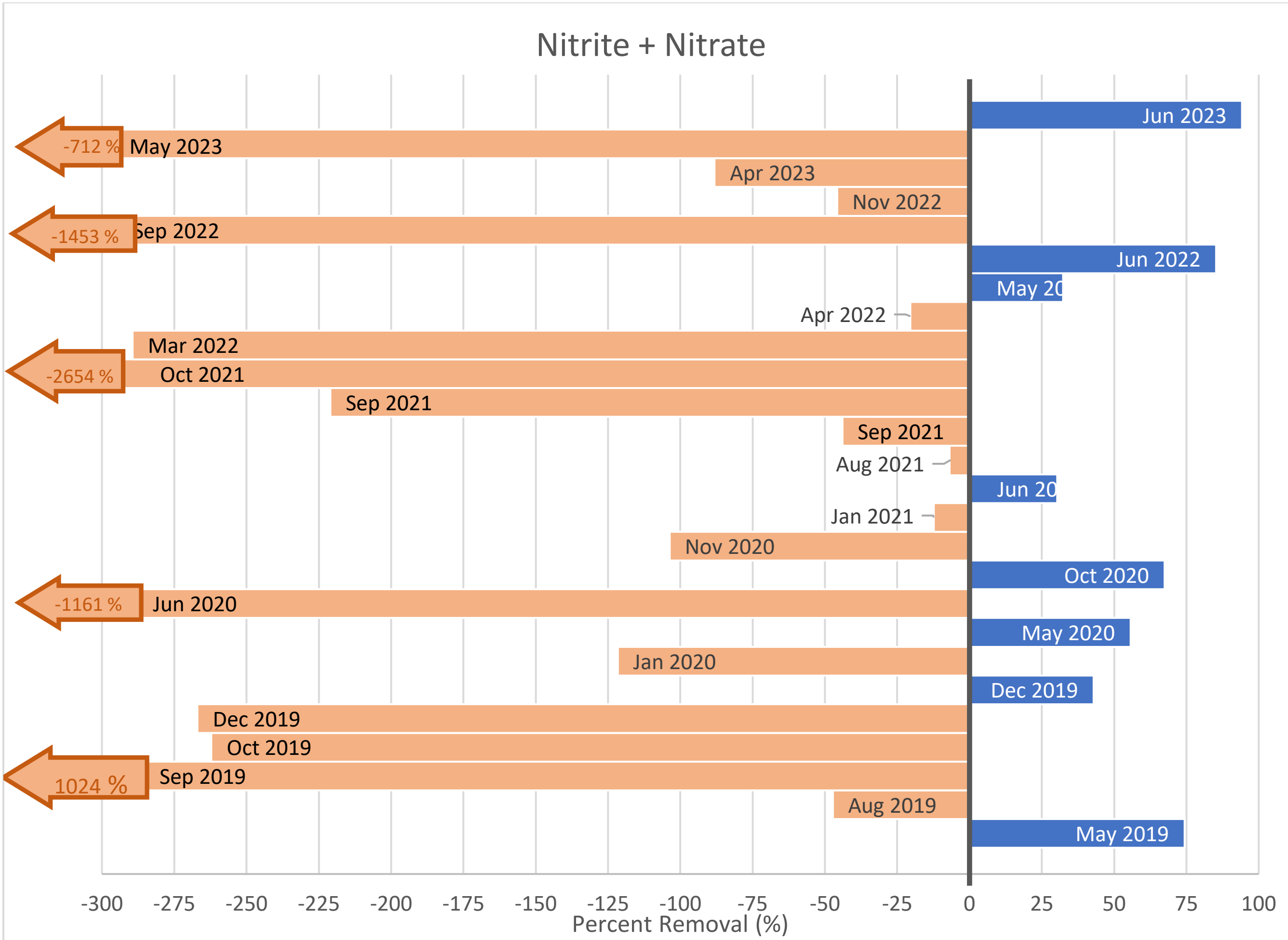

Figure C-3. Percent removal nitrogen .

