COHA Cluster #3 Project #7 Final Technical Report

Minimizing Horticultural Impacts on Surface Water Quality to Encourage Re-use Through Enhanced Pond Management

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Executive Summary

Irrigation water quality and quantity is a top research priority for the ornamental horticulture sector. Particulates and nutrients (particularly phosphorus) in shallow, warm ponds support the growth of excessive amounts of aquatic weeds, algae, and cyanobacteria. This excessive biological growth in ponds results in clogging of intake filters and expensive maintenance issues. This project demonstrated that novel methods of controlling nutrients, especially nitrogen and phosphorus, at and before the irrigation pond level can ultimately improve water quality for re-use purposes and decrease the risk of these nutrients leaving the farm. The main objectives of the project were to:

1. Define, collect, and analyze information about the current levels of nutrients entering and held in ponds in selected agricultural landscapes and production systems.
2. Test and investigate the efficacy of enhanced pond management practices at farms.

Overall Findings

While some clear results were obtained through this research, some technologies showed only marginal success. These results may be a factor of the pond characteristics, mesocosm design, and/or sampling period and treatment duration. Every pond is different, and caution must be taken when extrapolating results from this study to other ponds.

Pond water quality and measurement: In general, traditional water quality analyses (nutrient parameter testing) illustrated a picture of very good water quality: low phosphorus and potassium levels, and often non-detectable nitrate-nitrogen, and overall low salts. However, despite the apparent 'excellent' water quality, phytoplankton populations were excessive to the point of having blooms of blue-green (cyanobacterial) and green algae in several of the sites' ponds. Evaluation of water quality was more representative of actual conditions when biological measurements were made with a multiparameter YSI unit, including phycocyanin and chlorophyll *a* (pigments present in cyanobacteria), and optical dissolved oxygen. Phytoplankton levels measured indirectly through pigment levels correlated well with microscopic diagnostics of the population dynamics over the seasons.

Aeration: Aeration can be an effective tool in ponds for increased availability of oxygen throughout the water column and facilitating aerobic decomposition of organic matter in the sediment. However, in this study, water quality differences were marginal, and hence insufficient to make definitive conclusions. Long-term (i.e., multi-year) aeration with nanobubbles should result in water quality improvements and sediment reduction and be more effective that traditional aeration (which could still be useful in very shallow ponds).

Physical Shading/Covers: Solid coverings appear to be an effective way to limit phytoplankton growth by preventing light from entering the water column. Since covering may lower oxygen levels in the water column, aeration to improve oxygenation should be used in combination with covering.

Aquatic vegetation: In the project study, aquatic vegetation used as covers were highly variable in their effectiveness. Duckweed did not perform as well as expected, though the restricted conditions in the mesocosms may have affected the results. Anecdotally, the trial ponds with the best water quality had either extensive duckweed coverage or substantial macrophytes populations. Full coverage of water hyacinths had a significant impact on water quality. *Pontedaria* plantings were not extensive enough by the end of the study to show any effect. Seasonal variation, annual inputs, water flow rates, and condition of the pond prior to introducing vegetation all likely affected the results. There is potential for full plant coverings to be effective at minimizing light levels, and/or consuming nutrients, thereby improving pond water quality by limiting phytoplankton growth. However, annual maintenance and harvesting of the plants is required.

Phosphorus Removal Compounds: Insufficient improvements were observed to recommend wollastonite or ClariPhos™ treatment in ponds with generally low total P levels in the water column. Mesocosm design and/or volume may also be factors in the efficacy of these treatments.

Sediment Degradation Compounds: Bacterial cultures specifically chosen to address water quality issues appeared to have a beneficial impact in this study, particularly on total P, chlorophyll *a* and phycocyanin levels. However, it should be noted that to incorporate these treatments in full-scale irrigation ponds would cost 10's of thousands of dollars each year. These products have potential for supporting biotic health in ponds, but more sustainable alternatives are desirable.

Sonication: There is insufficient information from this study to comment on the effectiveness of sonication. Bloom-forming cyanobacteria have gas vesicles which provide buoyancy and result in the formation of surface scums. Sonication will collapse these vesicles resulting in visually better water quality and may result in substantial cell death. However, it does not address dormant spores (akinetes) or resting stages residing in the sediments and does not remove nutrients from the water column. Sonication may be useful for new ponds or silos to maintain water clarity, but in existing ponds with significant nutrients and high organic matter sediments, it should be combined with other technologies to enhance aerobic decomposition.

Media Beds and Hybrid Treatment Swales: Shallow woodchip media beds have clear potential for removal of nitrate-N from fertilizer and production leachate prior to reaching a watercourse. The application of this technology to commercial operations should be promoted as a best management practice to prevent nutrient runoff from reaching natural watercourses. Shallow hybrid treatment swales, acting passively with a gentle slope, have great potential to remove nitrate-N and P from outdoor field production water. Water quality exiting the HTS in this study still exceeded commonly accepted guidelines for P but met the requirement for N. Design adjustments for shallow systems need to be tailored to each site's specific inputs, layout and ultimate discharge quality desired. These systems do not require any plumbing, however, still require a significant footprint along the edge of field, depending on the complexity of the media choices.

Key Messages

1. Keep your clean water clean. Separate fresh water (e.g., rainwater) from recirculated water where possible.
2. Prevent nutrient loading through:
    a. production practices that mitigate fertilizer runoff (e.g., fertilizer choices, rates, & timing, and irrigation practices), and
    b. pre-pond treatments such as hybrid treatment swales or media based (e.g., woodchips) growing areas.
3. Combinations of treatments for maintaining or improving pond water quality are likely more successful than any individual treatment. Depending on the pond characteristics, covering, aeration and sediment degradation treatments may be suitable options.
4. Pond water quality assessments in low-nutrient ponds should include both nutrient parameter testing (complete analysis) as well as biological parameters such as chlorophyll *a* and phycocyanin levels.

Background

Over 90% of container nurseries, approximately a third of all floriculture greenhouses, and most sod and turf grass operations depend on irrigation ponds for their water source. Capture of stormwater followed by re-use represents a critical process to conserve stormwater and limit their impact on the environment. However, particulates and nutrients (particularly in nursery and turf facilities) can be present in the recaptured water, leading to inferior water quality. Further, as summer progresses, evaporation, increased water demand, and sedimentation lead to lower water levels and deteriorating water quality as water levels approach the bottom of the pond. Stratification and decomposition of organic matter in the pond create a low oxygen environment near the bottom, resulting in phosphorus release from the sediments, commonly resulting in cyanobacterial (blue-green bacteria) blooms during warmer temperatures. Improvements to irrigation pond water quality also benefit the environment as the vast majority of these ponds can overflow to natural watercourses.

