Technical Memorandum

To: Valley Branch Watershed District Landlocked Basin Comprehensive Planning Study Project Stakeholders
From: Kevin Menken, Jennifer Koehler
Subject: VBWD Landlocked Basin Flood Mitigation Comprehensive Planning Study —2021 Sediment Phosphorus Study Summary
Date: October 2023
Project: 23821268.00
c: John Hanson, Nicholas Vottero, Jeremiah Jazdzewski

1 Background

The Valley Branch Watershed District (VBWD) partnered with the United States Army Corp of Engineers (USACE) through the Planning Assistance to States program (PAS) to perform a comprehensive planning study to understand the conditions leading to and determine how to manage high water conditions at ten landlocked basins within VBWD.

This comprehensive planning study identified and provided preliminary sizing of high-water-management alternatives for each basin and evaluated the impact of the alternatives on receiving waters from a flood risk and mitigation standpoint. Additionally, the VBWD wanted to understand the impact of proposed high water outlets on the water quality (with a focus on eutrophication and nutrients) in downstream receiving waters.

2 Internal Phosphorus Loads as a Nutrient Source in Water Bodies

Internal phosphorus (P) loading in lakes, ponds, and wetlands, often called sediment P release, results from mobile sediment P fractions (loosely bound P, iron-bound P, and organic P) moving from the sediments to overlying water. In Upper Midwest lakes, mobile sediment P primarily comprises redox-sensitive species, including loosely bound and iron-bound P, which readily move into porewater and migrate to overlying water under anoxic conditions. These fractions are typically the primary drivers of sediment P release. Phosphorus bound up in labile organic material can also be a source of sediment P when the organic material is mineralized. This process occurs under both aerobic and anaerobic conditions, and released P can either migrate to surface waters or bind to metal hydroxides in the sediment, becoming available for release under anoxic conditions.

Poor water quality in lakes or ponds may be due to the release of phosphorus from lake bottom sediments. Understanding the potential contribution of sediment P to the overall phosphorus balance in a lake or water body can help target efforts to effectively manage and improve water quality in these waters. Installing outlets from the waterbodies in this study may require some treatment or mitigation to reduce phosphorus loads to downstream waterbodies and the St. Croix River to protect water quality.

3 Sediment Core Collection

As part of the VBWD comprehensive planning study, Barr collected sediment cores from several VBWD lakes in November 2021 using a gravity coring device with 7-cm-diameter coring tubes. We typically collected sediment cores from varying water depths around the basin, including collecting a core at the deepest portion of the basin. We sectioned the sediment cores collected at each site into discreet intervals in the field—2 cm sediment intervals for the upper 10 cm and 4 cm sediment intervals from 10 to 22 cm.

The sediment cores collected as part of this study are summarized in Table 1 and further discussed in the following sections. Barr collected three additional cores in both Downs Lake and McDonald Lake. We transported these cores intact to Barr's laboratory for anoxic phosphorus release experiments. These additional cores were collected because Downs Lake and McDonald Lake have poor water quality (typically at or worse than state standards for shallow lakes).

Table 1 Summary of VBWD sediment core collection

Basin	Number of Sediment Cores
Downs Lake	Four sediment cores for P fractionation analysis Three additional cores for laboratory release experiments
Friedrich's Pond	One sediment core for P fractionation analysis—west basin One sediment core for P fractionation analysis—middle basin Three sediment cores for P fractionation analysis—east basin
Klawitter Pond	Three sediment cores for P fractionation analysis
McDonald Lake	Three sediment cores for P fractionation analysis Three additional cores for laboratory release experiments
Reid Park Ponds	One sediment core for P fractionation analysis—west basin One sediment core for P fractionation analysis—east basin

3.1 Downs Lake

Barr collected sediment cores for P fractionation from four locations in Downs Lake, as shown in Figure 1. Additional sediment cores were collected from location "Downs-S3" for anoxic phosphorus release measurements.

The physical characteristics of the four sediment coring locations in Downs Lake were similar and consisted of organic silt.

3.2 Friedrich's Pond

Barr collected sediment cores from five locations on Friedrich's Pond, as shown in Figure 2, including one core from the west basin, one from the middle basin, and three from the east basin. The west basin is the smallest and most shallow. It was dry or filled with emergent vegetation as recently as 2011, as determined by a review of archived aerial imagery dated April 2011 in Google Earth. The east basin was also much smaller in 2011 than the pond's surface area in 2021. Only a relatively small portion appeared as open water in April 2011 aerial imagery.

Cores in all three basins consisted of brown organic silt, with some decaying plant fragments at the surface. A small amount of brown, decaying filamentous algae was also present on the surface of sediment cores collected from the east basin.

3.3 Klawitter Pond

Barr collected sediment cores from three locations in Klawitter Pond, as shown in Figure 3.

The physical characteristics of the three sediment cores in Klawitter Pond were similar, consisting of organic silt.

3.4 McDonald Lake

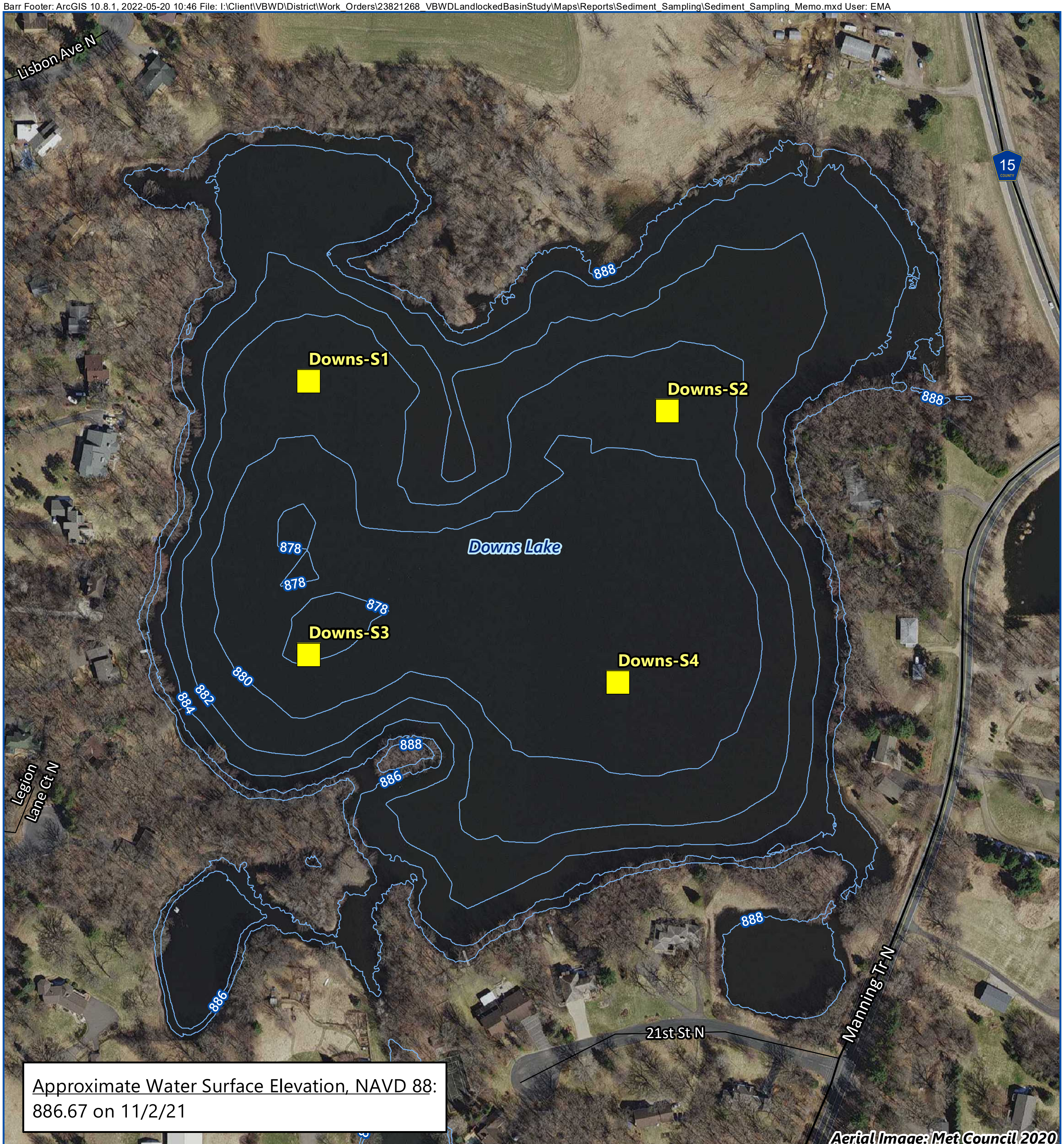
Barr collected sediment cores from three locations on the main basin (south) of McDonald Lake, as shown in Figure 4.

Sediment core McDonald-S1 was collected from an area with lily pads and other aquatic vegetation in the north portion of the lake, and fragments of dead aquatic vegetation were present in the sediment core. Vegetation was not observed at coring locations McDonald-S2 and McDonald-S3; sediment at these locations consisted of fine organic silts.

3.5 Reid Park Pond

Reid Park Pond consists of two separate basins, and Barr collected a sediment core from each basin, as shown in Figure 5.

The upper several centimeters of sediment in the sediment core Reid-S2, collected from the east basin, consisted of many aquatic plant fragments. The sediment at this location had very high water content and very little cohesiveness, typical for sediment with a large number of aquatic plant fragments. Sediment core Reid-S1, collected in the west basin, did not contain plant fragments and consisted of fine organic silt.



Sediment Core Location

Approximate Pond Bottom

(Elevation)

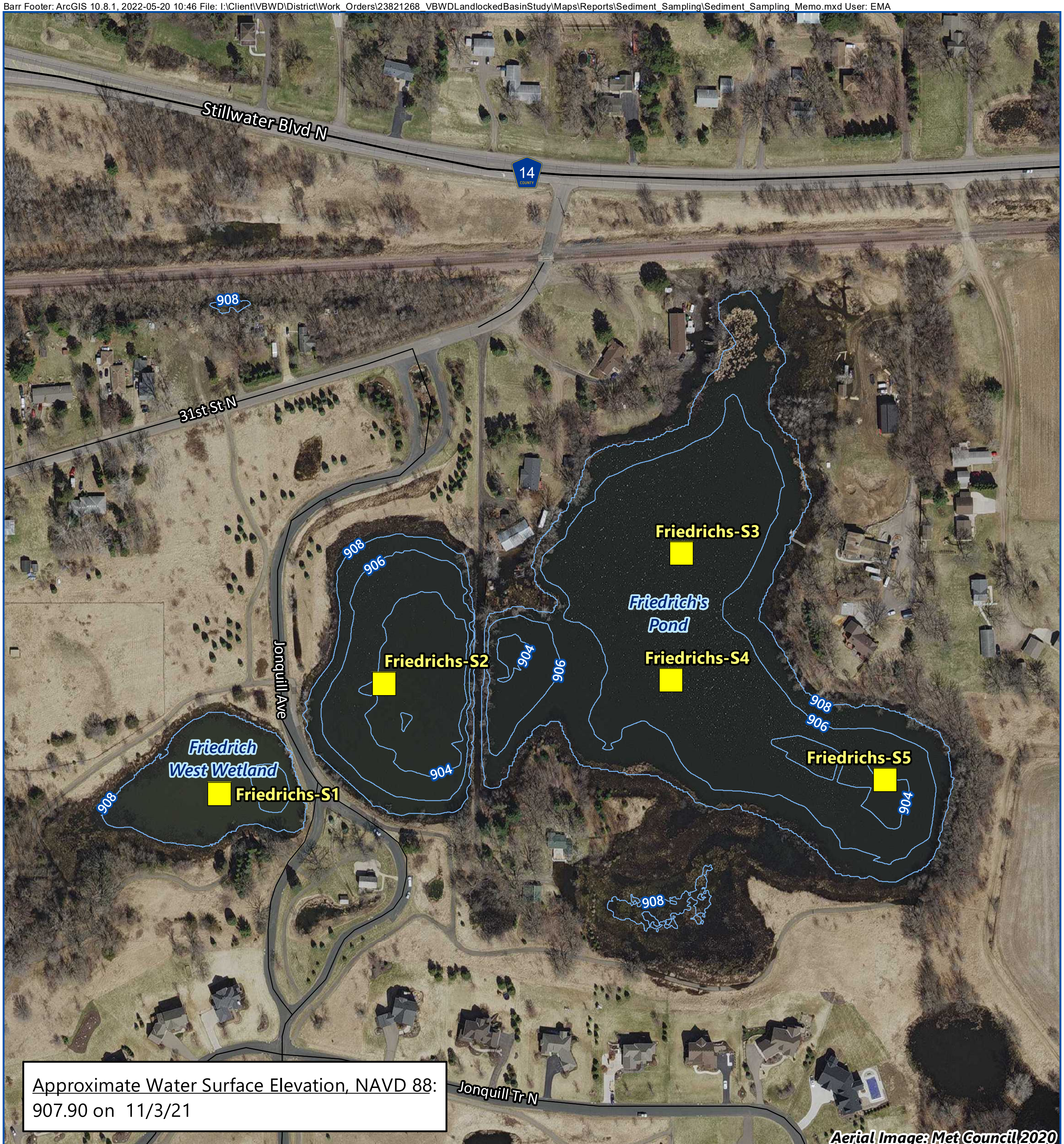
2 Foot Contour

N

0 250 500 Feet

DOWNS LAKE
2021 SEDIMENT
SAMPLING LOCATIONS
Landlocked Basin Study
Valley Branch Watershed District

FIGURE 1



Sediment Core Location

Approximate Pond Bottom

(Elevation)