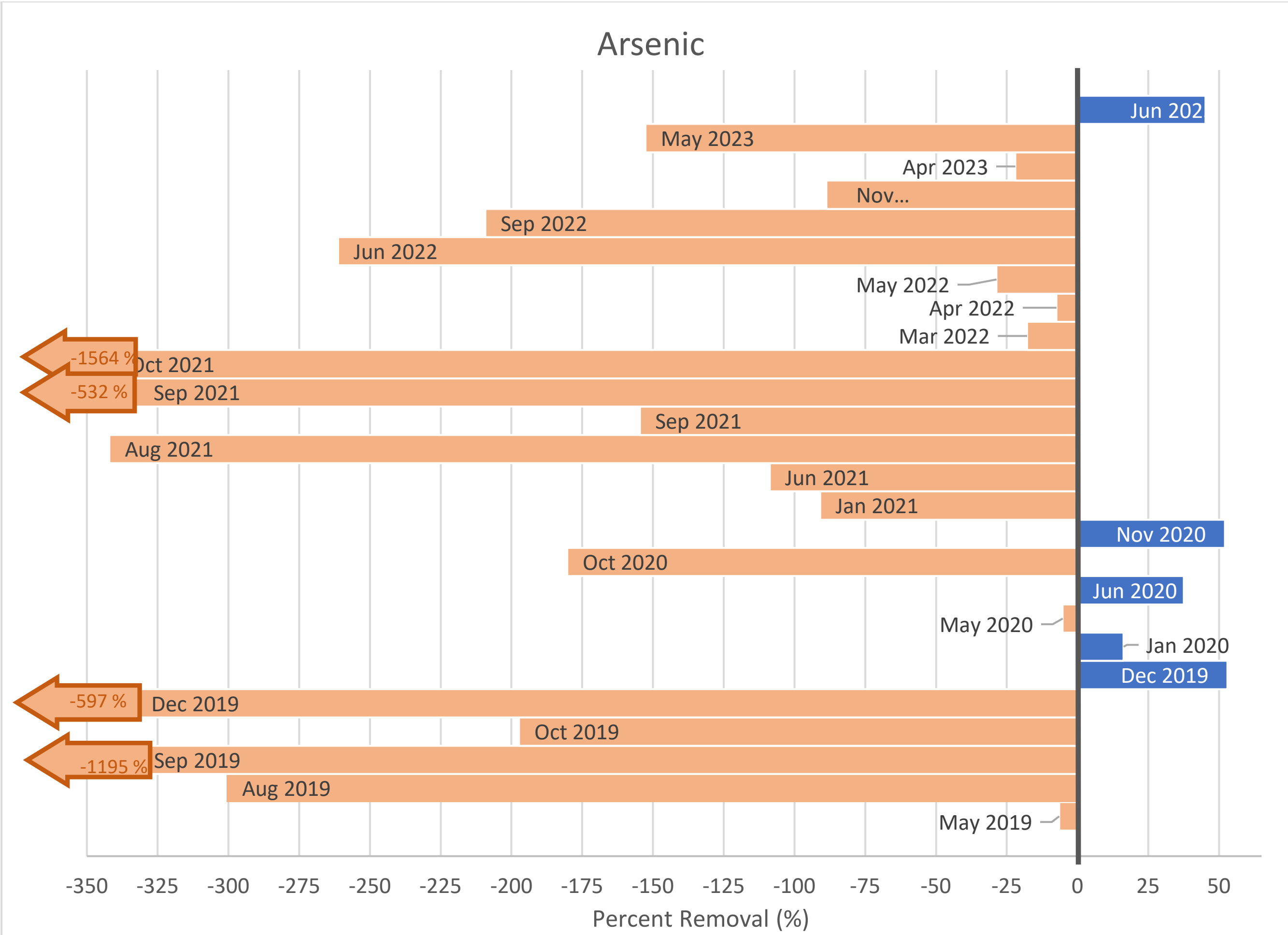

Figure C-4. Percent removal total arsenic .