Practical solutions implemented by farms for agricultural pond management have focused on simple aeration, pond covering, dredging, and biocide treatment, which have had variable levels of success. Without clear standards of practice and/or application, results vary widely between farms.

Aeration is commonly used in ponds, but the effectiveness varies as there are no standards for installation. The government of Alberta has a useful factsheet on aeration of ponds using compressed air (Alberta Agriculture and Forestry, 2008), but there is little literature on the effectiveness of traditional aeration, despite this being one of the primary technologies employed by farms in Canada to manage water quality.

Pond covers and shading have also shown promise for improving water quality. Maestre-Valero and others (2013) found a significant reduction in biological activity (chlorophyll *a* levels and bacterial activity) with a suspended pond cover. In another Spanish study, covers not only improved turbidity but were shown to decrease operational costs related to filter maintenance (Martinez-Alvarez and Maestre-Valero, 2015). Commercial shading chemicals can provide improved water quality by reducing photosynthetic production of biomass within the pond but may have negative implications for water re-use and were not as effective as physical covers (Martinez-Alvarez and Maestre-Valero, 2015). However, physical covering of ponds requires higher capital costs and continued maintenance. Using plants as a cover has also been explored, for example, floating islands/wetlands (e.g., PhytoLinks™) provide a shading function as well as actively removing nutrients from the water (White *et al.*, 2008). Duckweed (*Lemna minor*) covering a pond surface was also found to be quite effective in acquiring inorganic nitrogen (Cedergreen and Madsen, 2002).

Commonly promoted treatments for improving pond water quality include physical removal of sediments and chemical treatment. Several researchers found that dredging had no impact (Juan *et al.*, 2012; Bonachela *et al.*, 2013), and biocides (mainly copper sulphate and potassium permanganate) negatively impacted water quality through increased sediment levels (Bonachela *et al.*, 2013). The use of chemicals in surface waters in Canada is generally not recommended without provincial/territorial Ministry approvals.

Conversely, in shallow ponds, aquatic vegetation has been demonstrated to remove nutrients from water and sediments, as well as enhancing oxygen levels in the water resulting in better water quality (Bonachela *et al.*, 2013). In Spain, the use of submerged aquatic vegetation such as charophytes (a group of green algae) decreased Chlorophyll *a* levels, as well as slightly improving (decreasing) total suspended solids (Bonachela *et al.*, 2013; Juan *et al.*, 2014). In China, wetland species of plants were tested for their ability to remove nitrogen and phosphorus from pond water through bench-scale testing, with *Pontederia cordata* and *Iris pseudacorus* being quite effective (Li *et al.*, 2015). Generally, any aquatic vegetation must be harvested on a regular basis to remove nutrients and there is always the potential for certain species of plants or algae to overtake the pond. Again, most producers tend to remove aquatic plants and algae from ponds but maintaining a balanced population might be a better approach. However, using submerged aquatic vegetation for pond water management has not been evaluated under Canadian climate conditions.

Engineered (artificially constructed) wetlands have also been employed to manage water quality (White *et al.*, 2011) but they require a large footprint and are typically used for discharge/infiltration but not for recirculation purposes. Particulate removal through settling (as a result of slower water movement) is one of the primary functions of these wetlands, but the effectiveness of these wetlands for nutrient removal depends on physical harvesting of plant biomass on a regular basis (Prein, 2005). Other physical treatments such as phosphorus removal materials such as kaolinite and slag or by managing soil phosphorus levels have been tested, however these solutions are not practical for container nursery and greenhouse applications where plants are not grown in the ground (Penn *et al.,* 2017). Nutrient removal in the growing beds or non-production area runoff water is of particular interest and could potentially be accomplished by placing selected media in the flowpath of runoff before it reaches the pond, as well as in-pond direct treatments. In the United States, the use of edge-of-field woodchip media beds at various retention times was investigated for preventing excessive fertilizer runoff from field crop production (Schaefer *et al.*, 2021), and the Upper Thames River Conservation Authority recently produced a guidance document for woodchip biofilters for edge-of field fertilizer management (UTRCA, 2019). Pre-pond treatment using woodchips and various media could be adapted for container ornamental plant production runoff management.

Methodology & Technology Descriptions

General Testing Parameters – In-Pond Treatments

Testing the performance of various in-pond technologies usually involves bench scale or whole pond treatments. With bench-scale laboratory testing, controls and replicates are possible, although less representative of full-scale ponds so the results can be challenging to extrapolate. Whole pond treatments are typically performed without any controls as finding two identical ponds is extremely rare. In this project, the research team adapted a concept for in-pond treatment cells from Ozkan's research thesis in Turkey (2008). The plastic tubes, termed mesocosms, were used to provide replicate, similar volume treatment zones within a single lake.

Mesocosms for this study were designed to be 1.25-1.5m in diameter, using cattle/field wind-barrier (both 75 and 80% wind block, available through Custom Tarps Covers ETC LLC, NE, USA) geotextile for the cylindrical vertical walls. Sections of material and the upper and lower ring channels were sewn with a Hanchen bag sewing machine (Amazon.ca). The depth (and therefore volume) of the mesocosms were determined by the depth of the pond – which varied from 1-2.5m across the sites. Volume varied between 1 and 3.5m^3. The upper ring of the mesocosms were supported by a sealed, hollow 1.5" 75psi poly pipe inserted into a sewn channel and pool noodles were attached later with zip ties. The lower ring was made of an open 1-1.5" 75psi poly pipe with openings to allow water to fill the pipe and weighted down with bricks or construction blocks. Wires connected to the weights improved the ability to pull up the mesocosms at the end of each sampling season. The mesocosms were secured to docks or metal poles driven into the sediment. Despite several replicate mesocosms being installed at Site B in 2021, replication was challenging due to the size and configuration of ponds at both Site B and C, and the significant differences in water quality between the ponds. Standard deviation was calculated where replicates occurred, or over seasons from similar sampling sites.