2 Foot Contour

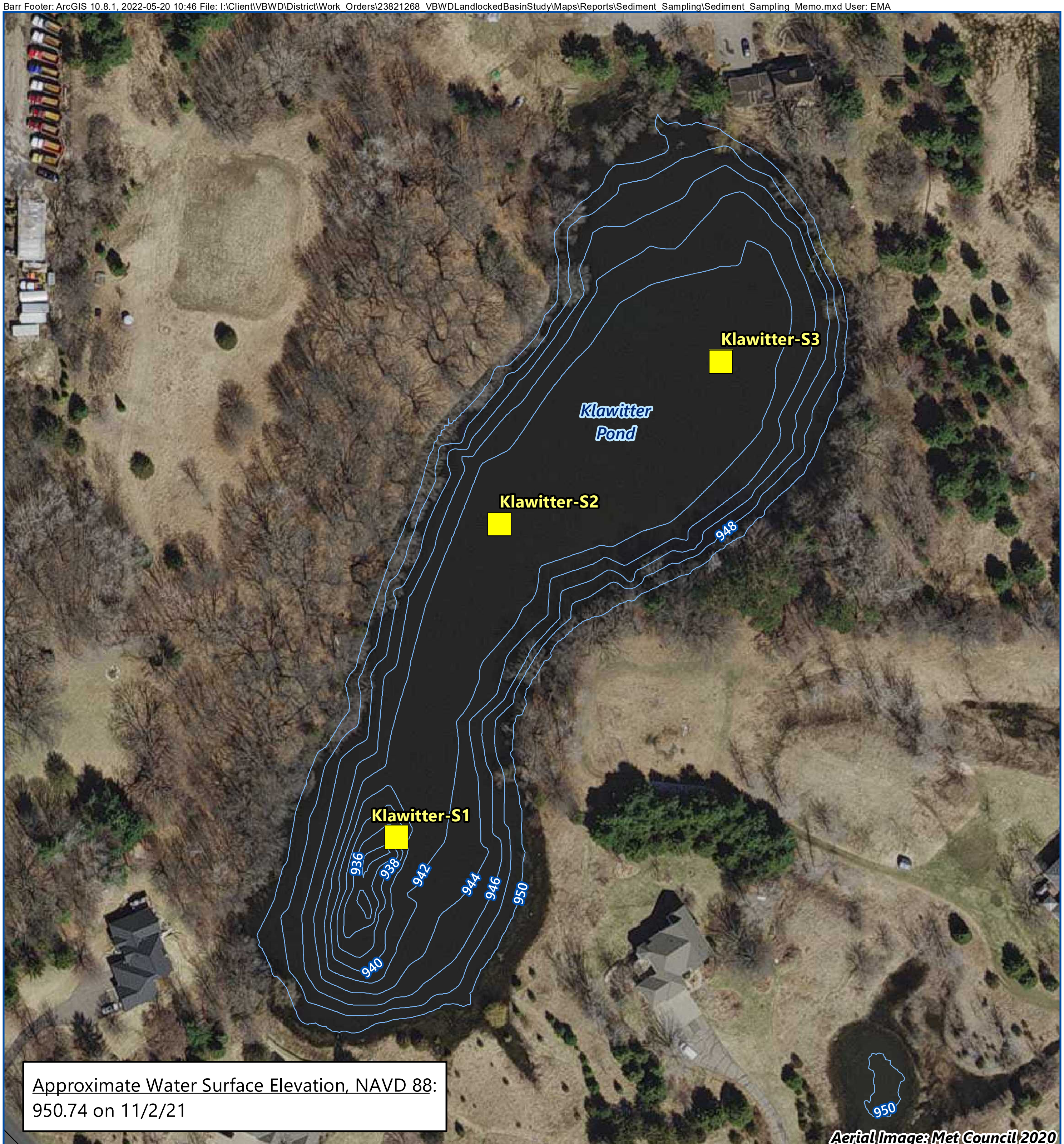
0 250 500 Feet

FRIEDRICH'S POND 2021 SEDIMENT SAMPLING LOCATIONS

Landlocked Basin Study

Valley Branch Watershed District

FIGURE 2



Sediment Core Location

Approximate Pond Bottom

(Elevation)

2 Foot Contour

0 250 Feet

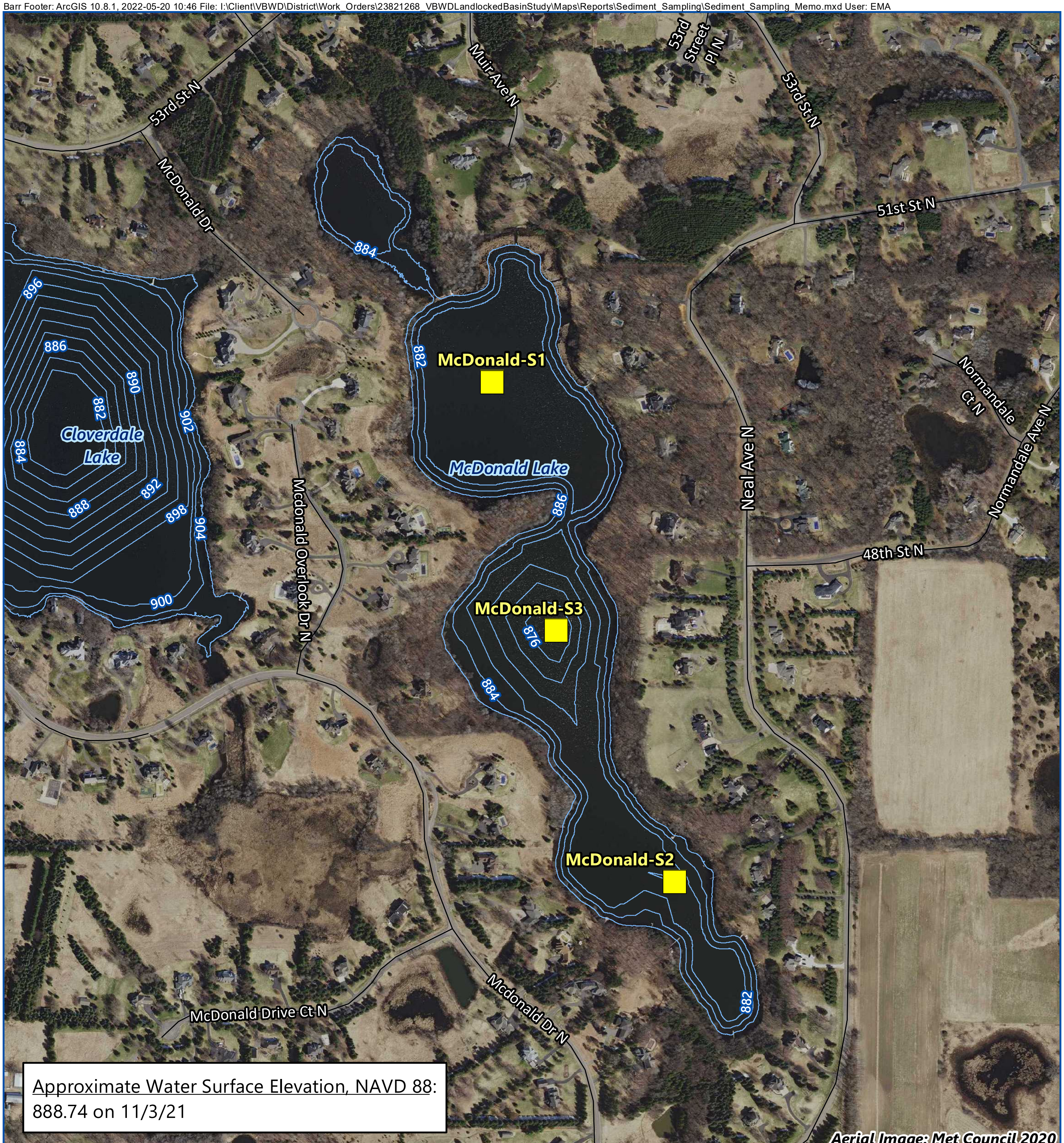
KLAWITTER POND 2021 SEDIMENT SAMPLING LOCATIONS

Landlocked Basin Study

Valley Branch Watershed District

FIGURE 3

Barr Footer: ArcGIS 10.8.1, 2022-05-20 10:46 File: I:\Client\VBWD\District\Work_Orders\23821268_VBWDLandlockedBasinStudy\Maps\Reports\Sediment_Sampling\Sediment_Sampling_Memo.mxd User: EMA



Approximate Water Surface Elevation, NAVD 88:
888.74 on 11/3/21

Sediment Core Location

Approximate Pond Bottom

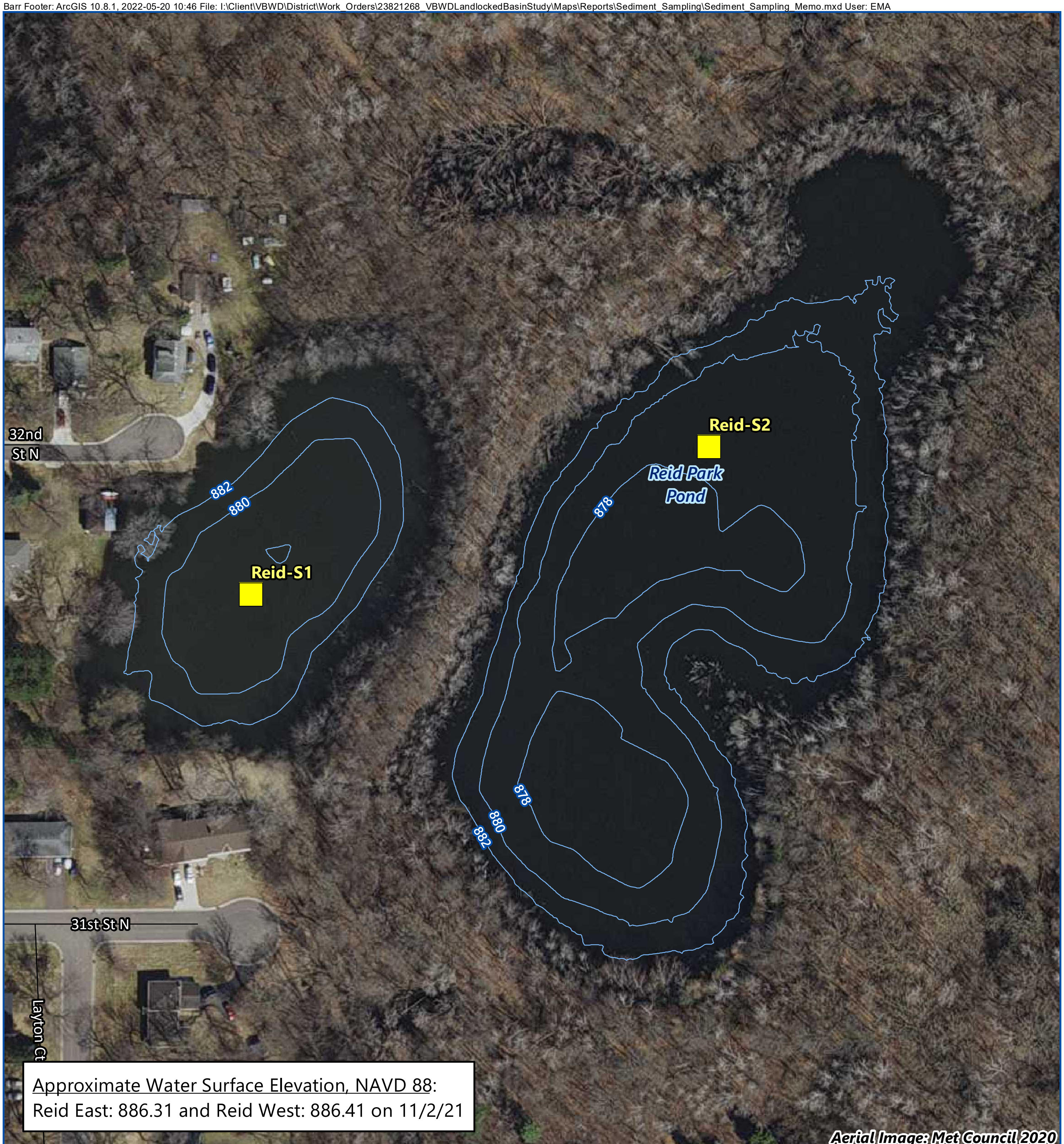
(Elevation)

2 Foot Contour

0 250 500 750 1,000 1,250 Feet

MCDONALD LAKE
2021 SEDIMENT
SAMPLING LOCATIONS
Landlocked Basin Study
Valley Branch Watershed District

FIGURE 4



Sediment Core Location

Approximate Pond Bottom

(Elevation)

2 Foot Contour

0 250 Feet

REID PARK POND 2021 SEDIMENT SAMPLING LOCATIONS

Landlocked Basin Study

Valley Branch Watershed District

FIGURE 5

3.6 Sediment Phosphorus Fractionation

3.6.1 Sediment Percent Water Content and Percent Loss on Ignition

Barr dried sediment samples in an oven at 105°C for 24 hours, and the percent water content (%H2O) was determined by recording the mass loss of water from drying. We measured the percent loss on ignition (%LOI) for sediment samples by burning dried sediment samples at 550°C for 2 hours and recording the mass loss. The %LOI was calculated by dividing the mass lost during combustion by the original dry subsample mass. The estimated sediment density was calculated using the %H2O and %LOI for each sediment sample, using a relationship described by Håkanson and Jansson (2002). Tabulated results of %H2O and %LOI are in Attachment A.

3.6.2 Sediment Phosphorus Fractionation

Barr analyzed sediment samples in Barr's laboratory for P fractions (iron-bound P, organic P, aluminum-bound P fraction, and calcium-bound P) following methods similar to Psenner and Puckso (1988). The P fractionation involves a sequential extraction as described below:

- <u>Iron-bound phosphorus (Fe-P):</u> Buffered dithionite—a solution of sodium bicarbonate and sodium dithionite. The bicarbonate buffers pH, and dithionite creates strong conditions that reduce insoluble ferric iron (Fe[III]) to soluble ferrous iron (Fe[II]).
- <u>Aluminum-bound phosphorus (Al-P)</u>: NaOH (without digestion)—a solution of 0.1M sodium hydroxide. The high pH solubilizes aluminum-bound and organic phosphorus.
- <u>Organic phosphorus (Org-P)</u>: NaOH (with digestion)—the 0.1M sodium hydroxide extract solution is digested with potassium permanganate in an autoclave, resulting in organic phosphorus being reactive with the phosphorus color reagent. The concentration of phosphorus in the NaOH extraction without digestion (the aluminum-bound phosphorus fraction) is subtracted from the digested concentration to calculate the organic phosphorus concentration.
- <u>Calcium-bound phosphorus (Ca-P)</u>: HCl—a solution of 0.5M hydrochloric acid. The low pH solubilizes calcium-bound phosphorus.

The Fe-P fraction is often considered the most significant contributor to sediment internal loading, driven by microbial respiration that reduces insoluble ferric iron (Fe[III]) to soluble ferrous iron (Fe[II]) when oxygen is absent. Shallow lakes, ponds, and wetland sediments can be dominated by Org-P fraction, with relatively low concentrations of Fe-P, and the decomposition of the organic matter can also result in internal phosphorus loading. Al-P and Ca-P fractions in sediment are not affected by redox or decomposition, and Al-P and Ca-P fractions are not considered a significant contribution to internal loading in water bodies.

Barr measured the P concentration in each extraction solution on a spectrometer using the molybdate/ascorbic acid colorimetric method. The organic P fraction only reacts with the color reagent after digestion, hence the persulfate digestion of the NaOH extract. Tabulated P fractionation results are included in Attachment A.