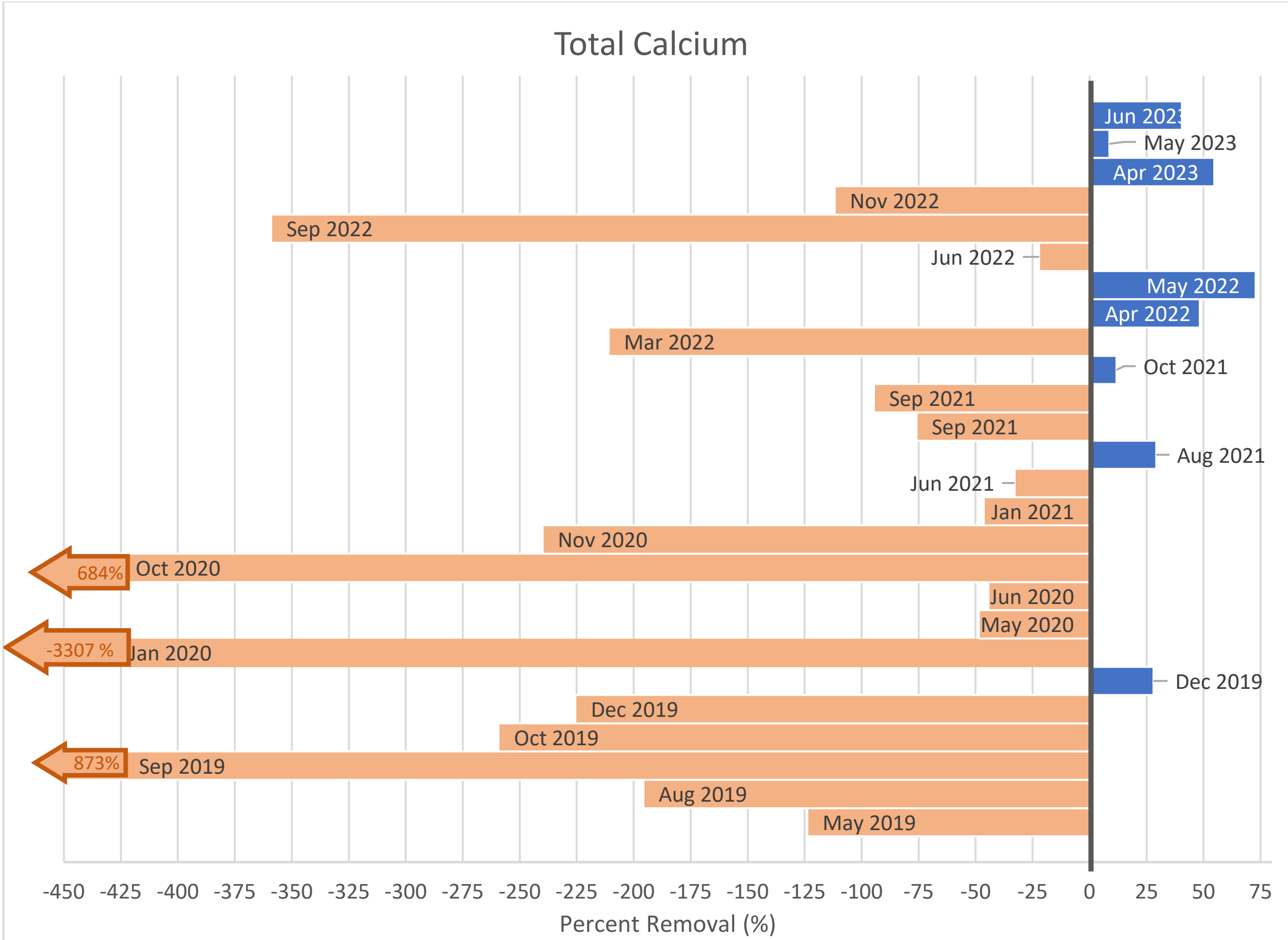

Figure C-5. Percent removal total calcium.