Traditional testing of pond water quality includes grab sampling of the surface of the pond, and analysis of key nutrient parameters. However, experience with analysis of irrigation and source ponds in previous studies (West, 2013; West, 2014) suggested that very low levels of nutrients were to be expected in nursery and floriculture collection waters. Therefore, a multiparameter meter (YSI ProDSS multiparameter digital water quality meter with a 4-port probe assembly from Xylem Inc., termed "YSI" throughout) was purchased to allow for *in situ* measurements of additional parameters that would demonstrate biological activity.

Water Quality Sampling Program

In 2019, preliminary sampling took place to test the mesocosm design and collect baseline water quality data from potential research sites (data not reported). Water samples (grab) were taken every two weeks at the surface of ponds in 2020 and 2021 at relevant drainage points, and within control and treatment mesocosms between May and October, and grab-type water column sampling of ponds and treatment cells (using a 2m sludge judge sampler system) occurred between August and October of 2021. Water samples were maintained in a cooler until transported to a laboratory for general nutrient testing (Greenhouse Complete package from A & L Canada Laboratories Inc., London, ON), plus ortho-phosphate analysis on specific samples. During the initial COVID-19 lockdown in March and April 2020, some benchmarking samples were submitted for similar analysis to ALS Environmental (Waterloo, ON).

Multiparameter Water Quality Testing

In-situ water quality parameter testing involved utilizing a portable/handheld water quality multiparameter meter (YSI) to test for electrical conductivity, optical dissolved oxygen, turbidity, temperature, chlorophyll *a* and phycocyanin levels directly in the ponds at specific depths (surface, mid-water column, and bottom). Data was logged concurrently with grab water sample collection.

Sediment Sampling Program

Sediment (grab) samples were collected at least twice per season in 2020 and 2021 using an Ekman Field sediment sampler (15cm). Attempts with a 3.5m sediment corer (Hoskin Scientific Ltd.) were less successful (except at Site C-H). Where sites had very loose sediment (e.g., Site B and E), a manual fuel suction pump was utilized (Canadian Tire) to collect sediment samples, after which the sample was settled out and the liquid portion was drained off the top before analysis. Sediment collection varied widely in terms of quality of sample and sampling depth, so the information gleaned from these samples was limited.

Phytoplankton Diagnostics

Grab samples from the surface of ponds were collected monthly for algae and cyanobacteria microscopic diagnostics (maintained in coolers/refrigerator until diagnostics performed). Samples were collected regularly at active sites between 2020 and 2022. Visual aquatic vegetation observations were also made on-site.

Weather & Precipitation

The Government of Canada's historical online weather data (Environment and Climate Change Canada) was downloaded as relevant for each site. Agriculture & Agri-Food Canada also generously loaned the team a WatchDog weather station for use at site B.

Assumptions

There were some general assumptions made through the study, for missing samples and samples with parameter levels below detection limit (BDL). If no sample was taken, averages ignored the missing data. Ortho-P detection limits varied between 2021 and 2022 depending on the sample and sampling date. Where Ortho-P values were ≤1 with a DL of 1ppm, and total P values were also less than 1ppm, no result was entered. A result was only entered if the value was >1, or if the DL was 0.1 for that sample. The use of a designated number allowed for conservative estimations of all sample results that were Below Detection Limit (BDL), and inclusion within the average. For parameters that were analyzed but below the detection limit (BDL), the following values were entered to allow for data summarization:

BDL Limits	Number Used
10	9
1	0.9
0.3	0.27
0.1	0.09

0.02	0.019
0.01	0.009

General Testing Parameters – Pre-Pond Treatments

Water Quality Testing

Sampling of ponds for site A occurred between 2019 and 2020. Installed woodchip trial beds were sampled pre- and post-treatment beds. Water samples were maintained in a cooler until transported to a laboratory for general nutrient testing (Greenhouse Complete package from A & L Canada Laboratories Inc., London, ON), plus ortho-phosphate analysis on specific samples.

For Site D, sampling of ponds and input source waters occurred monthly throughout 2019 and 2020 and were narrowed down to sampling only of the main pond and its inputs when the hybrid treatment swale (HTS) was installed in 2021. The influent into the HTS as well as the water after each cell/media bed section was sampled in fall of 2021 and between July and October of 2022.

Technologies and Sites

Refer to the following table for a brief description of sites and in-pond treatments at each location.

Site Code	Site Features	Technologies Tested	Testing Regime
A	Woodchip beds with container and field-grown nursery product storage, large new pond	**2020 – Pre-Pond** Woodchip, and Woodchip + Slag media beds under potted plant staging area In addition, the following sites were sampled: a) Pond inlet b) Main pond c) Pond outlet d) Bed fertigation water	Water samples
B	Container and field-grown nursery product storage, in-series pond	**2021 – In-Pond** Four 1.5m^3 mesocosms, with the following: 1) control 2) aeration (50W shallow aeration compression pump and diffuser airstone) 3) wollastonite (17g applied June 15, July 2, Sept 10)	Water samples, YSI readings, sediment sampling, aquatic phytoplankton diagnostics

		4) shade covering (70% pond knit shadecloth) In addition, the following sites were sampled: a) Pond Inlet b) Main Pond c) Pond Outlet **2022 – In-Pond** Ten 1.5m^3 mesocosms, with the following: 1) Control (no treatment) 2) Aeration only 3) Aeration + ClariPhos™ (p-removal, Bishop Water, Arnprior, ON) 100ppm (i.e., 100mL)/1m3 (rep 1) 4) Aeration + ClariPhos™ (p-removal) 100ppm (i.e., 100mL)/1m3 (rep 2) 5) Aeration + Bacterius® C (bacterial sediment treatment, Bishop Water, Arnprior, ON) 25mL/1m3 (rep 1) 6) Aeration + Bacterius® C (bacterial sediment treatment) 25mL/1m3 (rep 2) 7) Aeration + Bacterius® Pond (bacterial sediment treatment, Bishop Water, Arnprior, ON) 30mL/1m3 (rep 1) 8) Aeration + Bacterius® Pond (bacterial sediment treatment) 30mL/1m3 (rep 2) 9) Aeration + Bacterius® C plus Bacterius® Pond combination, 25+30mL/1m3 (rep 1) 10) Aeration + Bacterius® C plus Bacterius® Pond combination, 25+30mL/1m3 (rep 2) In addition, the following sites were sampled: a) Pond inlet b) Main pond c) Pond outlet (with *Pontedaria cordata* planting) d) ~40m^3 Partition area, with Aeration + 'Bacterius® C' plus 'Bacterius® Pond'	