Concentrations of P fractions are expressed as [mg P]/[g sediment dry weight], as well as [mg P]/[cm^3]. Barr plotted the results of P fractionation versus sediment depth for each core (Attachment B). Average concentrations in the top 6 cm were calculated for the various phosphorus fractions for each sediment core, for both dry-weight phosphorus concentrations (Figure 6) and phosphorus concentrations per volume of wet sediment (Figure 7). The results for sediment core Reid S1 were plotted on separate axes due to the considerably higher measured concentrations in that core.

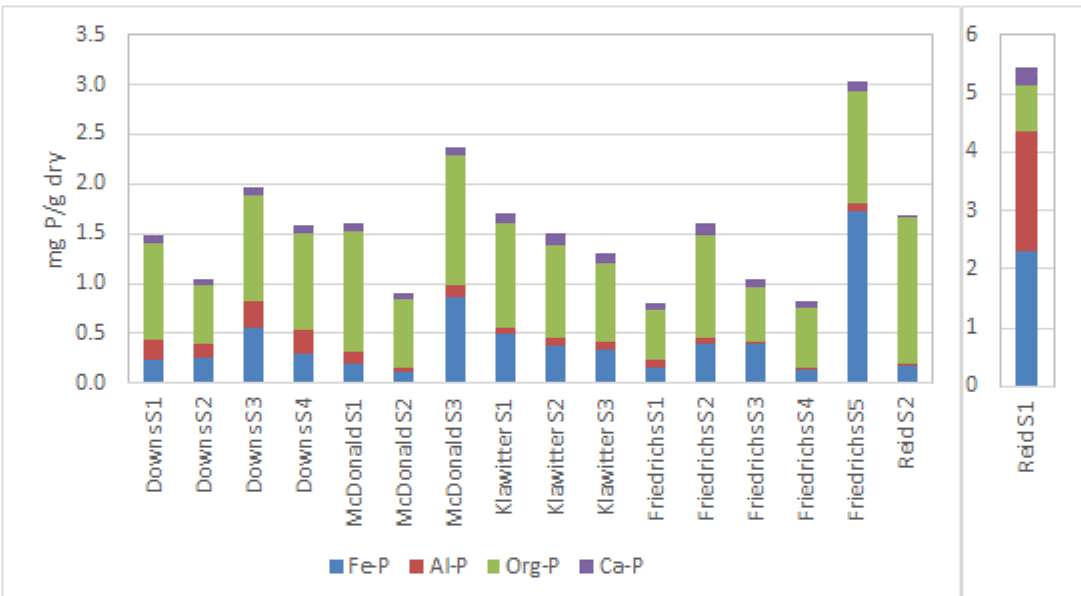


Figure 6 Concentrations of sediment phosphorus fractions in top 6 cm ([mg P]/[g dry sediment])

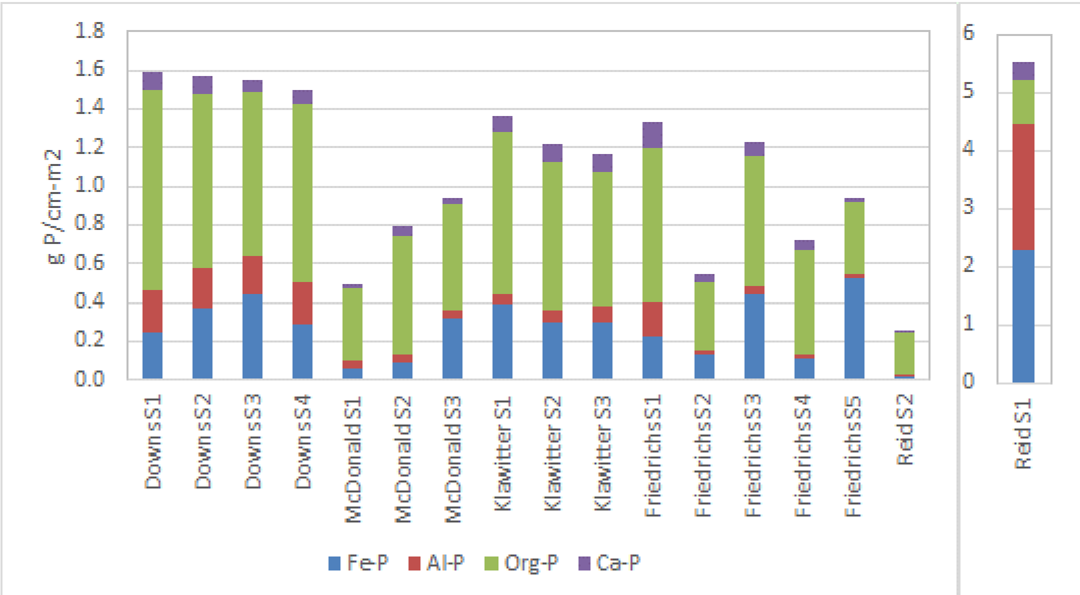


Figure 7 Concentrations of sediment phosphorus fractions in top 6 cm ([g P]/[cm-m²])

3.7 Sediment Column Phosphorus Release Measurements

Barr collected three additional cores in both Downs Lake and McDonald Lake and transported these cores intact to Barr's laboratory for anoxic phosphorus release experiments. Barr carefully removed the overlying water in the core tubes to minimize sediment disturbance. We replaced the water with filtered lake water to a depth of 20 cm above the sediment. Barr collected this water from the surface of each lake and filtered the water through a 0.45 µm cartridge filter using a peristaltic pump. Nitrogen gas was gently bubbled through an aquarium aeration stone placed 10 cm above the top of the sediment in each column. The bubble stream of nitrogen gas strips out the oxygen from the water, creates an oxygen-free headspace above the water in the microcosm, and gently mixes the water column in the microcosm.

Barr collected water samples from the center of the water column at various intervals—daily at first, less frequently as the test progressed. After collection, we immediately filtered samples through a 0.45 µm filter and analyzed for soluble reactive phosphorus (SRP) within 24 hours. Samples were typically analyzed within 2 hours of sample collection to minimize loss of SRP. We routinely added filtered lake water to replace the water volume removed for sample collection.

We calculated changes in overlying soluble reactive phosphorus concentrations to estimate daily P flux in [mg P]/[m^2-day] between measurements. We accounted for the mass of phosphorus removed due to sample collection for analyses and the mass of phosphorus added to the column in filtered lake water. We plotted concentrations of SRP measured in the P-release mesocosms for Downs Lake and McDonald Lake. The cumulative P release for each column was plotted separately. See figures in Attachment C.

4 Results Summary

The results of sediment P fractionation analyses are discussed below, along with measured anoxic P release rates for Downs Lake and McDonald Lake based on the microcosm experiments.

4.1 Phosphorus Fractionation Results.

Tabulated results of sediment P fractionation analyses are included in Attachment A for all sediment cores.

Barr calculated the average iron-bound P concentration for the top 6 cm in each sediment core (see Table 2). We estimated the maximum potential anoxic P release rate for each core, using the relationship of Pilgrim et al. (2007), which compared measured P release rates in laboratory microcosms with measured concentrations of iron-bound P in sediment cores collected from Minnesota lakes. The lakes included in Pilgrim et al. (2007) were mostly deeper, dimictic lakes in the Minneapolis-St. Paul metropolitan area. "Dimictic" is the term for lakes deep enough to stay thermally stratified during the growing season and only turn over in spring and fall.

The lakes investigated in this landlocked basin study are generally shallow and, therefore, polymictic, meaning they do not form strong thermal stratification and can mix throughout the growing season. Additionally, shallow lakes can have higher organic matter content in sediment, especially if aquatic vegetation is present in the lake. The reduction of ferric iron to ferrous iron in anoxic sediment and the associated release of phosphorus bound to ferric iron are considered the primary mechanisms of internal loading in most Minnesota lakes. The decay of sediment organic matter and associated internal loading of organic phosphorus can be a substantial contribution to internal loading in shallow lakes and ponds; therefore, shallow lakes and ponds with high concentrations of sediment organic P and relatively low iron-bound P may have higher internal loading rates than estimated by the iron-bound P relationship described in Pilgrim et al. (2007) or may experience internal loading of sediment phosphorus even when the sediment-water interface is not anoxic.

Table 2 Iron-bound P in the top 6 cm of sediment and estimated maximum potential anoxic release rates from sediment core fractionation

Coring Location	Average Fe-P in 0–6 cm (g P/cm-m2)	Maximum Potential Anoxic P Release Rate* (mg P/m2-day)
Downs S1	0.248	3.1
Downs S2	0.373	4.9
Downs S3	0.438	5.9
Downs S4	0.283	3.6
McDonald S1	0.060	0.20
McDonald S2	0.094	0.71
McDonald S3	0.313	4.0
Reid S1	2.295	34
Reid S2	0.022	0.0
Klawitter S1	0.388	5.2
Klawitter S2	0.294	3.7
Klawitter S3	0.298	3.8
Friedrichs S1	0.226	2.7
Friedrichs S2	0.136	1.4
Friedrichs S3	0.440	5.9
Friedrichs S4	0.115	1.0
Friedrichs S5	0.521	7.2

* Maximum potential anoxic P release rate estimated from the relationship of release rate and iron-bound P concentrations, as described in Pilgrim et al. (2007).

The west basin of Reid Park Pond (sediment core Reid S1) had the highest concentration of iron-bound P and maximum potential anoxic P release rate. In contrast, the east basin of Reid Park Pond (Reid S2) had the lowest observed concentration and associated maximum potential anoxic P release rate. The sediment of the west basin had high concentrations of aluminum-bound P and iron-bound P, which may be due to clay soil particles that are accumulating in the pond from stormwater runoff and soil erosion. Additionally, no submerged aquatic vegetation was observed in the west basin of Reid Park Pond. This is likely due to the dominance of algae or small floating vegetation (duckweed or watermeal) in the basin that would prevent submerged plant growth by blocking sunlight. The east basin of Reid Park Pond has substantial submerged aquatic plant growth, and the upper portion of the sediment core collected in the east basin consisted largely of decomposing aquatic plant fragments (e.g., coontail leaf fragments).

Organic bound P is the most significant fraction of P in Downs Lake. Concentrations of iron-bound P were relatively similar among the four coring locations in Downs Lake.

Organic bound P is the most significant fraction of P in Klawitter Pond. The three coring locations sampled had relatively similar iron-bound P concentrations.

Organic bound P is the most significant fraction of P in McDonald Lake. Iron-bound P concentrations varied between coring locations, with the deepest location in the lake's center (McDonald S3) having the highest concentration, and coring location McDonald S1 having the lowest iron-bound P concentration.

Organic bound P is the most significant fraction of P in Friedrich's Pond. Iron-bound P concentrations varied between coring locations on Friedrich's Pond, with the cores collected in the east basin of Friedrich's Pond (Friedrichs S3 and S5) having the highest concentrations.

4.2 Measured Anoxic Release Rates for Downs Lake and McDonald Lake

Figures showing the measured concentrations of SRP in anoxic phosphorus release microcosms for Downs Lake and McDonald Lake are included in Attachment C. Barr also plotted the cumulative phosphorus release over time separately for each sediment core (Attachment C). We calculated the peak phosphorus flux in the sediment microcosms for each core, as summarized in Table 3, along with the average peak phosphorus flux for each lake. We also calculated the average phosphorus flux throughout the study (38 days) for each sediment microcosm (Table 3).

The Downs Lake sediment cores showed a rapid release of phosphorus over the first 9 days of the experiment, followed by a slower phosphorus release over the remainder of the study, which ended at 38 days of incubation under anoxic conditions. The peak phosphorus flux for Downs Lake microcosms was calculated for the first 9 days of the study, and the average was calculated for the three cores. The microcosm-measured phosphorus release rate for the first 9 days (26 mg P/m2-day) was four times that predicted by Pilgrim et al. using Fe-P and concentrations of iron-bound P in Downs Lake sediment (5.9 mg P/m2-day). The 38-day average microcosm release rate for Downs Lake was 11 P/m2-day, nearly double the rate predicted by Pilgrim et al. Downs Lake sediment cores had the highest concentrations of total phosphorus per sediment volume (as determined by the sum of sediment P-fractions) of the basins sampled for this study, except for the west basin of Reid Park Pond. The organic P fraction in the top 6 cm was nearly double the iron-bound P fraction of core Downs S3 (where mesocosm cores were collected). It may be contributing to the higher phosphorus release rates than predicted by Pilgrim et al.

McDonald Lake had a lower phosphorus release rate than Downs Lake; phosphorus release from McDonald Lake sediment was most rapid during the first 4 days of anoxia, followed by several days with little or no increase in SRP concentrations in the microcosms. SRP concentrations began to rise in the McDonald Lake microcosm again around Day 12 and continued to rise steadily through the end of the study. The microcosm phosphorus release rate for the first 4 days (9.7 mg P/m2-day) was double what was predicted by Pilgrim et al. using Fe-P, and iron-bound P concentrations in McDonald Lake sediment (4.0 mg P/m2-day). However, the 38-day average microcosm release rate for McDonald Lake was 3.1 P/m2-day, slightly lower than the rate predicted by Pilgrim et al.

Table 3 Measured phosphorus release rate in Downs Lake and McDonald Lake anoxic microcosms

Sediment Core	Duration (days)	SRP Flux (mg P/m2-day)
Downs 3A	9	28
Downs 3A	38	13
Downs 3B	9	18
Downs 3B	38	9.2
Downs 3C	9	32
Downs 3C	38	12
Downs Average (Initial Flux)	***9***	***26***
Downs Average (Entire Flux)	***38***	***11***
McDonald 3A	4	8.2
McDonald 3A	38	3.5
McDonald 3B	4	11
McDonald 3B	38	3.0
McDonald 3D	4	9.4
McDonald 3D	38	2.8
McDonald Average (Initial Flux)	***4***	***10***
McDonald Average (Entire Flux)	***38***	***3.1***

5 References

Håkanson, L., and Jansson, M. 2002. Principles of lake sedimentology. The Blackburn Press, Caldwell, NJ USA.

Nürnberg, G.K. 1988. Prediction of phosphorus release rates from total and reductant soluble phosphorus in anoxic lake sediments. Can. J. Fish. Aquat. Sci. 45:453-462.

Pilgrim, K.M., et al. 2007. A method for comparative evaluation of whole-lake and inflow alum treatment. Water Res., 41 (6), pp. 1215-1224.

Psenner, R., and Puckso, R. 1988. Phosphorus fractionation: Advantages and limits of the method for the study of sediment P origins and interactions. Arch. Hydrobiol. Biel. Erg. Limnol. 30:43-59.

Table A1. Valley Branch Watershed District 2021 sediment phosphorus fractionation results.