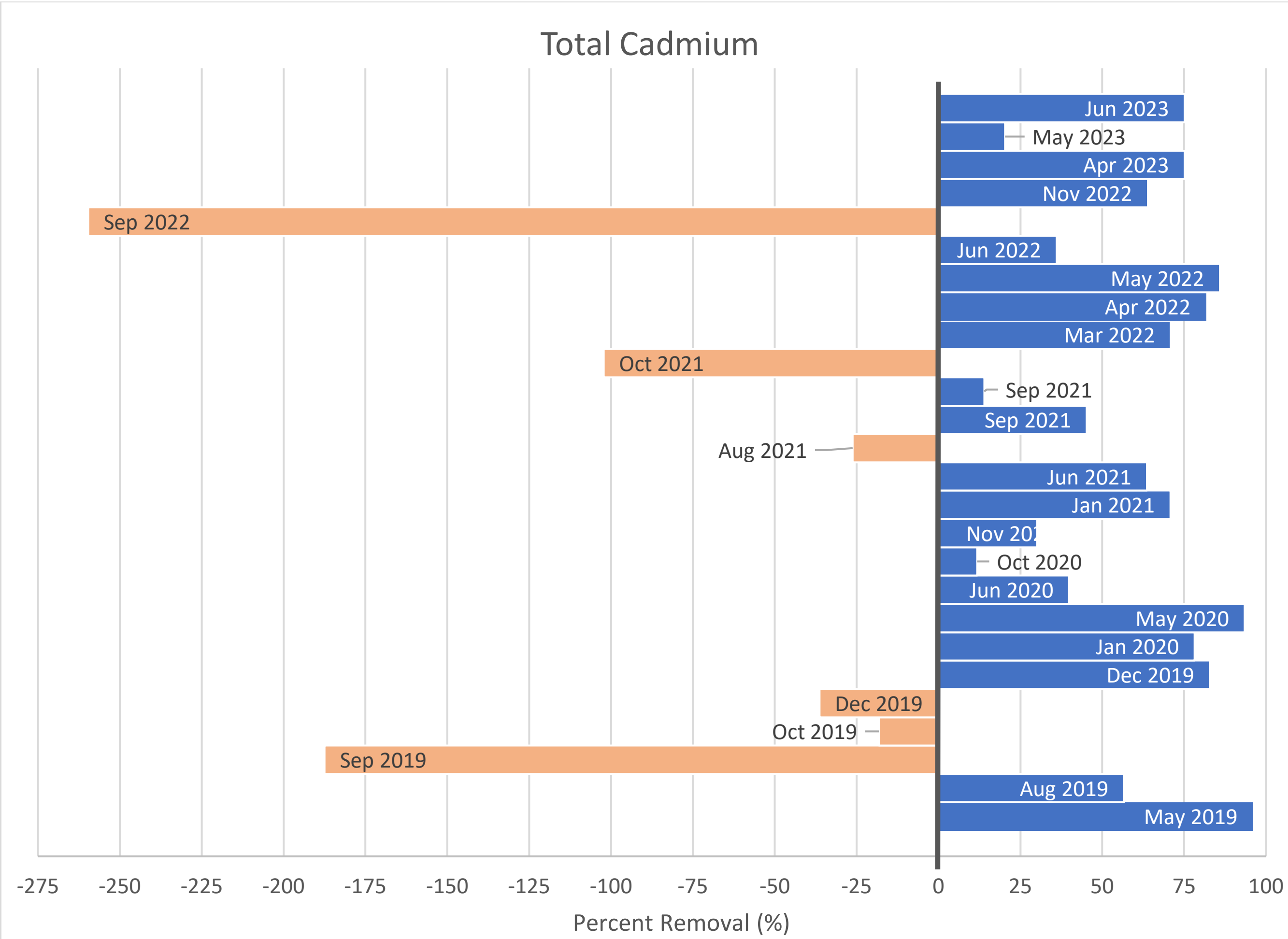

Figure C-6. Percent removal total cadmium .