		combination (Bishop Water, Arnprior, ON), 25+30mL/1m3 (starting in July 2021)	
C-H	Container and field-grown nursery production, in-series pond	**2021 & 2021– In-Pond** Five 2.5m^3 mesocosms, with the following: 1) control 2) aeration (25W shallow aeration compression pump and diffuser airstone) 3) native duckweed covering 4) *Chara spp.* green alga planting 5) shade covering (70% pond knit shadecloth) In addition, the following sites were sampled: a) Main Pond	Water samples, YSI readings, sediment sampling, aquatic phytoplankton diagnostics
C-L	Container and field-grown nursery production, narrow channel pond	**2020 – In-Pond** Three-channel (6m long x 1.75m wide) system installed: 1) control 2) two PhytoLinks™ (pre-planted floating islands 2019, Terrapin Water, Owen Sound, ON) 3) two PhytoLinks™ (pre-planted floating islands 2019) with attached rope netting to increase surface area/binding sites for periphyton In addition, the following sites were sampled: a) upstream pond **2021 – In-Pond** Three-channel (6m long x 1.75m wide) system installed: 1) control (centre channel) 2) three PhytoLinks™ (pre-planted floating islands 2019)	Water samples, YSI readings, sediment sampling, aquatic phytoplankton diagnostics

		3) control (near-shore channel) In addition, the following sites were sampled: a) upstream pond	
D	Container and field-grown nursery production, multiple ponds	**Pre-Pond Hybrid Treatment Swale 2021 & 2022:** 1) HTS Influent 2) Post Cell 1 (woodchips) 3) Post Cell 2 (slag/gravel mix) 4) Post Cell 3 (gravel) In addition, the following sites were sampled between 2019 and 2022: a) main pond b) main pond NE inlet c) container drain outlet d) east pond e) east pond inlet	Water samples, YSI readings, sediment sampling, aquatic phytoplankton diagnostics
E	Floriculture greenhouse, pond	**Three Whole-Pond Treatments (combined) 2020 – 2022** a) Nano-bubbler (2020 Moleaer Clear 50, 2021-2022 Moleaer Clear 150) b) Sonication (USAF ST 60 Watt, Ultramins) 2021-2022 c) Water hyacinths (*Eichhornia crassipes*) 2021 and 2022 Water samples were collected near the nano-bubbler and in the main pond, and mesocosms were used as controls: Three 6m^3 mesocosms, sampled in 2020 after installation and throughout 2021: 1) E1 mesocosm control 2) E2 mesocosm control 3) E3 mesocosm control	Water samples, YSI readings, sediment sampling, aquatic phytoplankton diagnostics

		In addition, the following sites were sampled between 2020 and 2022: a) west pond	
F	Outdoor floriculture GH potted plant production, pond and two recapture silos	**2022 – Whole Silo Cover Bird Balls** a) main pond b) west silo – with bird balls (Bird-X) c) east silo – with bird balls (Bird-X)	Water samples, YSI readings, aquatic phytoplankton diagnostics
G	Floriculture greenhouse, pond	**2022 – Whole Pond Cover Geotextile** a) main pond (benchmark sampling prior covering with Erfgoed Kristaldek geotextile)	Water samples, YSI readings, aquatic phytoplankton diagnostics

Details of Pre-Pond Treatments

Woodchip trial beds at Site A

Two 2.4m (8') square pre-pond media beds were prepared in April 2020 with one bed containing hardwood mulch, and the second bed containing a mixture of the same mulch plus iron slag (fines, 0-10mm, bulk density approximately 2). The base of each trial bed was lined with heavy pond liner supported by 1.3cm (½") plywood to prevent leakage or cross contamination. Plants were held/grown for nursery sales on the surface of these beds. The trial beds were built with a 2% grade, with a sampling port on the lower edge that drained into a sample collection bottle ('ping-pong' sampler). Initial testing of water drainage volumes and water quality was completed between May and mid-July to ensure the two trial beds were similar in design. Initial benchmarking indicated that the slopes and drainage rates of the two trial beds were dissimilar, and subsequent adjustments to the slope were made to ensure both beds had a 2% slope. Slag was added by mixing throughout the mulch layer to the more westerly trial bed on July 29 (6L) and again on September 25, 2020 (40L). For comparison, the main plant holding areas for the site had a similar 0.15m (6") layer of mulch covering the entire area (prepared in the 2019-2020 fiscal year). A sub-surface drainage system was installed under the main holding bed, with a collection point where the bed drains into a discharge swale. Irrigation water from the main storage pond was also sampled as it was the source water used for applications to the trial and mulch beds. No fertigation was applied to the beds throughout the 2020 sampling season. Further investigation through a catch-can test highlighted that irrigation volumes were not equivalent between the beds, therefore, a two-day experiment was performed in October 2020 with identical volumes of fertilizer-spiked (35L of 20-8-20 Plant Products, ~150mg/L total P) irrigation water being applied to both trial beds. Initial water samples of effluent exiting the beds were taken, as well as after one day and after an additional irrigation water application (no added fertilizer, 45L per bed).

Hybrid Treatment Swale at Site D

The 5x30m gravity-flow media bed was designed to capture and treat 13,000L every two days (replicating irrigation and typical storm events) and included a preliminary 40m^3 woodchip cell for nitrate removal, a central 2m^3 slag/pea gravel mixed cell for phosphorus removal, and a final polishing cell with ~12m^3 of gravel. The installation was completed in the spring of 2021.

Results & Discussion by Technology

A subset of the data was plotted in line graphs and histograms, and these can be found in Appendix A-F, referring to plots from Sites A-F respectively.

In-Pond: Aeration

Two forms of aeration were evaluated in this study, traditional compressed air through an airstone, as well as the new nanobubble technology.

Figure 1. Traditional airstone (L) and the nanobubblers Clear 50 (C) & Clear 150 (R).

Traditional aeration with compressed air/diffuser airstone

Traditional aeration was tested using the mesocosms at Sites B and C-H. All chemical and biological treatments in the mesocosms at Site B (2021) included aeration to maintain circulation of the water column.