Coring Location	Water Depth (ft)	Sediment Depth Interval (cm)		% Moisture	% LOI	Density (g/cm3)	Fe-P (mg P/g dry)	Al-P (mg P/g dry)	Organic-P (mg P/g dry)	Ca-P (mg P/g dry)	Total Extracted P (mg P/g dry)	Fe-P (mg P/cm3)	Al-P(mg P/cm3)	Organic-P (mg P/cm3)	Ca-P (mg P/cm3)	Total Extracted P (mg P/cm3)
Downs S1	6	0	2	92%	22%	1.04	0.315	0.196	0.973	0.091	1.576	0.0268	0.0167	0.0826	0.0078	0.134
Downs S1		2	4	90%	21%	1.05	0.209	0.189	0.965	0.097	1.460	0.0213	0.0192	0.0981	0.0099	0.148
Downs S1		4	6	87%	18%	1.07	0.192	0.213	0.930	0.077	1.413	0.0264	0.0294	0.1283	0.0107	0.195
Downs S1		6	8	87%	19%	1.07	0.191	0.175	0.770	0.088	1.224	0.0263	0.0242	0.1061	0.0121	0.169
Downs S1		8	10	84%	18%	1.09	0.199	0.197	0.654	0.081	1.130	0.0341	0.0336	0.1118	0.0139	0.193
Downs S1		10	14	80%	16%	1.12	0.186	0.215	0.563	0.078	1.042	0.0419	0.0486	0.1272	0.0176	0.235
Downs S1		14	18	71%	16%	1.18	0.143	0.227	0.388	0.084	0.841	0.0485	0.0770	0.1320	0.0286	0.286
Downs S2	6	0	2	89%	16%	1.06	0.404	0.139	0.642	0.056	1.241	0.0477	0.0164	0.0759	0.0067	0.147
Downs S2		2	4	85%	16%	1.08	0.210	0.128	0.572	0.061	0.971	0.0334	0.0204	0.0910	0.0098	0.155
Downs S2		4	6	82%	16%	1.10	0.159	0.121	0.546	0.060	0.886	0.0306	0.0234	0.1051	0.0115	0.171
Downs S2		6	8	80%	16%	1.11	0.184	0.153	0.534	0.067	0.939	0.0404	0.0335	0.1172	0.0148	0.206
Downs S2		8	10	77%	15%	1.14	0.174	0.167	0.470	0.069	0.881	0.0461	0.0444	0.1248	0.0183	0.234
Downs S2		10	14	70%	12%	1.19	0.147	0.169	0.387	0.068	0.772	0.0532	0.0609	0.1397	0.0245	0.278
Downs S2		14	18	65%	12%	1.24	0.145	0.174	0.350	0.056	0.725	0.0630	0.0757	0.1519	0.0244	0.315
Downs S3	8	0	2	93%	26%	1.03	0.662	0.276	1.036	0.081	2.056	0.0450	0.0188	0.0705	0.0055	0.140
Downs S3		2	4	93%	26%	1.03	0.581	0.277	1.109	0.085	2.053	0.0448	0.0214	0.0855	0.0066	0.158
Downs S3		4	6	91%	24%	1.04	0.448	0.231	1.033	0.080	1.792	0.0415	0.0214	0.0956	0.0074	0.166
Downs S3		6	8	90%	25%	1.05	0.398	0.242	0.895	0.085	1.620	0.0402	0.0244	0.0903	0.0086	0.163
Downs S3		8	10	89%	23%	1.06	0.418	0.311	0.897	0.075	1.701	0.0490	0.0364	0.1051	0.0088	0.199
Downs S3		10	14	87%	24%	1.06	0.466	0.376	0.883	0.086	1.812	0.0644	0.0520	0.1220	0.0119	0.250
Downs S3		14	18	84%	22%	1.08	0.512	0.391	0.775	0.084	1.762	0.0879	0.0671	0.1330	0.0145	0.302
Downs S3		18	22	71%	14%	1.18	0.482	0.624	0.350	0.093	1.550	0.1631	0.2111	0.1185	0.0316	0.524
Downs S4	7	0	2	93%	25%	1.03	0.362	0.238	1.017	0.092	1.709	0.0267	0.0175	0.0750	0.0068	0.126
Downs S4		2	4	90%	22%	1.05	0.284	0.242	0.924	0.076	1.526	0.0297	0.0254	0.0968	0.0079	0.160
Downs S4		4	6	90%	23%	1.05	0.267	0.207	0.983	0.081	1.537	0.0284	0.0220	0.1045	0.0086	0.163
Downs S4		6	8	89%	24%	1.05	0.276	0.187	0.962	0.085	1.510	0.0308	0.0209	0.1073	0.0094	0.168
Downs S4		8	10	87%	22%	1.07	0.339	0.248	0.866	0.083	1.536	0.0467	0.0343	0.1194	0.0114	0.212
Downs S4		10	14	83%	20%	1.09	0.350	0.308	0.683	0.083	1.423	0.0638	0.0560	0.1244	0.0150	0.259
Downs S4		14	18	69%	14%	1.19	0.331	0.379	0.425	0.078	1.212	0.1207	0.1381	0.1549	0.0284	0.442
Downs S4		18	20	64%	13%	1.23	0.386	0.441	0.497	0.073	1.397	0.1693	0.1936	0.2179	0.0321	0.613
Friedrichs S1	2	0	2	94%	29%	1.03	0.181	0.010	0.459	0.039	0.689	0.0109	0.0006	0.0277	0.0024	0.041
Friedrichs S1		2	4	88%	25%	1.06	0.164	0.067	0.587	0.083	0.901	0.0209	0.0086	0.0750	0.0107	0.115
Friedrichs S1		4	6	74%	19%	1.15	0.122	0.151	0.460	0.087	0.820	0.0360	0.0446	0.1360	0.0257	0.242
Friedrichs S1		6	8	58%	14%	1.28	0.144	0.202	0.376	0.082	0.804	0.0776	0.1084	0.2021	0.0438	0.432
Friedrichs S1		8	10	47%	12%	1.40	0.137	0.190	0.229	0.062	0.619	0.1011	0.1407	0.1696	0.0459	0.457
Friedrichs S1		10	14	47%	12%	1.40	0.147	0.167	0.240	0.051	0.605	0.1087	0.1232	0.1775	0.0380	0.447
Friedrichs S2	4	0	2	97%	36%	1.01	0.485	0.085	1.128	0.133	1.832	0.0130	0.0023	0.0303	0.0036	0.049
Friedrichs S2		2	4	96%	35%	1.01	0.391	0.039	1.041	0.102	1.574	0.0141	0.0014	0.0376	0.0037	0.057
Friedrichs S2		4	6	96%	34%	1.02	0.326	0.035	0.928	0.099	1.389	0.0136	0.0015	0.0387	0.0041	0.058
Friedrichs S2		6	8	95%	31%	1.02	0.299	0.049	0.870	0.111	1.329	0.0154	0.0025	0.0448	0.0057	0.068
Friedrichs S2		8	10	94%	29%	1.03	0.292	0.071	0.956	0.115	1.434	0.0183	0.0044	0.0598	0.0072	0.090
Friedrichs S2		10	14	90%	25%	1.05	0.131	0.073	0.684	0.131	1.019	0.0142	0.0080	0.0744	0.0142	0.111
Friedrichs S2		14	18	84%	26%	1.08	0.156	0.083	0.669	0.119	1.027	0.0278	0.0147	0.1193	0.0212	0.183
Friedrichs S3	3	0	2	91%	33%	1.04	0.592	0.031	0.575	0.069	1.267	0.0530	0.0028	0.0515	0.0062	0.113
Friedrichs S3		2	4	88%	31%	1.05	0.345	0.030	0.555	0.066	0.997	0.0418	0.0036	0.0671	0.0080	0.121
Friedrichs S3		4	6	85%	27%	1.07	0.228	0.037	0.505	0.063	0.834	0.0371	0.0061	0.0821	0.0103	0.136
Friedrichs S3		6	8	83%	26%	1.08	0.197	0.034	0.479	0.060	0.770	0.0368	0.0063	0.0896	0.0111	0.144
Friedrichs S3		8	10	81%	25%	1.09	0.141	0.022	0.438	0.053	0.654	0.0289	0.0045	0.0894	0.0108	0.134
Friedrichs S3		10	14	75%	19%	1.14	0.120	0.036	0.357	0.048	0.560	0.0337	0.0101	0.1005	0.0135	0.158
Friedrichs S3		14	18	64%	20%	1.21	0.074	0.039	0.263	0.047	0.423	0.0322	0.0168	0.1138	0.0204	0.183

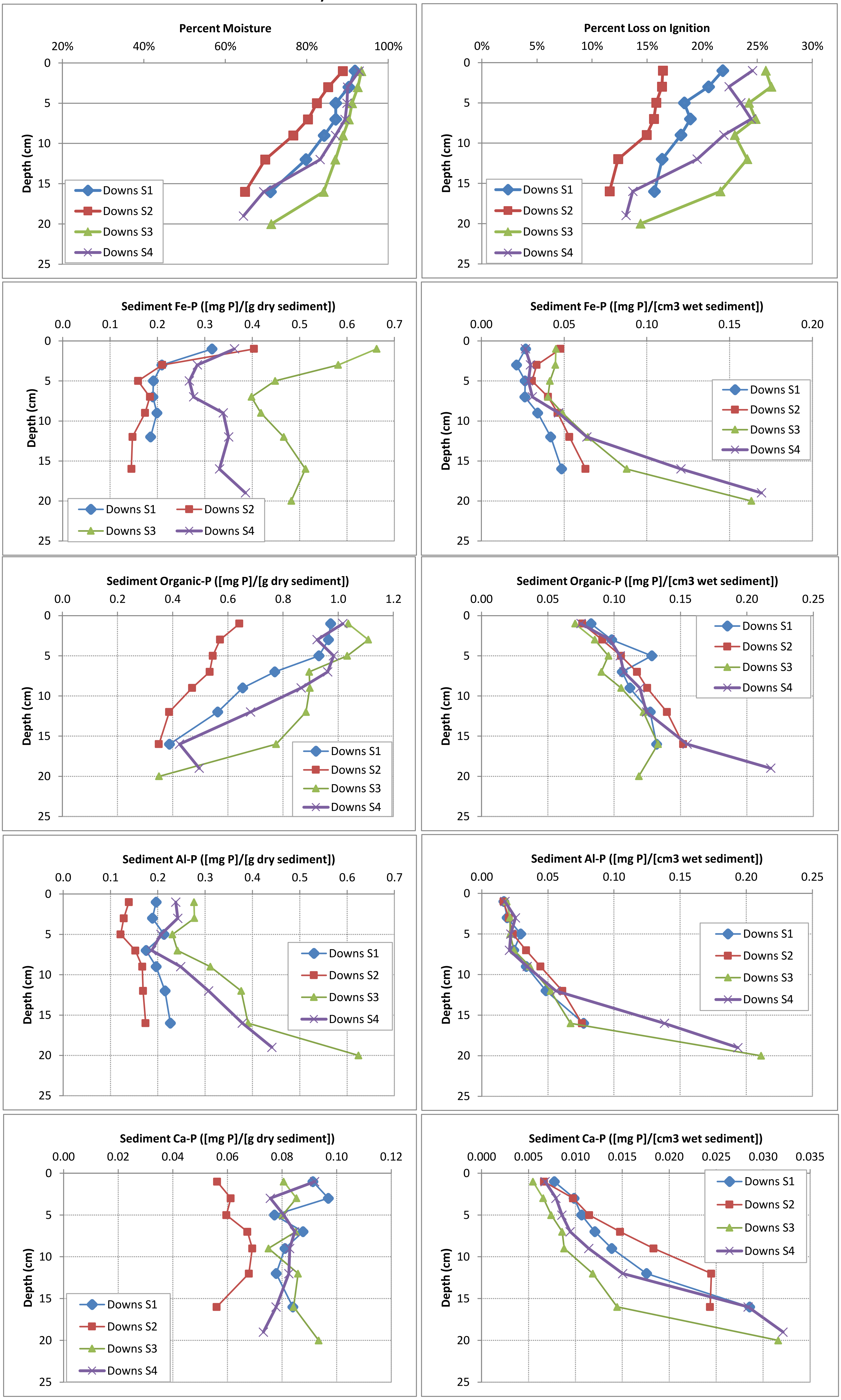
Table A1. Valley Branch Watershed District 2021 sediment phosphorus fractionation results.