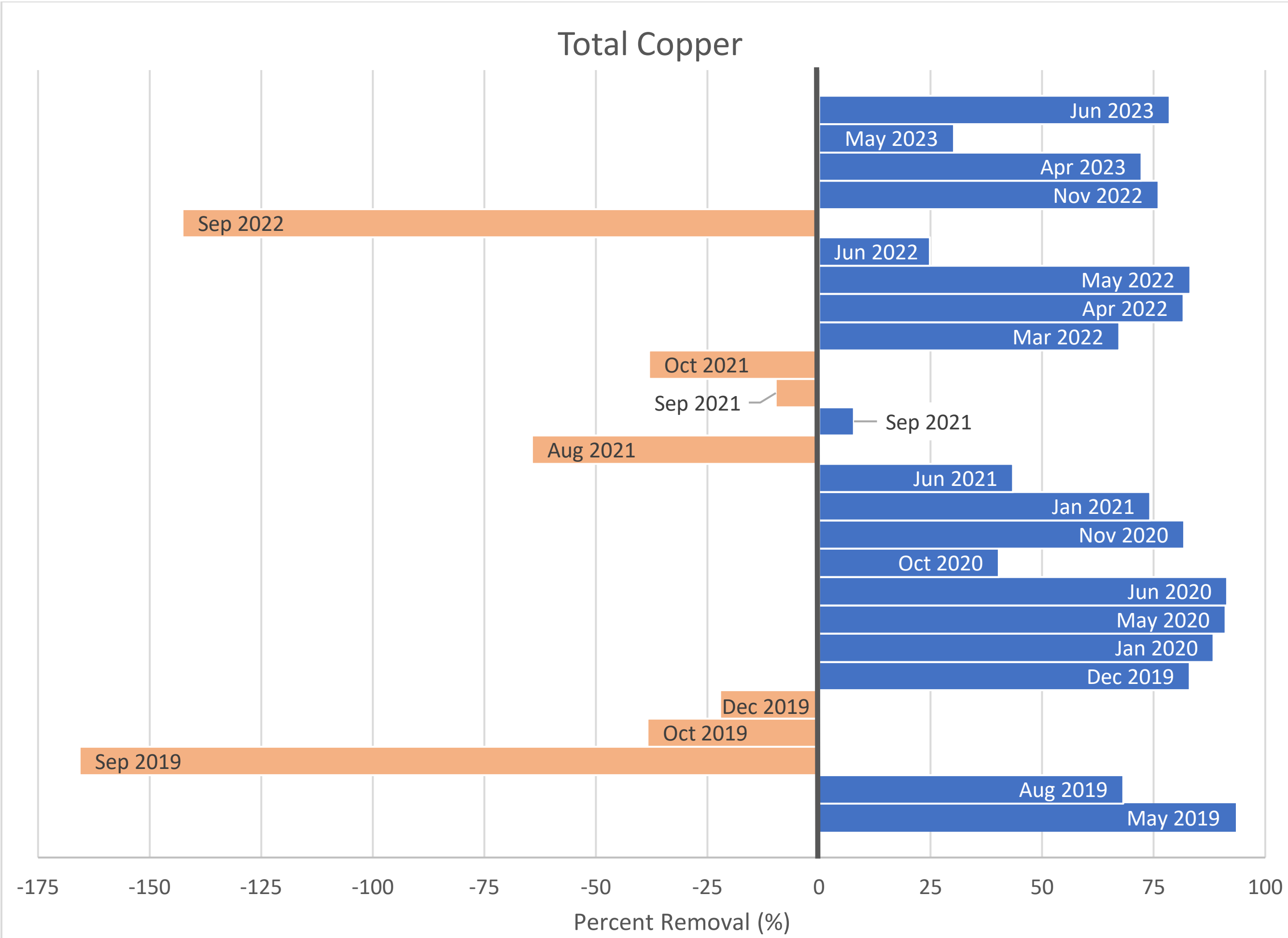

Figure C-7. Percent removal total copper.