<u>Site B</u>

- Water column quite shallow (<1m), expected similar surface vs column water sample results.
- Great variability in ODO, but some of the lowest values on certain dates (e.g., late July and mid-late August 2020), and overall, ODO was lower than all other sample sites (when entire seasons were averaged).
- Phytoplankton (chlorophyll *a*/phycocyanin) levels were consistent between pond and all mesocosm treatments in 2020, but in 2021 the mesocosms seemed to have more phytoplankton in general than the main pond, inlet, and outlet.
- The cyanobacteria *Planktothrix* and *Cylindrospermopsis* dominated the plankton populations in 2020 from August to October, with very little difference throughout the pond or mesocosms treatments. In 2021, another blue-green - *Oscillatoria* sp. - was dominant early in the year (May), but by late June *Planktothrix* was present in large numbers. Interestingly in early August the phytoplankton populations decreased and were very mixed indicating a sharp decline in the blue-green populations, possibly due to the

filling of the pond with lake water as water levels were dropping. However, by late September *Oscillatoria* was again in high numbers.

<u>Site C-H</u>

- The aeration air compressor unit was solar powered, and only functioned consistently after enhancement of the panel and battery system in 2021. Therefore, 2020 aeration mesocosm results were inconsistent. The unit resulted in a relatively intense level of aeration in this mesocosms, and more pronounced results than in Site B.
- In 2021, both surface and whole column samples of the water in the mesocosms and main pond were collected.
- Average ammonium-N and ODO levels were lower in the aeration treatment. Over the 2021 season, ammonium-N was consistently lower than the control, shade, *Chara*, and duckweed mesocosms as well as the main pond, suggesting that long-term aeration had a beneficial impact through aerobic sediment degradation.
- Biological activity of phytoplankton, as observed through chlorophyll *a* and phycocyanin measurements as well as microscopic diagnosis, suggest that overall the results from the aerated cell at Site C-H appeared to be lower than other treatments, particularly in the surface samples (where phytoplankton tend to reside).
- In general, phytoplankton populations were low in this pond compared to Sites B and E. Small flagellates (e.g., *Chlamydomonas*, *Cryptomonas*) were common, but cyanobacterial species were rarely found in substantial numbers in the water surface or column, in either the pond or any of the treatments mesocosms.

Nanobubbler

The nanobubbler results at Site E were difficult to isolate, as there were other treatments occurring in the pond at the same time (sonication, water hyacinth covering). However, for portions of 2020, the nanobubbler was the only technology in the pond. Further, after inspection and maintenance by the supplier, it was determined that the unit was not functionally optimally until late 2022 as a result of inadequate cleaning.

- Note that the main pond was only sampled once during 2021.
- Major blue-green blooms were observed in 2020, a significant blue-green bloom in 2021, and recurrence of the major blooms occurred in 2022. Blooms occurred in early spring in 2020, but more typically are observed later in the summer (e.g., Aug-Sept 2022). The level of phycocyanin in most control mesocosms (except #3, located furthest from the nanobubbler) was similar to the pond water.
- In 2020, the blue-green bloom was dominated by *Microcystis* from August through September, whereas the dominant blue-green in 2021 was *Planktothrix*, and in 2022

Planktothrix dominated in August followed by *Microcystis* in September. These changes in dominant species may reflect the sonication treatment introduced in 2021. A wide variety of other algal types were present (greens, euglenoids, dinoflagellates, etc.) were present throughout the season. Differences in the plankton populations between the pond, pond near the nanobubbler or mesocosms were minimal.

- Chlorophyll *a* levels in the pond peaked in the spring of 2020, indicating a green algae bloom. Nanobubbler and control mesocosms were not sampled until later in the season and were higher for chlorophyll *a* for the rest of the season compared to the main pond.
- Water near the nanobubbler (in SW corner of pond) was less stratified in 2020 compared to the control mesocosms (E1, E2, and E3, or combined as AVG123).
- No real increase in ODO near the nanobubbler was observed, which was unexpected. In fact, 2020 and 2022 averaged data suggest a decrease in ODO in the pond near the nanobubbler treatment. This pond is deep (nearly 2.5m), and there is a fair bit of organic sediment in this area. Potentially, the nanobubbler may have had significant impact on aerobic digestion, resulting in an overall drop in oxygen level that could improve with time, or conversely, the nanobubbler may not have been functioning properly, resulting in a generally low-oxygen state near the sediment that was mixed into the main column.
- Interestingly, the total and particularly ortho-P were higher for the water near the nanobubbler in 2021 compared to open pond (as seen for aerated mesocosms at Site B and C-H).
- The average pH was not different for any year compared to the main pond and AVG123.
- Ammonium-N appeared to be higher near the nanobubbler than the main pond, although the results were highly variable. When the three 'control' mesocosms were averaged and compared to the main pond and nanobubbler,
- The extreme peaks of phytoplankton activity were not observed in 2021 and 2022, indicating that a general improvement of the pond water quality was taking place. However, due to the installation of both sonication and a plant cover (water hyacinths), it's not clear if the nanobubbler was particularly effective. Ongoing evaluation of the pond would be valuable now that the nanobubbler has been repaired.
- Ammonium-N appeared to be higher near the nanobubbler than the main pond, although the results were highly variable. When the three 'control' mesocosms were averaged and compared to the main pond and nanobubbler, only the 2022 results were significantly higher.
- The extreme peaks of phytoplankton activity were not observed in 2021 and 2022, indicating that a general improvement of the pond water quality was taking place. Summing chlorophyll *a* and phycocyanin and plotting against time illustrated that there

were differences in water quality between the pond and the control mesocosms and nanobubbler. However, due to the installation of both sonication and a plant cover (water hyacinths), it's not clear if the nanobubbler was particularly effective. Ongoing evaluation of the pond would be valuable now that the nanobubbler has been repaired.

- The depth of sediment observed near the nanobubbler appeared to be less than in the rest of the pond, which may indicate improved organic matter decomposition and sediment reduction.

Overall recommendations:

It is possible that the low ODO values observed through the mesocosm and nanobubbler trials may be the result of oxygen consumption during organic decomposition, and that further aeration in subsequent seasons may improve the overall ODO (target is 9mg/L for temperatures under 20C, and 10mg/L for temperatures over 20C)). Aeration may be an effective tool in ponds for increased availability of oxygen throughout the water column and facilitating aerobic decomposition of organic matter in the sediment. However, in this study, there was insufficient data to make definitive conclusions. Long-term (i.e., muti-year) aeration with nanobubbles should result in water quality improvements and be more effective that traditional aeration (which could still be useful in very shallow ponds).

In-Pond: Physical Shade Covering

Physical shading included 70% shade and a solid landscape cloth covers on mesocosms at Sites B and C-H (2020-2021), as well as bird-ball coverings on two silos at Site F (2022). See Appendices B, C-H and F for selected plots. The geotextile cover at Site G was not installed before project end, so results are not included in this report.