Coring Location	Water Depth (ft)	Sediment Depth Interval (cm)		% Moisture	% LOI	Density (g/cm3)	Fe-P (mg P/g dry)	Al-P (mg P/g dry)	Organic-P (mg P/g dry)	Ca-P (mg P/g dry)	Total Extracted P (mg P/g dry)	Fe-P (mg P/cm3)	Al-P(mg P/cm3)	Organic-P (mg P/cm3)	Ca-P (mg P/cm3)	Total Extracted P (mg P/cm3)
Friedrichs S4	3	0	2	95%	43%	1.02	0.212	0.024	0.791	0.063	1.089	0.0098	0.0011	0.0368	0.0029	0.051
Friedrichs S4		2	4	91%	33%	1.04	0.098	0.015	0.497	0.048	0.657	0.0095	0.0014	0.0483	0.0046	0.064
Friedrichs S4		4	6	86%	29%	1.06	0.102	0.022	0.510	0.051	0.685	0.0150	0.0032	0.0752	0.0075	0.101
Friedrichs S4		6	8	73%	20%	1.16	0.246	0.043	0.340	0.040	0.669	0.0779	0.0136	0.1078	0.0128	0.212
Friedrichs S4		8	10	60%	16%	1.26	0.065	0.036	0.296	0.036	0.432	0.0323	0.0179	0.1473	0.0179	0.215
Friedrichs S4		10	14	50%	14%	1.36	0.024	0.034	0.238	0.027	0.323	0.0163	0.0231	0.1618	0.0184	0.220
Friedrichs S4		14	16	47%	13%	1.39	0.045	0.023	0.182	0.026	0.276	0.0331	0.0168	0.1346	0.0191	0.204
Friedrichs S5	4	0	2	98%	46%	1.01	2.942	0.160	1.358	0.120	4.580	0.0738	0.0040	0.0340	0.0030	0.115
Friedrichs S5		2	4	97%	44%	1.01	1.557	0.050	1.108	0.080	2.794	0.0513	0.0016	0.0365	0.0026	0.092
Friedrichs S5		4	6	96%	42%	1.02	0.703	0.031	0.912	0.062	1.708	0.0312	0.0014	0.0405	0.0027	0.076
Friedrichs S5		6	8	95%	40%	1.02	0.449	0.033	0.887	0.077	1.445	0.0232	0.0017	0.0458	0.0040	0.075
Friedrichs S5		8	10	93%	35%	1.03	0.314	0.043	0.786	0.079	1.222	0.0214	0.0029	0.0536	0.0054	0.083
Friedrichs S5		10	14	91%	32%	1.04	0.247	0.067	0.675	0.079	1.068	0.0225	0.0061	0.0614	0.0072	0.097
Friedrichs S5		14	18	91%	31%	1.04	0.214	0.080	0.634	0.098	1.027	0.0205	0.0077	0.0608	0.0094	0.098
Klawitter S1	14	0	2	94%	31%	1.03	0.791	0.070	1.266	0.100	2.228	0.0525	0.0047	0.0840	0.0066	0.148
Klawitter S1		2	4	92%	26%	1.04	0.427	0.055	1.029	0.099	1.610	0.0346	0.0044	0.0833	0.0080	0.130
Klawitter S1		4	6	90%	24%	1.05	0.288	0.062	0.822	0.108	1.279	0.0294	0.0063	0.0841	0.0110	0.131
Klawitter S1		6	8	88%	22%	1.06	0.258	0.084	0.715	0.109	1.165	0.0317	0.0103	0.0878	0.0134	0.143
Klawitter S1		8	10	87%	22%	1.07	0.256	0.102	0.675	0.109	1.142	0.0349	0.0139	0.0921	0.0149	0.156
Klawitter S1		10	14	90%	26%	1.05	0.286	0.107	0.731	0.120	1.243	0.0313	0.0117	0.0798	0.0131	0.136
Klawitter S1		14	18	87%	25%	1.06	0.271	0.107	0.672	0.115	1.165	0.0373	0.0147	0.0924	0.0158	0.160
Klawitter S1		18	22	83%	22%	1.09	0.269	0.179	0.561	0.133	1.143	0.0515	0.0342	0.1073	0.0255	0.218
Klawitter S2	10	0	2	93%	31%	1.03	0.561	0.081	1.113	0.111	1.866	0.0415	0.0060	0.0822	0.0082	0.138
Klawitter S2		2	4	92%	28%	1.04	0.291	0.067	0.927	0.109	1.393	0.0230	0.0053	0.0732	0.0086	0.110
Klawitter S2		4	6	91%	27%	1.04	0.256	0.092	0.787	0.122	1.258	0.0237	0.0085	0.0729	0.0113	0.116
Klawitter S2		6	8	89%	26%	1.05	0.254	0.085	0.696	0.117	1.151	0.0283	0.0094	0.0777	0.0130	0.129
Klawitter S2		8	10	86%	22%	1.08	0.266	0.148	0.608	0.139	1.160	0.0413	0.0230	0.0946	0.0216	0.180
Klawitter S2		10	14	84%	20%	1.09	0.253	0.186	0.573	0.129	1.141	0.0449	0.0329	0.1017	0.0229	0.202
Klawitter S2		14	18	72%	14%	1.17	0.288	0.347	0.474	0.119	1.227	0.0931	0.1124	0.1534	0.0385	0.397
Klawitter S2		18	22	53%	9%	1.36	0.196	0.389	0.223	0.132	0.940	0.1265	0.2516	0.1443	0.0854	0.608
Klawitter S3	10	0	2	92%	28%	1.04	0.493	0.044	0.776	0.062	1.374	0.0408	0.0036	0.0641	0.0051	0.114
Klawitter S3		2	4	92%	27%	1.04	0.280	0.100	0.921	0.112	1.413	0.0226	0.0080	0.0743	0.0090	0.114
Klawitter S3		4	6	90%	24%	1.05	0.238	0.108	0.643	0.121	1.110	0.0262	0.0120	0.0708	0.0133	0.122
Klawitter S3		6	8	89%	24%	1.05	0.240	0.103	0.617	0.120	1.080	0.0281	0.0121	0.0724	0.0141	0.127
Klawitter S3		8	10	87%	22%	1.07	0.238	0.109	0.623	0.122	1.091	0.0329	0.0151	0.0863	0.0169	0.151
Klawitter S3		10	14	83%	19%	1.09	0.245	0.162	0.533	0.148	1.088	0.0455	0.0302	0.0990	0.0275	0.202
Klawitter S3		14	18	76%	16%	1.14	0.258	0.255	0.506	0.125	1.144	0.0692	0.0686	0.1360	0.0337	0.307
Klawitter S3		18	22	73%	13%	1.17	0.277	0.301	0.409	0.128	1.116	0.0889	0.0969	0.1316	0.0412	0.359
McDonald S1	7	0	2	98%	49%	1.01	0.319	0.239	1.873	0.139	2.570	0.0053	0.0040	0.0314	0.0023	0.043
McDonald S1		2	4	97%	37%	1.01	0.175	0.097	1.051	0.058	1.382	0.0062	0.0034	0.0372	0.0021	0.049
McDonald S1		4	6	94%	30%	1.03	0.097	0.053	0.662	0.048	0.860	0.0064	0.0035	0.0438	0.0032	0.057
McDonald S1		6	8	91%	28%	1.04	0.085	0.050	0.555	0.039	0.729	0.0081	0.0047	0.0528	0.0037	0.069
McDonald S1		8	10	88%	27%	1.06	0.081	0.064	0.607	0.038	0.790	0.0103	0.0081	0.0773	0.0049	0.101
McDonald S1		10	14	81%	21%	1.10	0.048	0.058	0.501	0.034	0.640	0.0099	0.0118	0.1026	0.0069	0.131
McDonald S2	8	0	2	94%	24%	1.03	0.159	0.049	0.819	0.061	1.089	0.0098	0.0030	0.0505	0.0038	0.067
McDonald S2		2	4	90%	19%	1.05	0.079	0.047	0.554	0.051	0.732	0.0086	0.0052	0.0605	0.0056	0.080
McDonald S2		4	6	90%	22%	1.05	0.091	0.042	0.674	0.050	0.857	0.0096	0.0044	0.0708	0.0052	0.090
McDonald S2		6	8	87%	22%	1.07	0.092	0.058	0.501	0.058	0.710	0.0127	0.0081	0.0693	0.0081	0.098
McDonald S2		8	10	80%	13%	1.12	0.076	0.062	0.371	0.051	0.560	0.0175	0.0143	0.0852	0.0116	0.129
McDonald S2		10	14	74%	12%	1.16	0.053	0.075	0.327	0.043	0.497	0.0159	0.0223	0.0973	0.0127	0.148
McDonald S2		14	18	53%	7%	1.37	0.052	0.092	0.210	0.030	0.383	0.0337	0.0593	0.1361	0.0192	0.248

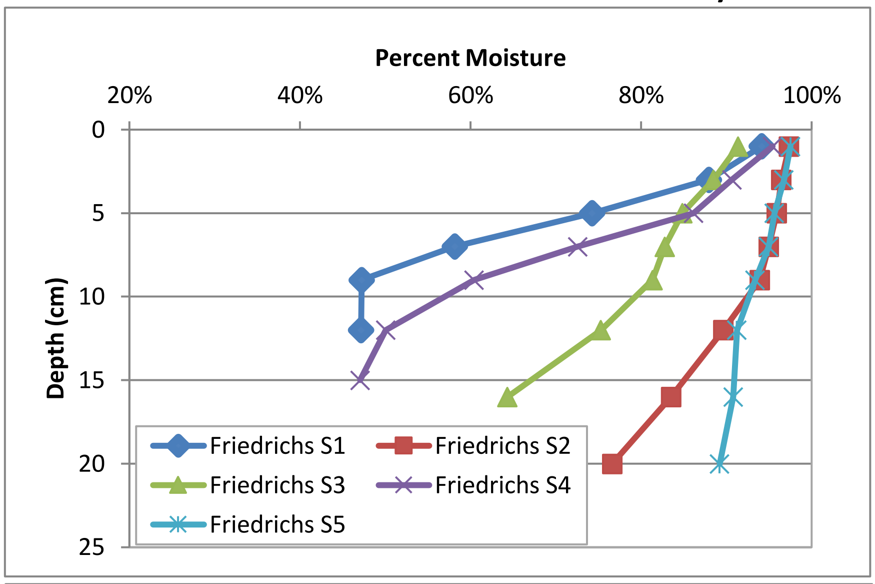
Table A1. Valley Branch Watershed District 2021 sediment phosphorus fractionation results.

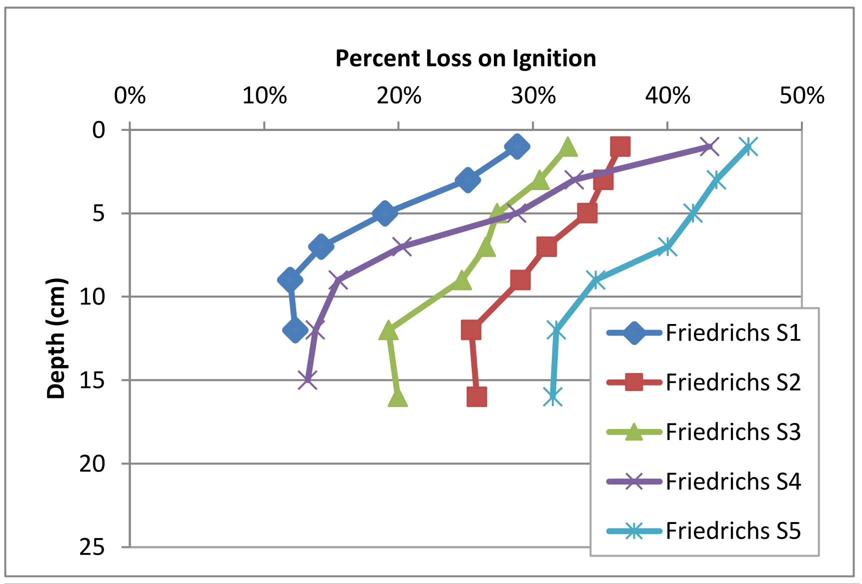
Coring Location	Water Depth (ft)	Sediment Depth Interval (cm)		% Moisture	% LOI	Density (g/cm3)	Fe-P (mg P/g dry)	Al-P (mg P/g dry)	Organic-P (mg P/g dry)	Ca-P (mg P/g dry)	Total Extracted P (mg P/g dry)	Fe-P (mg P/cm3)	Al-P(mg P/cm3)	Organic-P (mg P/cm3)	Ca-P (mg P/cm3)	Total Extracted P (mg P/cm3)
McDonald S3	14	0	2	97%	46%	1.01	1.748	0.110	1.650	0.110	3.618	0.0502	0.0032	0.0474	0.0032	0.104
McDonald S3		2	4	96%	41%	1.02	0.472	0.096	1.253	0.077	1.899	0.0210	0.0043	0.0557	0.0034	0.084
McDonald S3		4	6	94%	36%	1.02	0.386	0.108	1.045	0.076	1.615	0.0226	0.0063	0.0613	0.0045	0.095
McDonald S3		6	8	93%	31%	1.03	0.320	0.153	0.890	0.083	1.446	0.0244	0.0117	0.0678	0.0064	0.110
McDonald S3		8	10	91%	29%	1.04	0.272	0.167	0.733	0.078	1.250	0.0263	0.0161	0.0708	0.0075	0.121
McDonald S3		10	14	88%	23%	1.06	0.203	0.170	0.616	0.069	1.058	0.0268	0.0225	0.0814	0.0091	0.140
McDonald S3		14	18	85%	22%	1.08	0.169	0.175	0.616	0.065	1.025	0.0277	0.0288	0.1012	0.0107	0.169
McDonald S3		18	22	60%	21%	1.24	0.070	0.095	0.275	0.031	0.471	0.0351	0.0476	0.1375	0.0153	0.236
Reid S1	6	0	2	92%	27%	1.04	2.383	3.290	0.955	0.412	7.040	0.2075	0.2865	0.0831	0.0359	0.613
Reid S1		4	6	93%	36%	1.03	2.816	0.899	0.921	0.177	4.813	0.2135	0.0681	0.0699	0.0134	0.365
Reid S1		6	8	91%	35%	1.04	2.501	0.769	0.895	0.300	4.465	0.2234	0.0687	0.0799	0.0268	0.399
Reid S1		8	10	83%	25%	1.08	0.227	0.186	0.656	0.191	1.260	0.0412	0.0337	0.1190	0.0347	0.229
Reid S1		10	14	74%	21%	1.14	0.977	1.279	0.104	0.082	2.442	0.2892	0.3786	0.0309	0.0244	0.723
Reid S2	8	0	2	99%	74%	1.00	0.280	0.047	1.541	0.000	1.868	0.0019	0.0003	0.0107	0.0000	0.013
Reid S2		2	4	99%	58%	1.00	0.163	0.023	1.744	0.023	1.953	0.0024	0.0003	0.0258	0.0003	0.029
Reid S2		4	6	97%	53%	1.01	0.084	0.012	1.114	0.024	1.234	0.0021	0.0003	0.0283	0.0006	0.031
Reid S2		6	8	95%	43%	1.02	0.086	0.014	1.034	0.029	1.163	0.0039	0.0007	0.0473	0.0013	0.053
Reid S2		8	10	93%	37%	1.03	0.073	0.013	0.807	0.030	0.922	0.0054	0.0010	0.0603	0.0022	0.069
Reid S2		10	14	92%	38%	1.03	0.064	0.014	0.947	0.037	1.061	0.0054	0.0012	0.0805	0.0031	0.090
Reid S2		14	18	86%	32%	1.06	0.058	0.014	0.826	0.032	0.931	0.0087	0.0022	0.1233	0.0048	0.139

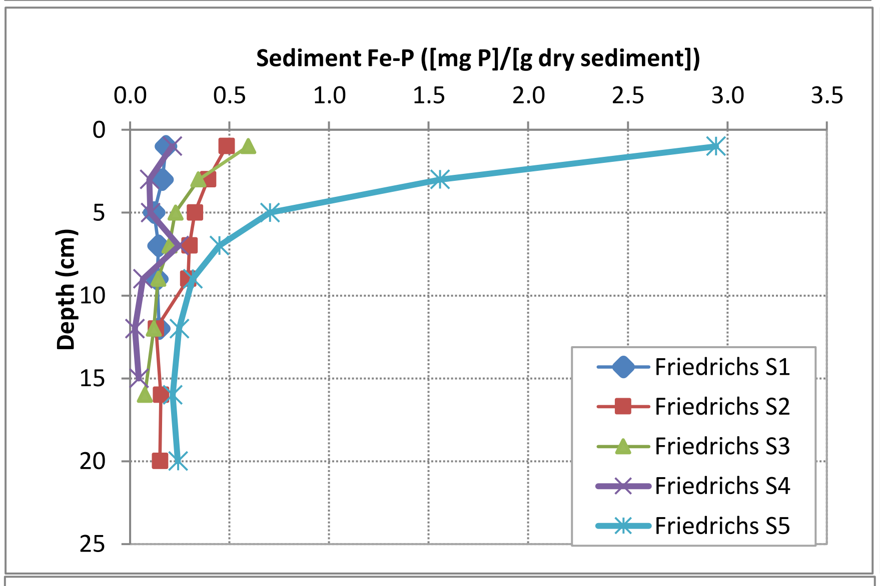
Downs Lake Sediment Core Fractionation Summary