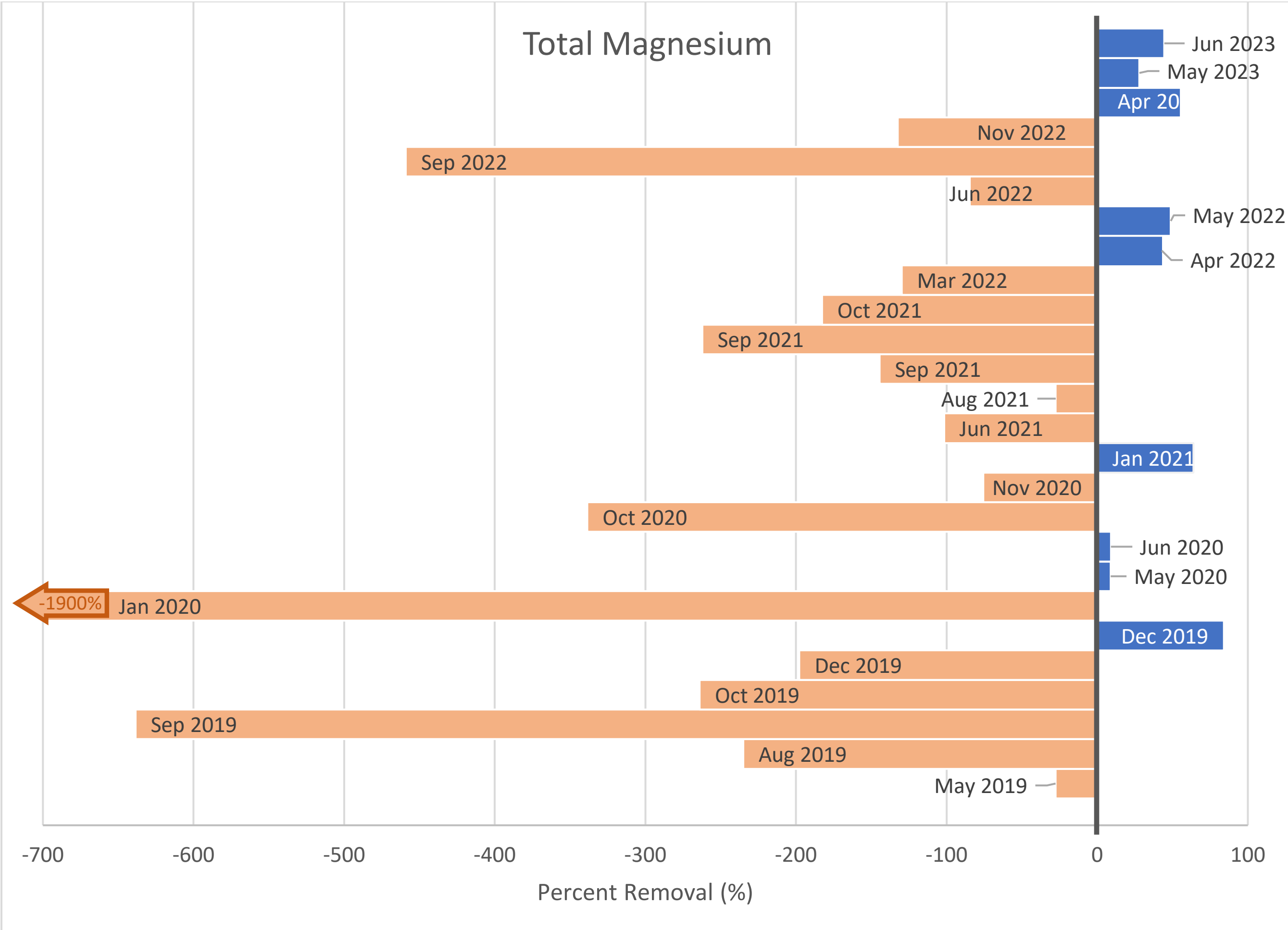

Figure C-8. Percent removal magnesium .