Figure 2. Shadecloth (L), solid covering (C), and the bird balls (R).

Shadecloth

- Sites B and C-H had 70% shadecloth covered mesocosms in 2020.

- At Site B, the ODO was lower in the shaded mesocosm compared the other treatments throughout the summer, resulting in the overall average ODO being lower than all other treatments.
- At Site C-H, there was also an overall lower ODO average compared to the other mesocosms and the pond (with the exception of duckweed), as well as a gradual increase in ammonium-N between summer and fall of 2020 (although this did not realize into an overall high average level of ammonium-N for the season)

Solid covers

- The only solid cover was installed over a mesocosm at Site C-H in 2021.
- Interestingly, the average ODO was quite low (average ~2mg/L) in the 'shade' mesocosm treatment; almost as low as the aeration mesocosm treatment.
- No significant differences in phytoplankton populations were noted between the shade and other mesocosms treatments in either 2020 or 2021

Bird balls

- The main pond at Site F was the irrigation source pond and had no cover or treatment. The two silos were for storage of re-captured field leachate after fertigation and irrigation events. Both silos had bird balls on the water surface as well as a netting cover (>1" opening) at the tops of the silos to prevent wildlife entry.
- Nutrient levels in the pond were reasonably low in 2022 (below detection limit for nitrate-N, less than 1mg/L for total P), and ODO ranging between 4 and 11 mg/L, with lowest values observed in late July and early September. Nutrient levels in the silos, in contrast, were much higher (as expected from return fertigation runoff), ranging from ~17-35 mg/L nitrate-N and ~1-5 mg/L total P. Levels of ODO in the silos were generally lower than the pond.
- Chlorophyll and phycocyanin levels in the east silo were particularly high in July, but quickly dropped to levels lower than in the pond by August and remained low for the rest of the season.
- Observed phytoplankton populations were consistently very low in the tanks from mid-August to October. (Note: assessments were not done in July when high phycocyanin and chlorophyll levels were measured in the east silo.)
- Despite having an excess of nutrients available, phytoplankton levels were generally lower in the silos (aside from the initial spring peak).

Overall Recommendations:

Solid coverings appear to be an effective way to limit phytoplankton growth by preventing light from entering the water column. Since covering may lower oxygen levels in the water column, aeration to improve oxygenation should be used in combination with covering.

In-Pond: Aquatic Vegetation

Aquatic vegetation tested in this study included aquatic plant coverings as well as a submerged charophyte (green algae) treatment. For both 2020 and 2021, Site C-H had mesocosms with a duckweed cover (primarily *Lemna minor*) and *Chara spp.* submerged plantings (Appendix C-H), and Site D had a planting of *Pontedaria* (pickerel weed) near the pond outlet. At Site C-L, floating islands of plants (PhytoLinks™) were placed into narrow channels (Appendix C-L). Site E introduced a covering of common water hyacinths in the main pond in both 2021 and 2022 (Appendix E).

Figure 3a. Duckweed covered mesocosm (L) and Chara ready to go in the mesocosm (R).

Figure 3b. *Pontedaria* close up (L), at outlet of pond (R).

Figure 3c. PhytoLinks™ setup in Site C-L pond (L), individual units in early spring (R).

Figure 3d. Common water hyacinth *Eichhornia crassipes* (L), later in the season (R).

Duckweed cover

- Duckweed was present throughout the main pond at SiteC-H in both 2020 and 2021 and was not harvested.
- Levels of ammonium-N, nitrate-N and total P were slightly elevated (BDL-1.4, BDL-1.2, BDL-0.35 mg/L respectively), and sometimes exceeded all other treatments. However, overall, these levels are very low compared to most ponds characterized in this study.
- Anecdotally, duckweed covering was expected to clarify the water, and while this pond had generally clear water and low nutrient levels, phytoplankton levels actually exceeded all other treatments in the surface layer and was similar to levels in other treatments for the whole water column samples. It is possible that restricting the movement of the duckweed in the mesocosms resulted in more rapid turnover of the population resulting in increased nutrients in the surface water (e.g., higher ammonium-N, total P) to support the growth of phytoplankton. Chlorophyll *a* levels in the duckweed mesocosm were still lower than other sites that had evidence of blooms and turbidity issues. Phycocyanin levels were very low compared to other sites.

Submerged Charophyte (Chara)

- The *Chara* did not seem to survive well through the 2020 season, so results are unreliable for drawing any conclusions. In 2021, additional plants were secured to netting and weighted down with rocks, but still did not seem to establish. It is possible that this pond was too deep for good establishment. It was observed that the water above the *Chara* in the nearby source pond was extremely clear.
- For many parameters, the *Chara* mesocosm results were similar to the control.

- Other macrophytes which were present throughout the pond, in particular, *Potomogeton* spp. and *Ceratophyllum* self-established in the mesocosms. This additional growth was a confounding variable, making interpretation more difficult.
- Planktonic cyanobacteria were not found in this mesocosm (or others) in 2020 or 2021. Certainly, no blooms were evident, although a healthy population of a range of algae species were observed. Dissolved oxygen levels were generally lower at Site C-H compared to Site B, but the data was quite realistic based on water column depth and water flows.

Pontedaria Planting

- *Pontedaria cordata* (pickerelweed) is a native rooted aquatic plant found in healthy ponds and is considered useful in improving water quality. It was planted near the outlet of Site B pond, but while it established well, the populations were not extensive enough to result in any significant changes in water quality over the study. Tissue analysis (>2%N and 0.2%P) indicated that it could remove substantial nutrients from the surrounding water.
- 2021 data for the inlet and outlet of the main pond, compared to the pond and the control mesocosm cell, were plotted separately from the mesocosm data to improve visual interpretations.

PhytoLinks™

Floating islands, pre-planted in a previous year, were installed in May 2020 at Site C-L, tethered to posts in three channels, which were maintained and sampled in 2020 and 2021, although challenges with changing water levels impacted the ability to collect samples (Appendix C-L).