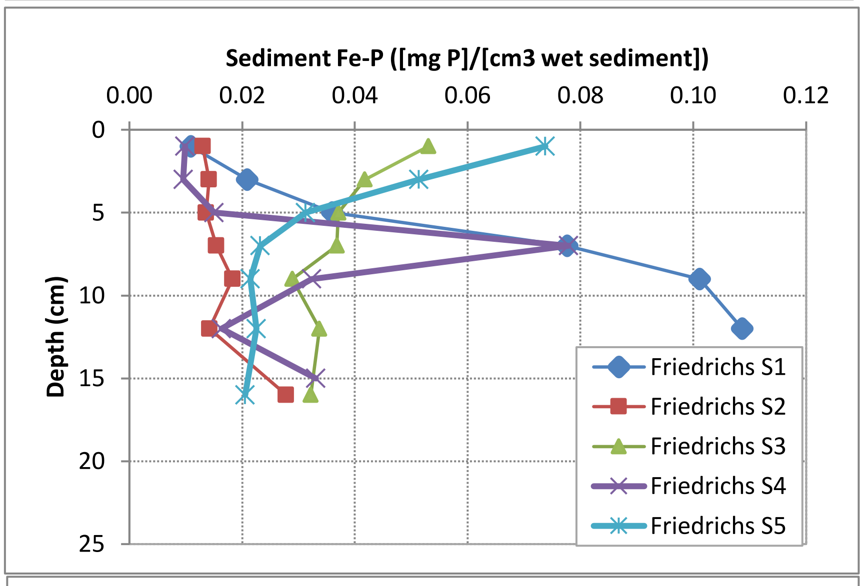


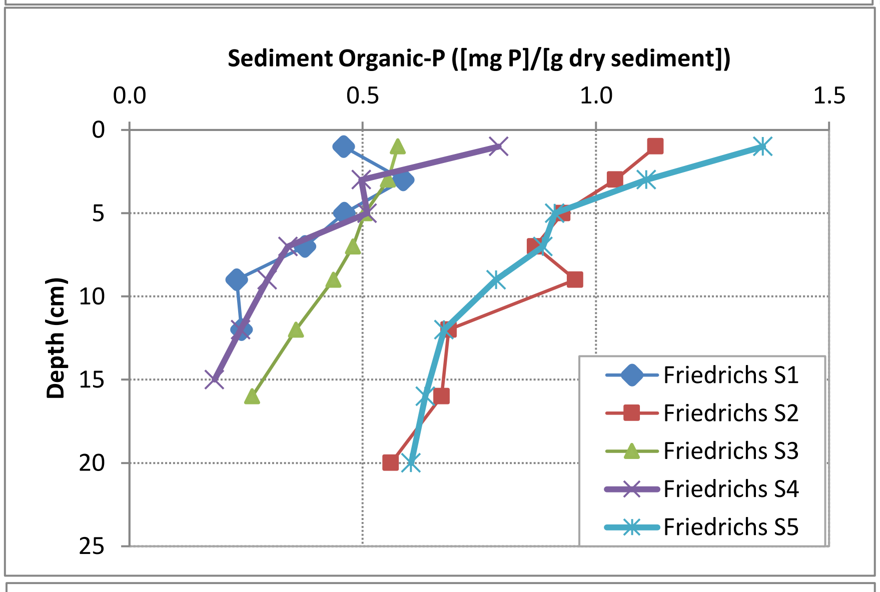
Friedrich's Pond Sediment Core Fractionation Summary