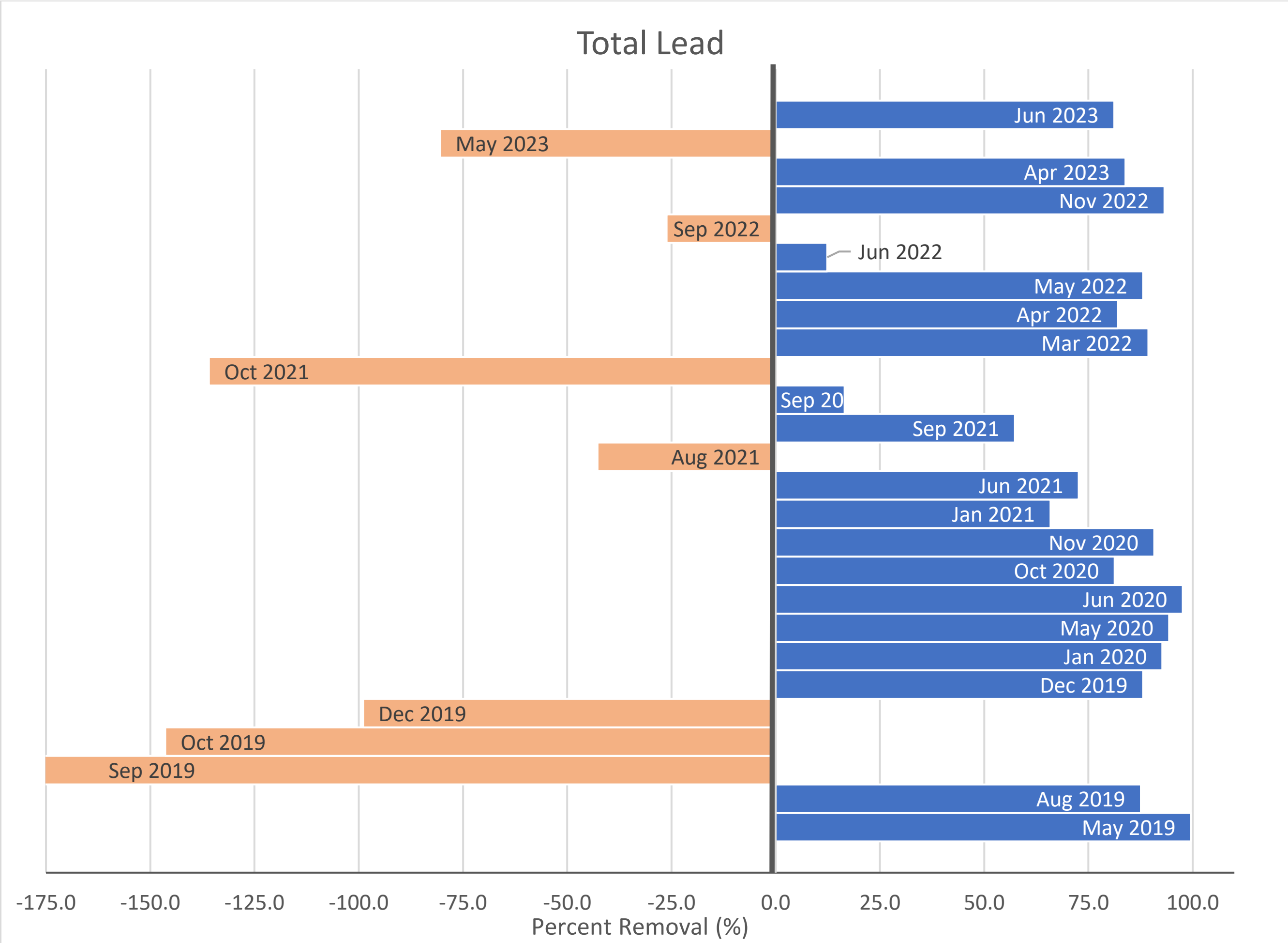

Figure C-9. Percent removal total lead.

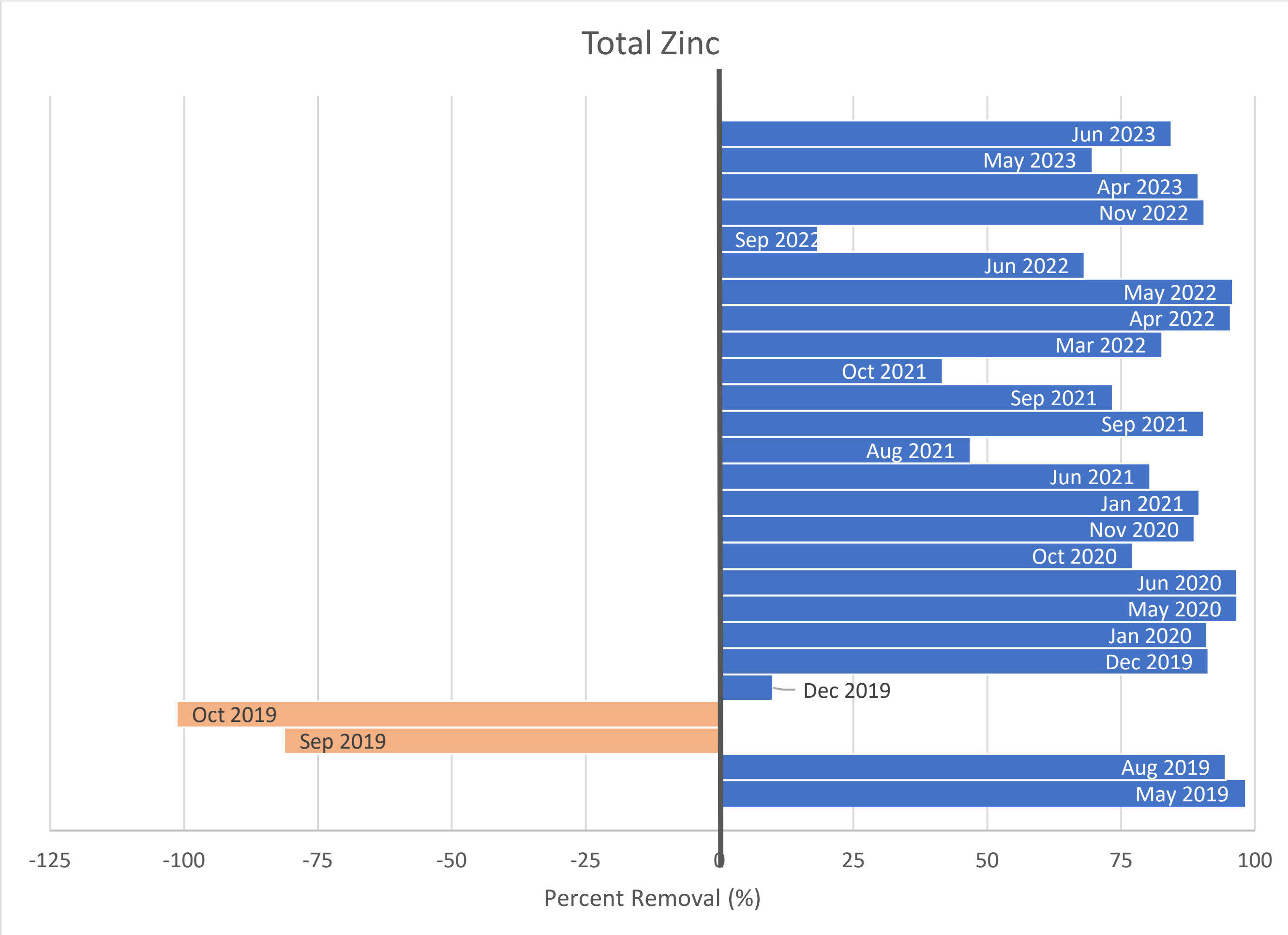

Figure C-10. Percent removal total zinc.