- In 2020, water samples were taken between June and July, however, water levels dropped to extremely low levels due to a dry and hot summer with intensive irrigation needs by the farm. At times, the PhytoLinks™, were not in contact with the water. No differences in water quality were observed during this period between the control channel (no PhytoLinks™), the PhytoLinks™ plus rope (for periphyton adhesion), and the PhytoLinks™ only channel. All three channels had slightly higher ammonium-N than the pre-channel/upstream pond samples.
- In the spring of 2021, the PhytoLinks™ were maintained by discarding dead plant material and adding fresh plants (native reed canary grass, *Phalaris arundinacea*). Three units were placed in series in the middle channel (essentially filling the channel), with two control channels maintained at the centre and shoreline. By late July, the pond level rose to the point where water flowed freely over the top of the three channels. During May and June, ammonium-N levels were lower in the channels

compared to the upstream pond, and the channels had lower turbidity. The early spring peak in ammonium-N in upstream waters may have been a result of resuspension of decaying material and organic matter when the water levels rose.

- A significant spike in nitrate-N was observed during the spring of 2020 and 2021, closely following the application of fertilizer to the in-field nursery tree production in the field adjacent to the pond.
- In 2020 after the pond level dropped, chlorophyll *a* and phycocyanin levels increased, and ODO levels dropped sharply, corresponding to changing pond conditions.
- Possible that the fast water flow through the channels prevented observation of any nutrient reduction by the plants in early summer of either year. Periphyton and benthic populations were observed on plant roots, so nutrient uptake was likely. Further, baseline levels of nutrients (aside from the spring nitrate-N peaks) were quite low. PhytoLinks™ are typically used with success in more eutrophic water bodies such as sewage ponds.

Water Hyacinth Cover

- Several thousand water hyacinth plants (*Eichhornia crassipes*) were introduced to the pond in early summer 2021. Plant coverage of the pond increased to approximately 25% by early September, and then rapidly expanded to nearly full pond coverage (including all control mesocosms) by late September. Many of the plants were harvested at the end of 2021 (October) and there was little overwintering survival of remaining plants. In 2022, a fresh lot of plants were introduced in July, but coverage never exceeded approximately 10% of the surface of the pond.
- Tissue analysis (1.8%N and 0.14%P) indicated that the plantings could remove substantial nutrients from the pond. Based on these concentrations, the estimated N and P removal from the whole pond, at even 20% coverage, was 29 kg N and 2.2 kg P.
- The impact of the water hyacinth cover is best compared for the period of July-September 2021. While the nanobubbler was also treating the pond throughout the three sampling seasons, the effectiveness of the treatment was unknown as the equipment was found to require cleaning and maintenance which was not completed until September 2022. Ultrasonic equipment (sonication) was introduced in late fall of 2021.
- The main pond experienced a major cyanobacterial bloom in the spring and summer of 2020, and a smaller bloom again in 2022. Measured phycocyanin levels reached nearly 30ug/L in 2020, and closer to 8ug/L in 2022. While there was limited data from 2021 for the main pond (only two YSI sampling dates), since the hyacinths

essentially covered the whole pond during the late summer, average phycocyanin levels from all treatments (nano, control mesocosms, and pond) can be viewed. Average phycocyanin levels in 2021 were far lower than the other two seasons. Column samples taken in the late summer of 2021 illustrate decreasing phycocyanin levels in both the pond near the nanobubbler and in the mesocosms.

- Phytoplankton populations support the evidence from the YSI measurements that the hyacinth covering had a significant beneficial impact on reducing the cyanobacterial bloom activity.
- In 2020, the blue-green bloom was dominated by *Microcystis* from August through September. This species forms extensive floating ‘scums’ on the surface of the water. (This is the same cyanobacteria that causes blooms in Lake Erie). Though less extensive (as measured by phycocyanin levels), the dominant blue-green in 2021 was *Planktothrix*, which tends to be more distributed through the water column. In 2022 *Planktothrix* dominated in August followed by resurgence of *Microcystis* in September. These changes in dominant species and extent of growth may reflect the sonication treatment introduced in 2021. A wide variety of other algal types were present (greens, euglenoids, dinoflagellates, etc.) were present throughout the season. Differences in the plankton populations between the pond, pond near the nanobubbler or mesocosms were minimal.
- Plots of the sum of chlorophyll *a* and phycocyanin (Chl *a* + PC), over time, and against ODO, suggest that 2021 was certainly a unique year, with lower levels of these pigment complexes (and thus, lower phytoplankton levels) without a major impact on the overall oxygen level of the pond. The water hyacinths may keep oxygen from diffusing in the water column, as other research has suggested that water hyacinths do not produce as much oxygen as other submerged vegetation and phytoplankton (REFERENCE), and possibly only decomposition of organic matter (an oxygen consuming activity) is occurring below the mat of plants. Oxygen levels would typically be higher during active photosynthesis (by phytoplankton) but would drop as the population declined.

Overall Recommendations:

In the project study, aquatic vegetation used as covers were highly variable in their effectiveness. Duckweed did not perform as well as expected, but full coverage of water hyacinths had a significant impact on water quality. *Pontedaria* plantings were not extensive enough by the end of the study to show any effect. Seasonal variation, annual inputs, water flow rates, and condition of the pond prior to introducing vegetation all likely affected the results. There is potential for full plant coverings to be effective at minimizing light levels, and/or consuming nutrients, thereby improving pond water quality by limiting phytoplankton growth. However, annual maintenance and harvesting of the plants is required.

In-Pond: P-Removal Compounds

Phosphorus removal compounds tested included wollastonite in 2020, and ClariPhos™ in 2021 at Site B in mesocosms (Appendix B). Wollastonite is an inosilicate mineral suitable for adsorbing P, and ClariPhos™ is a rare earth coagulant marketed to remove P from water through tight bonding with P and subsequent precipitation.

Figure 4. Wollastonite crystals in pilot treatment system cell (L), and ClariPhos™ being dosed into a treatment mesocosm (R).

Wollastonite

- Wollastonite was added three times during the season, indicated by a "W" in the graphs. Although insignificant, the average chlorophyll *a* levels in the wollastonite mesocosm were slightly higher than in other mesocosms.
- Wollastonite additions to the mesocosm appeared to have minimal impact Total P in the water column following application, and in fact, some marginal increases in Ortho-P were observed.
- Phytoplankton populations were similar to those in the pond and other mesocosms, with the blue-green *Planktothrix* dominating in September–October 2020.

ClariPhos™

- ClariPhos™ was supplied to the replicate mesocosms at Site B at the manufacturer's recommended rate four times in 2021 (June 1, June 29, August 5, and September 1)
- Total P was not significantly reduced over the main pond, and in fact had higher levels on average. However, compared to the aeration control, TP levels were slightly less.

pH levels were slightly lower than the pond and most mesocosms on average, as was ammonium-N.