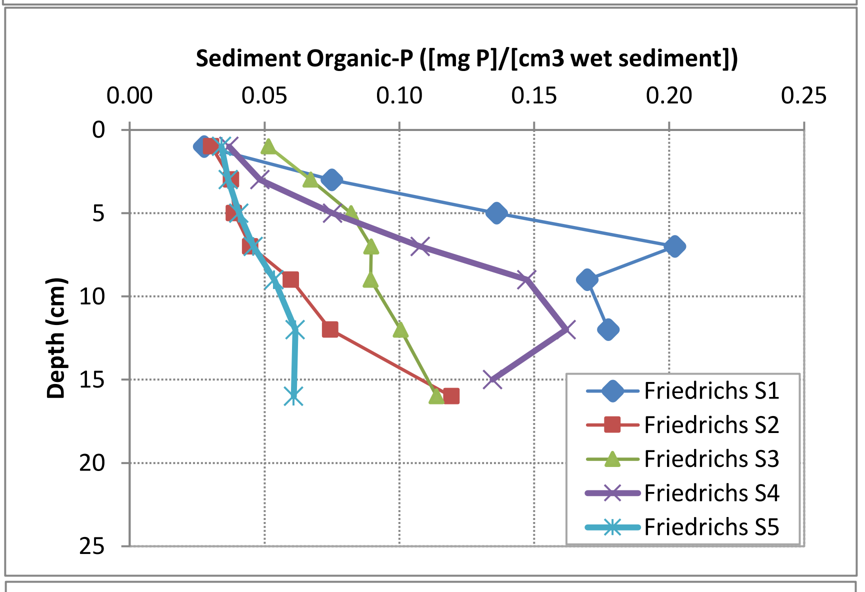


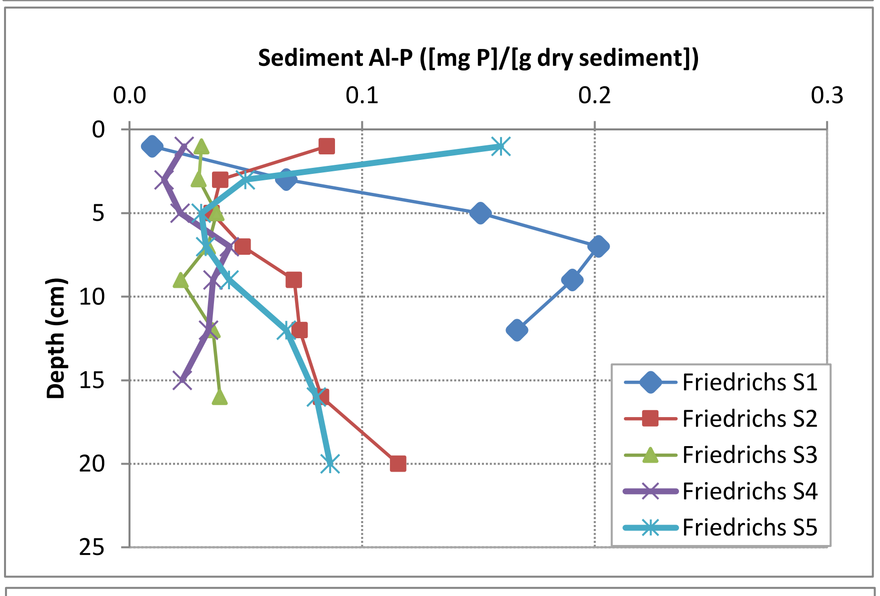


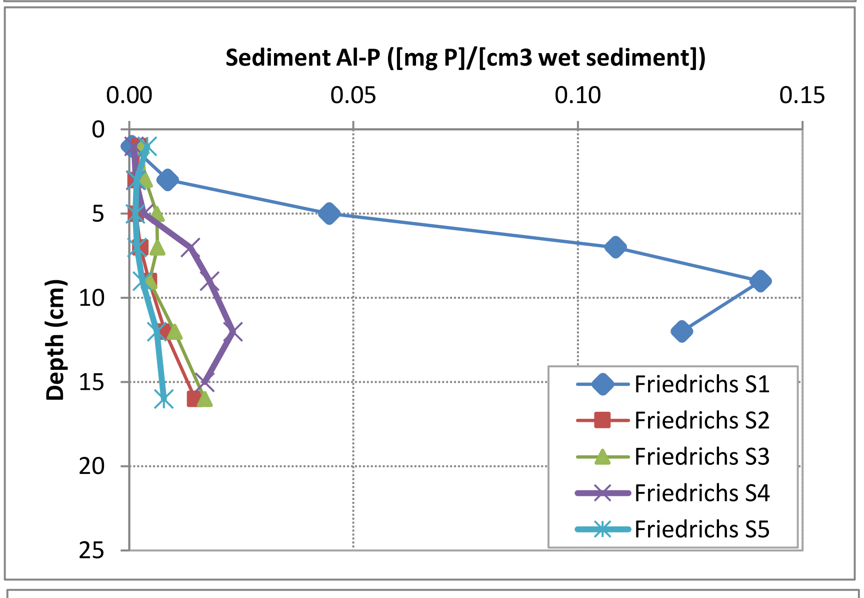


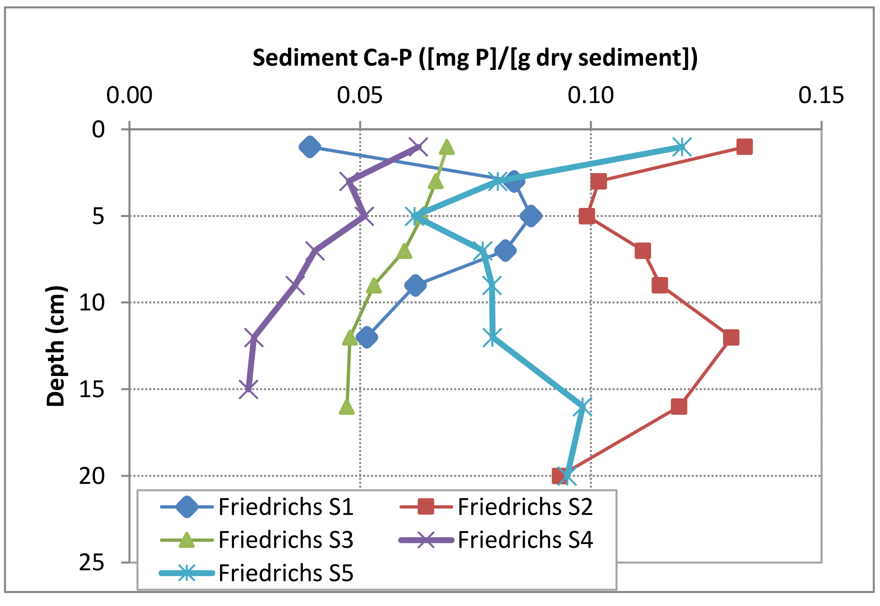


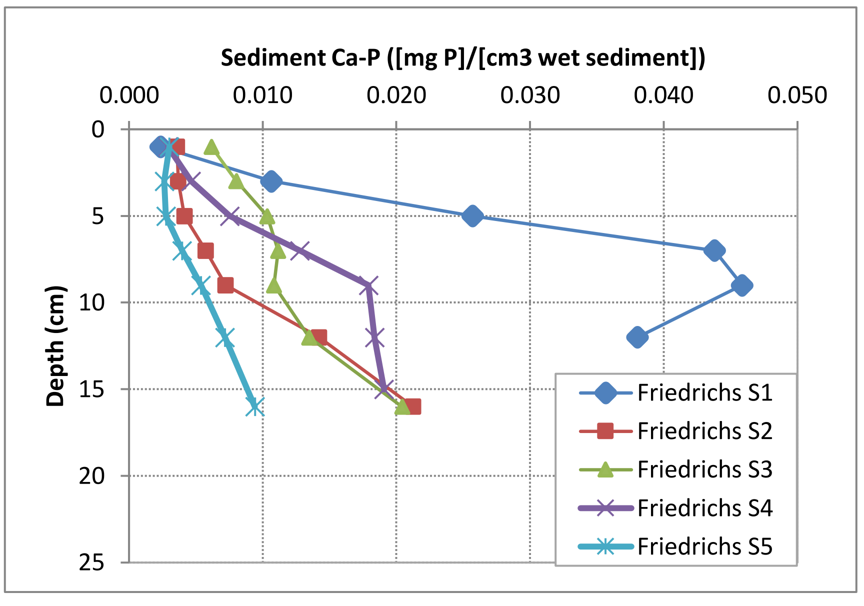




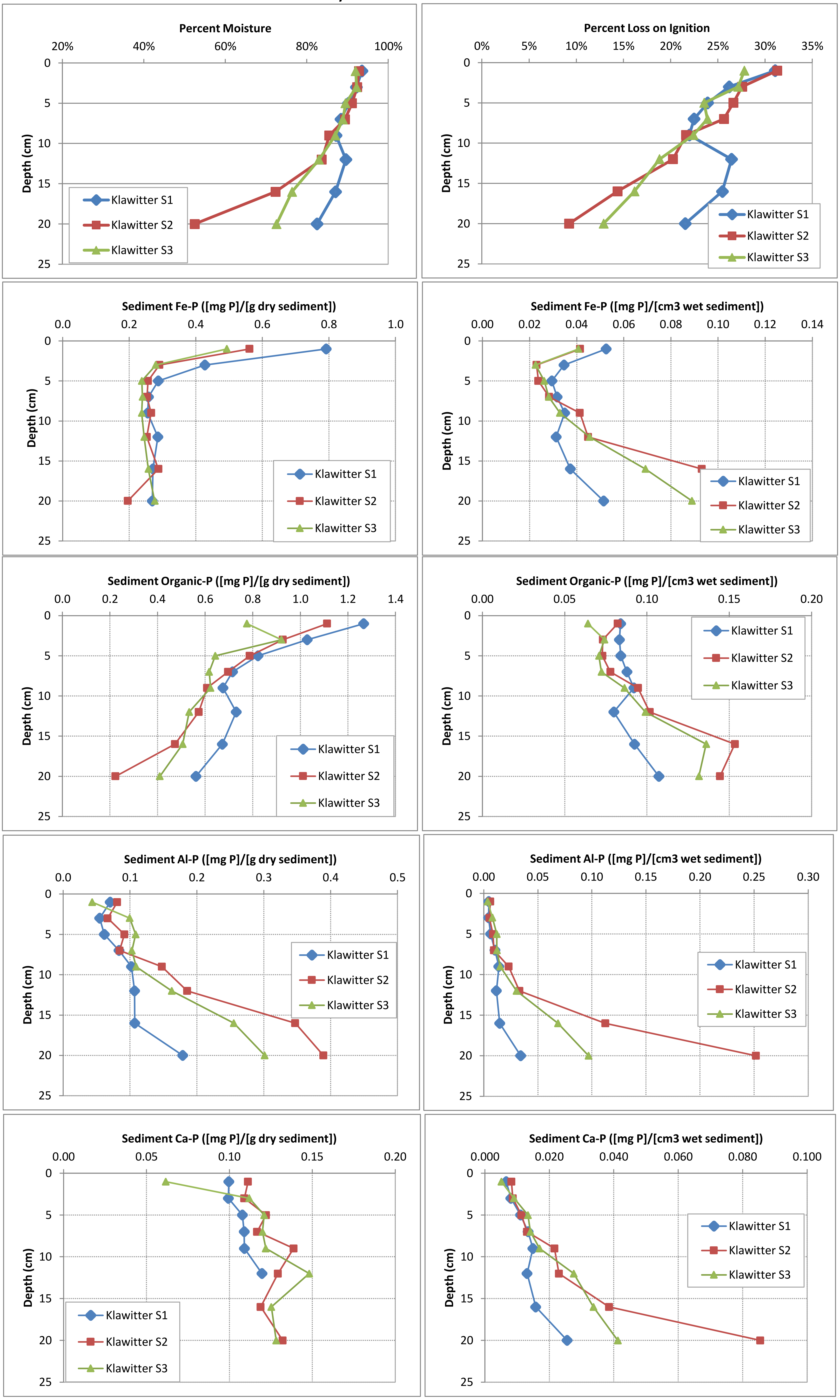




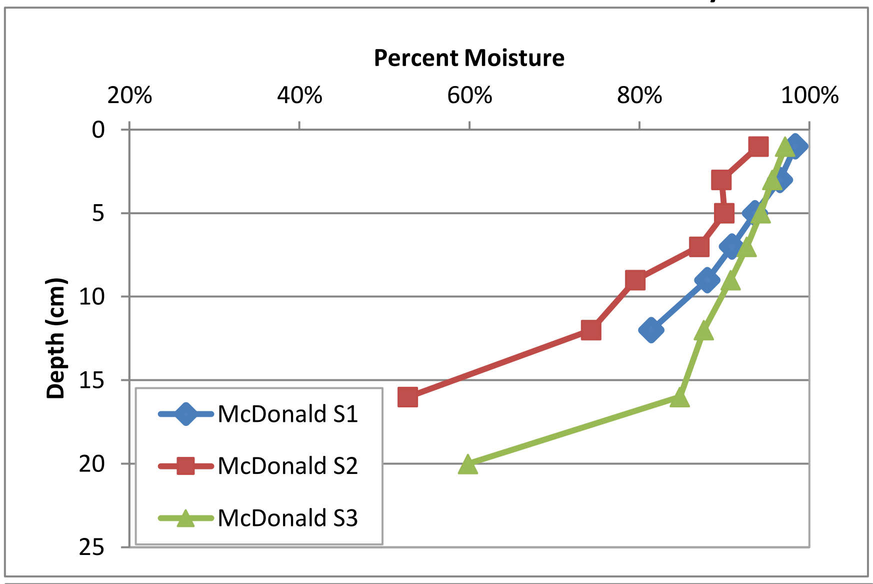


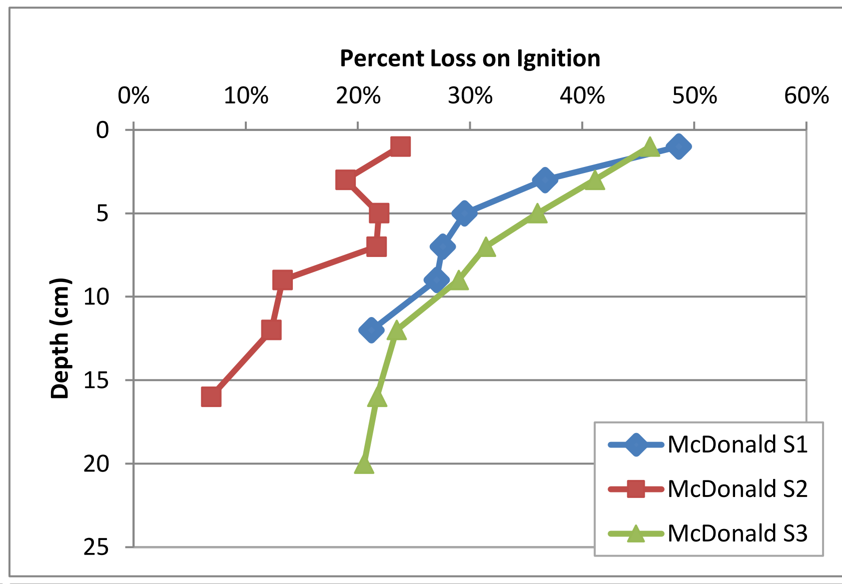


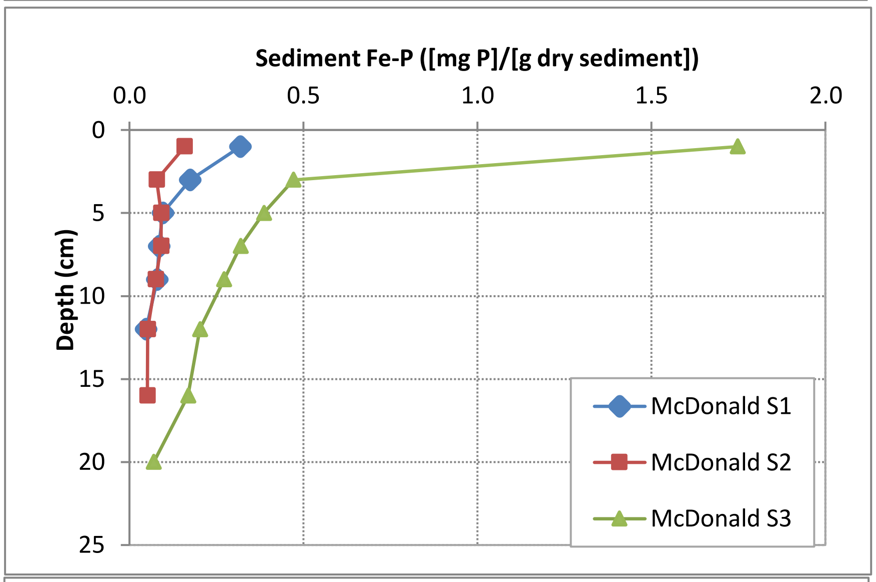
Klawitter Pond Sediment Core Fractionation Summary

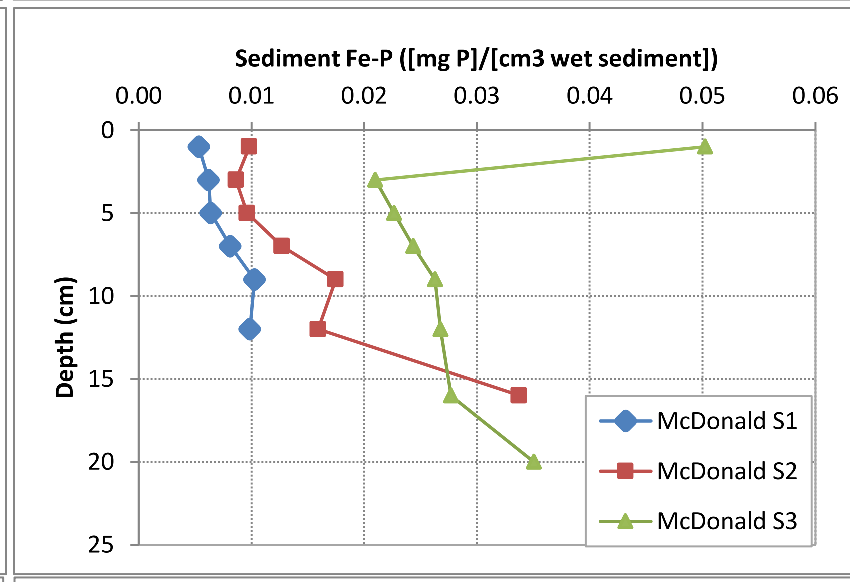


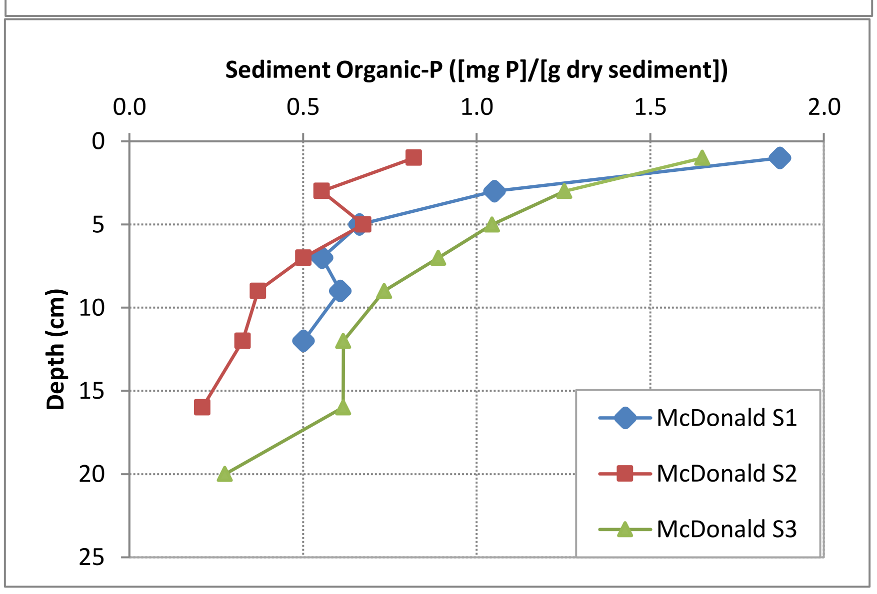
McDonald Lake Sediment Core Fractionation Summary