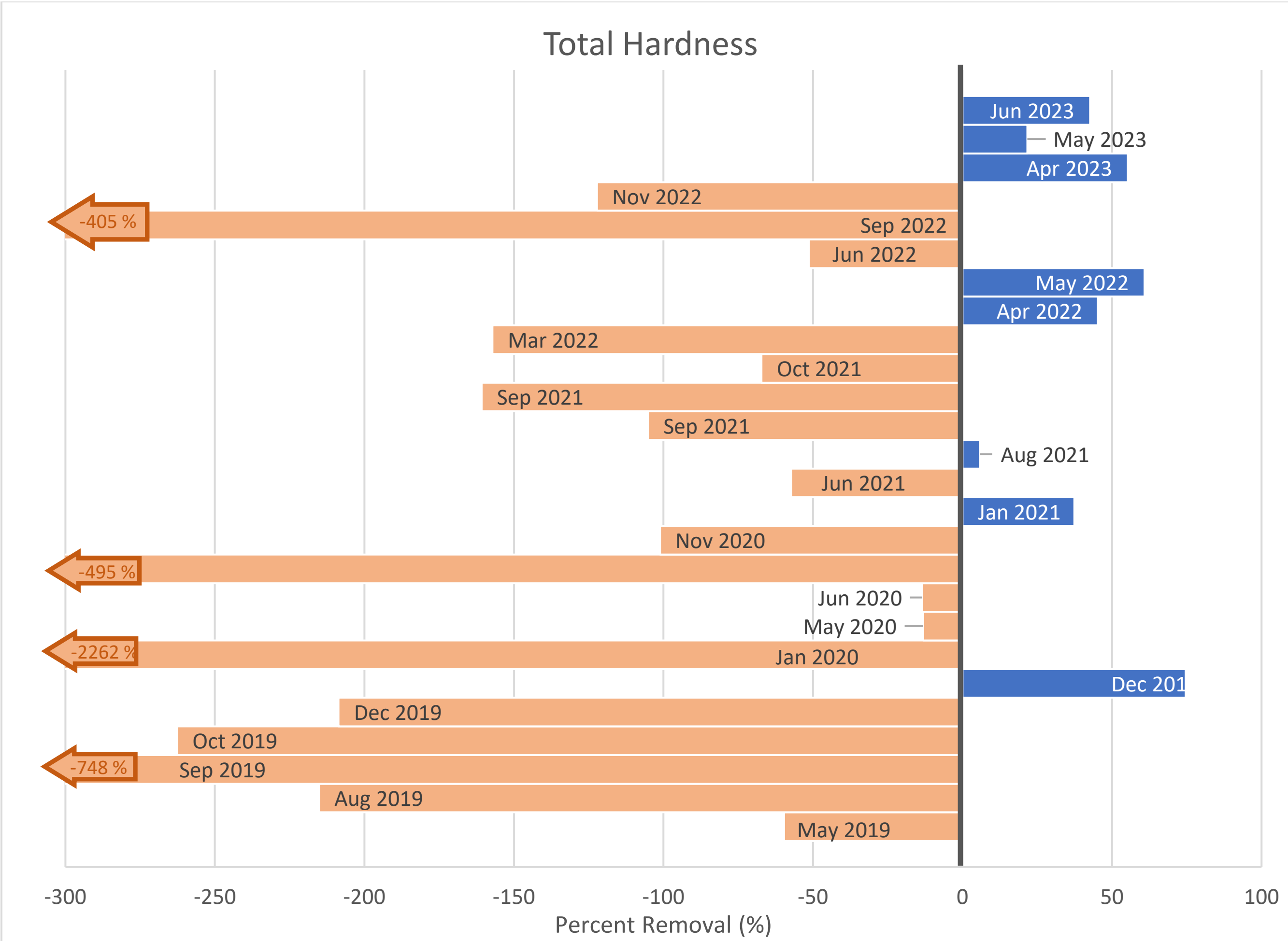

Figure C-11. Percent removal total hardness .