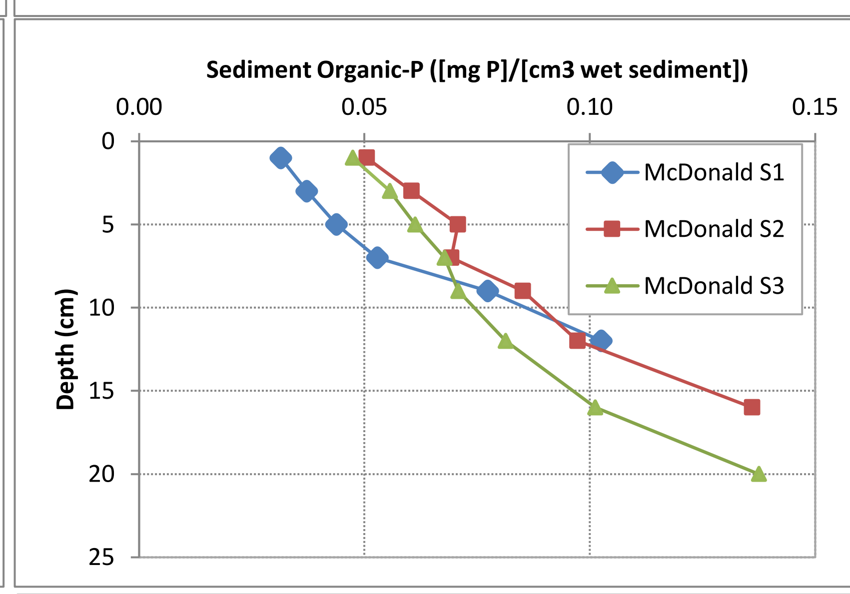


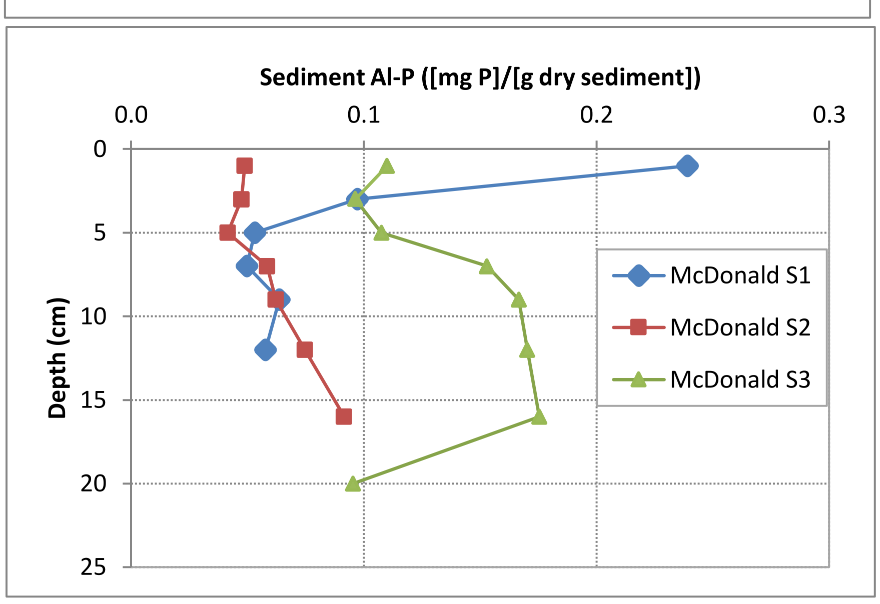


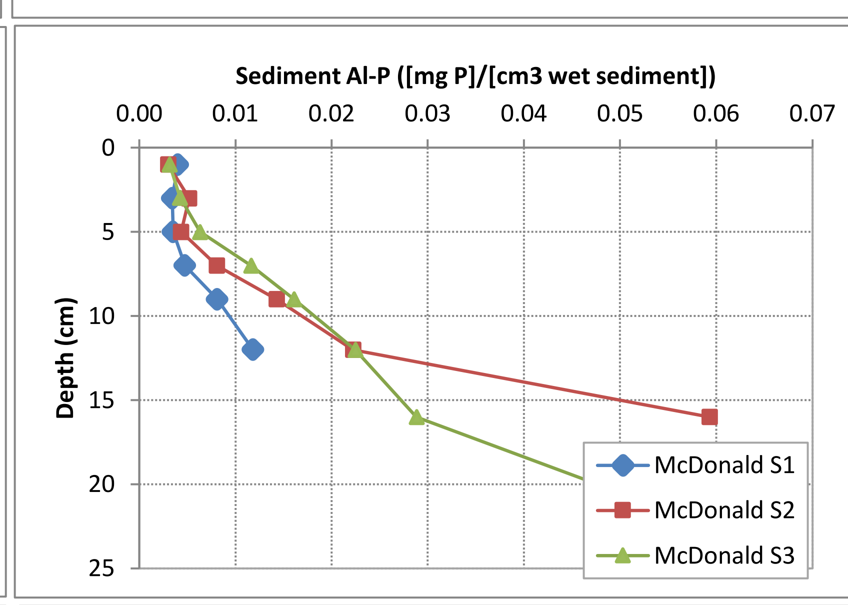


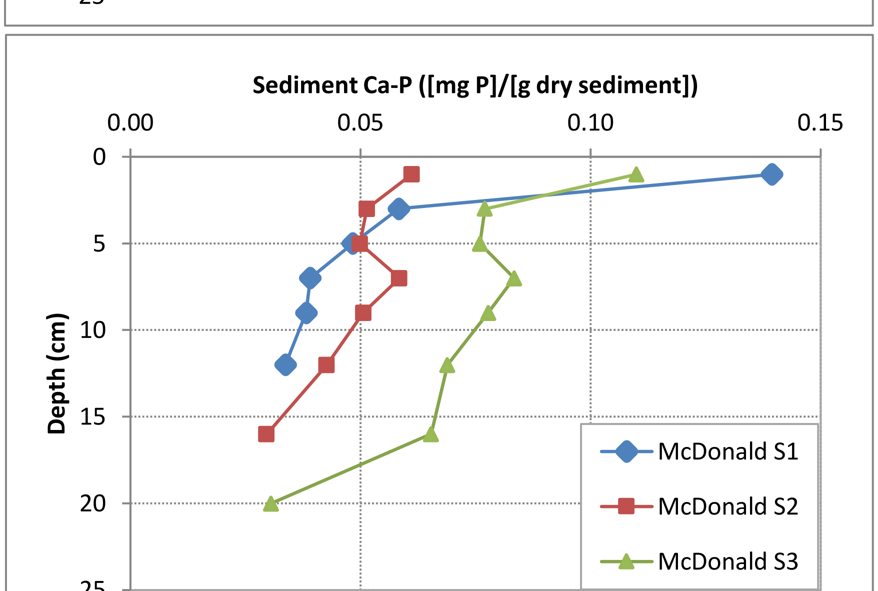


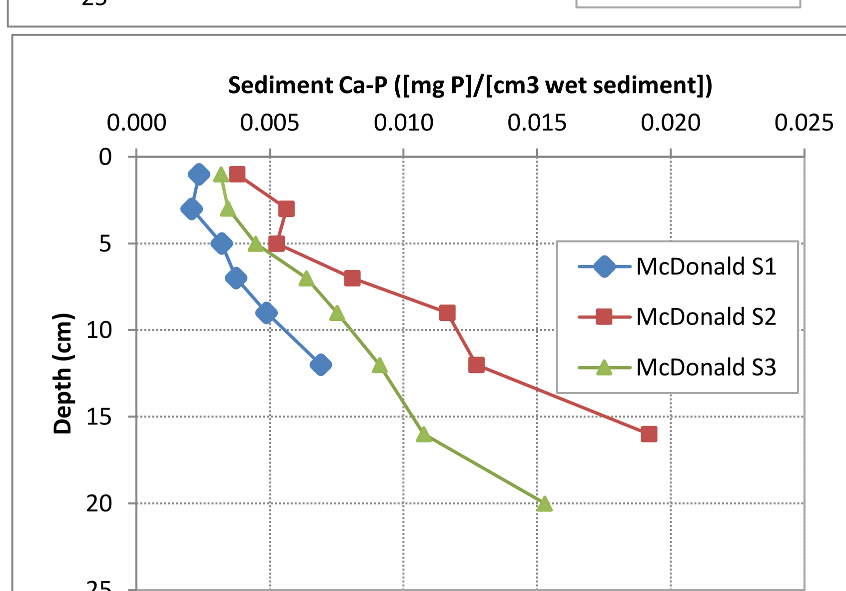




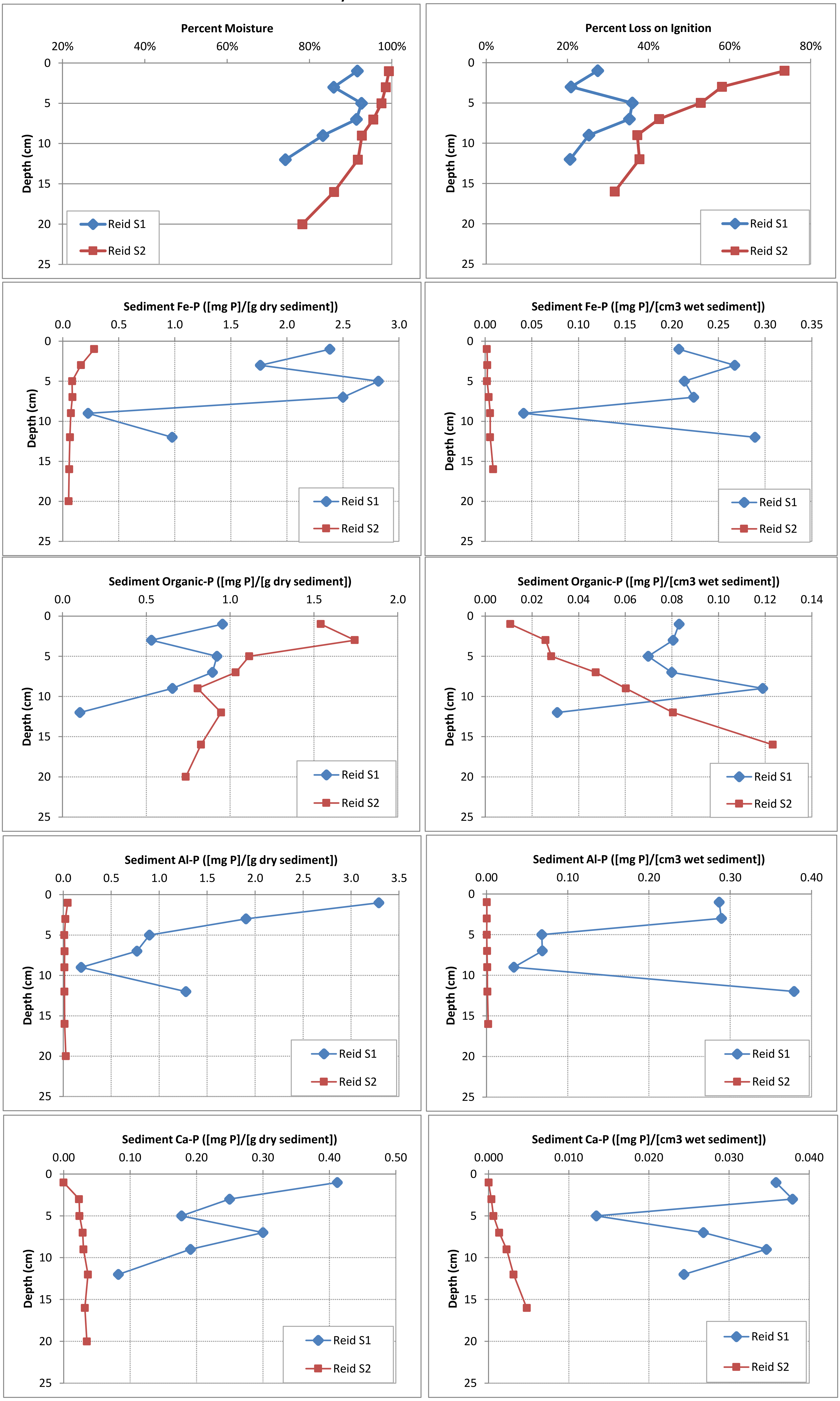


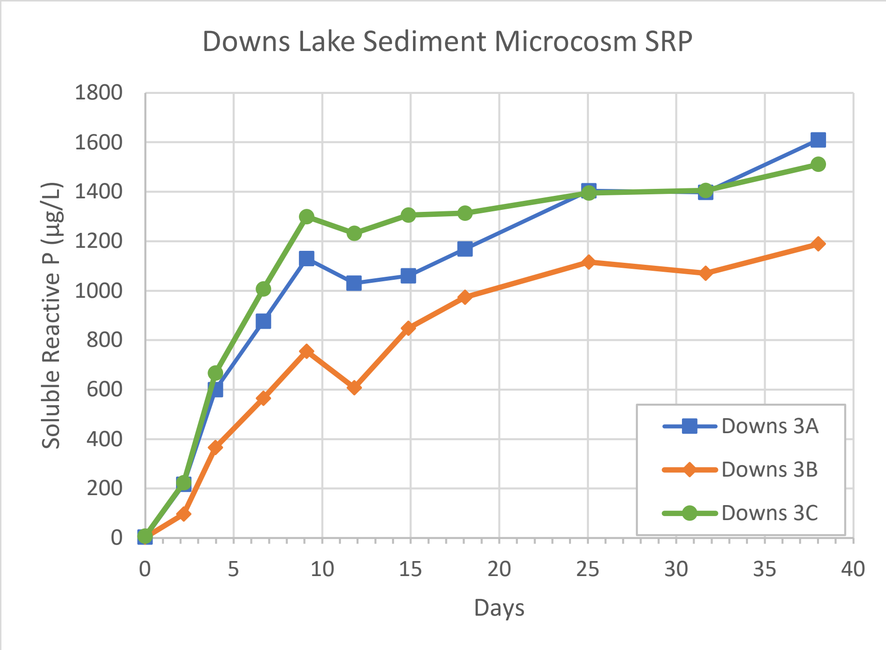


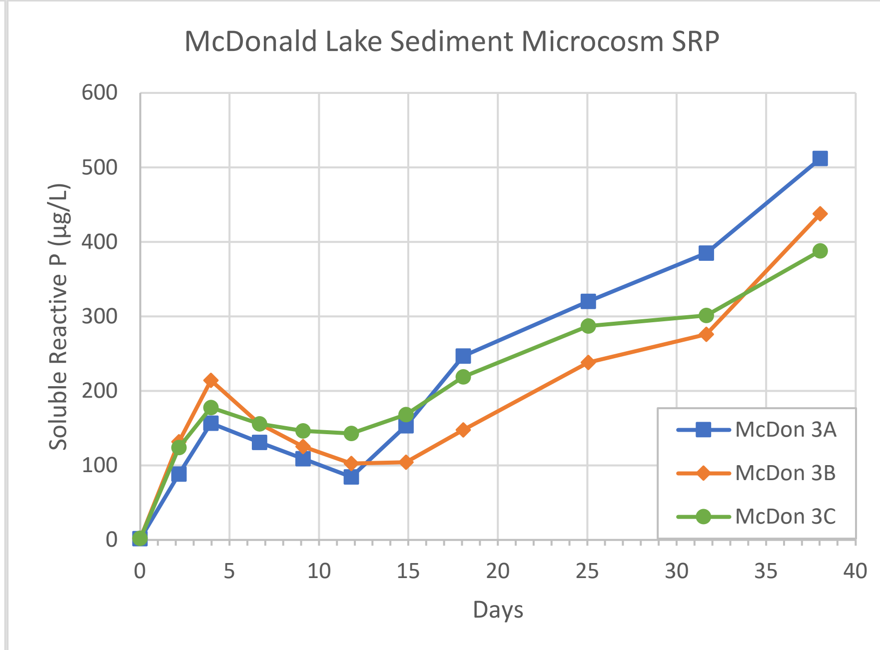


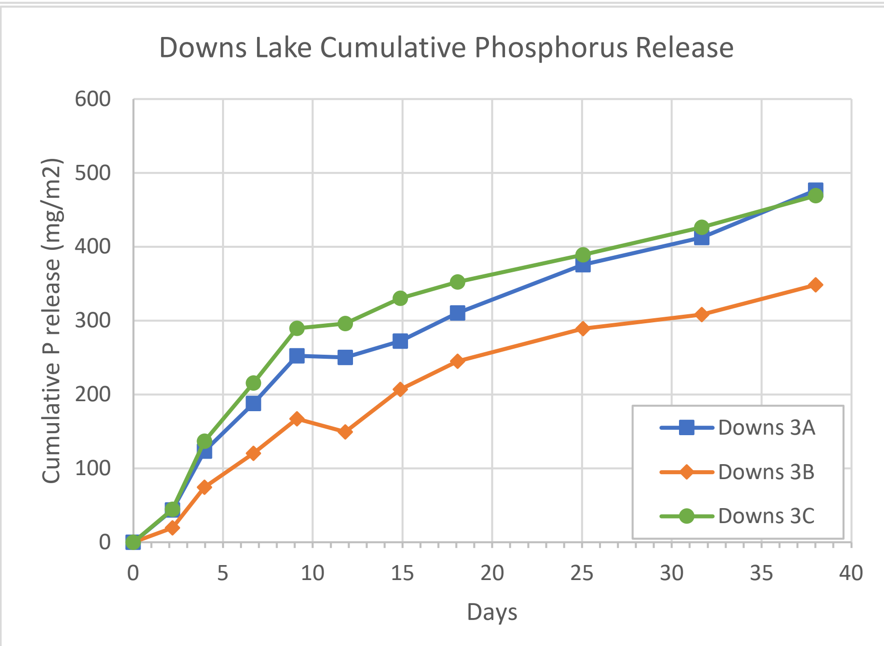


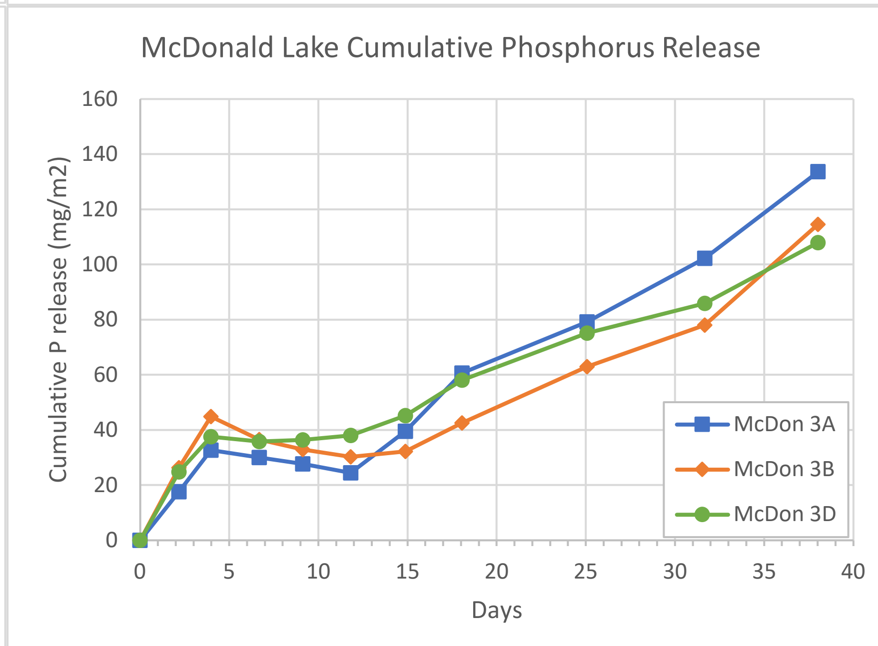
Reid Park Pond Sediment Core Fractionation Summary




Downs Lake Sediment Microcosm SRP
Soluble Reactive P (µg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
Days
Downs 3A
Downs 3B
Downs 3C


McDonald Lake Sediment Microcosm SRP
Soluble Reactive P (µg/L)
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
Days
McDon 3A
McDon 3B
McDon 3C


Downs Lake Cumulative Phosphorus Release
Cumulative P release (mg/m2)
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
Days
Downs 3A
Downs 3B
Downs 3C


McDonald Lake Cumulative Phosphorus Release
Cumulative P release (mg/m2)
160
140
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35
40
Days
McDon 3A
McDon 3B
McDon 3D