- Chlorophyll *a* and phycocyanin levels were similar or slightly higher than other mesocosm treatments.
- As with the wollastonite treatment, phytoplankton populations in the ClariPhos™ mesocosms were similar to those in the pond and other mesocosms, and were quite mixed with the blue-green *Planktothrix* and *Oscillatoria* dominating in late June, and *Oscillatoria* dominating in late September 2021 (samples were not taken in October).

Overall Recommendations:

Insufficient improvements were observed to recommend wollastonite or ClariPhos™ treatment in ponds with generally low total P levels in the water column. Mesocosm design and/or volume may also be factors in the efficacy of these treatments.

In-Pond: Sediment Degradation Compounds

Two different bacterial cultures were added individually to replicate mesocosms at Site B in 2021, and in a combined treatment (Appendix B). Later in the season, starting in July, a combined treatment was also applied to a larger partitioned area of the same pond. Bacterial treatments were introduced approximately monthly (June 1 & 29, August 5, and September 1) at the manufacturer's recommended rate. The two culture mixes were recommended for aerobic degradation of organic matter in the pond after a preliminary review of the water quality results, providing the treatment areas (mesocosms and partition) were aerated to ensure continuous mixing of the water column. Comparisons were made to the aerated mesocosm (not control).

Figure 5. Dosing a mesocosm with bacterial culture.

Bacterius® C

- The "C" treatment, designed for muck and organic matter degradation, had slightly higher ammonium-N levels in the mesocosms compared to other treatments, and slightly elevated total P levels at the end of June, mid-August, and late September, although averages over the season suggest that this treatment was not different than the control mesocosm.
- Slight increases in chlorophyll *a* and phycocyanin were observed at the end of the season (although overall turbidity was slightly below average).
- There were slight differences between the two replicates, but well within the margin of error.

Bacterius® Pond

- The "Pond" culture is designed to promote nitrification and consumption of organic matter in ponds.
- Total P levels in these mesocosms (both on individual dates and on average) appeared to be reduced with this bacterial treatment, compared to the control or aeration mesocosm.
- There were slight differences between the two replicates, but well within the margin of error.

Combination Bacterius® C + Bacterius® Pond

- Two replicate mesocosms and one larger partitioned area of the pond were treated with the combination of the two bacterial cultures.
- Total P, chlorophyll *a* and phycocyanin levels in these mesocosms (both on individual dates and on average) appeared to be reduced with this bacterial treatment.
- There were some differences between the two mesocosm replicates, particularly with total P, chlorophyll *a* and phycocyanin results so the significance of observed reductions is not clear.
- Variability over time was also observed in the partition area, but generally chlorophyll *a* and phycocyanin levels were higher than the pond samples, and very similar to the aerated mesocosm.

Overall Recommendations:

Bacterial cultures specifically chosen to address water quality issues appeared to have a beneficial impact in this study, particularly on total P, chlorophyll *a* and phycocyanin levels. However, it should be noted that to incorporate these treatments in full-scale irrigation ponds would cost 10's of thousands of dollars each year. These products have potential for supporting biotic health in ponds, but more sustainable alternatives are desirable.

In-Pond: Sonication (Ultrasonic Wave Treatment)

The sonication results at Site E were difficult to isolate as described previously (other treatments occurring in the pond at the same time included a nanobubbler and water hyacinth covering). In the fall of 2021, the site had nearly complete coverage from water hyacinths, and the nanobubbler was not functioning optimally. In response to the phytoplankton issues that were affecting greenhouse crop production, the facility also installed a single ultrasonic transmitter (USAF 60W) in October 2021 in the northwest part of the pond and upgraded the unit to a double ultrasonic transmitter (USAF 100W) by the following spring.

Figure 6. A single transmitter sonication unit (L), installed in the pond at Site E (R).

- Note that the main pond was only sampled once during 2021.
- Major blue-green blooms were observed in 2020, a significant blue-green bloom in 2021, and recurrence of the major blooms occurred in 2022. Blooms occurred in early spring in 2020, but more typically are observed later in the summer (e.g., Aug-Sept).
- Chlorophyll *a* and phycocyanin levels in the pond peaked in the spring of 2020, indicating a cyanobacterial bloom (with this being the highest phycocyanin peak of the entire study). Microscopic examinations were not added into the study until August 2020, and so the specific identification of this bloom is not known. The control mesocosms were not installed and sampled until later in the season and were marginally higher for chlorophyll *a* for the rest of the season compared to the main pond.
- The level of phycocyanin in most control mesocosms (except #3, located in the north portion of the pond) was similar to the pond water, with a slight peak in phycocyanin in the late summer of 2020.
- By looking at the column data for the area of the pond near the nanobubbler and comparing it to the control mesocosms (and looking at the overall trend of all sampling data), water quality started to improve in September 2021 (turbidity, chlorophyll *a*, and

phycocyanin), but there was no sampling after mid-September so any potential impact from the installation of the sonication unit was not captured. Surface data from 2022 (nanobubbler and AVG123) in mid-summer would have had the sonication unit functioning in the pond with less interference from the limited hyacinth cover and a less-than optimally functioning nanobubbler. During this period, there may have been some slight improvement in phycocyanin and chlorophyll *a* (as well as turbidity), which reversed after the end of August. *Planktothrix* was the dominant blue-green early in the season, but was overtaken by *Microcystis* by the end of August.

Overall Recommendations:

There is insufficient information from this study to comment on the effectiveness of sonication. Anecdotally, the water quality concerns at the farm did resolve after the fall of 2021, and the bloom of 2022 was certainly less intense that in 2020. Bloom-forming cyanobacteria have gas vesicles which provide buoyancy and result in the formation of surface scums. Sonication will collapse these vesicles resulting in visually better water quality and may result in substantial cell death. However, it does not address dormant spores (akinetes) or resting stages residing in the sediments and does not remove nutrients from the water column. Sonication may be useful for new ponds or silos to maintain water clarity, but in existing ponds with significant nutrients and high organic matter sediments, it should be combined with other technologies to enhance aerobic decomposition.

Pre-Pond: Woodchip Treatment Options

The two 900L-capacity trial beds at Site A (woodchips (WC), and woodchips plus slag (WC+S)) were installed in 2020 in a nursery staging area (Appendix A). A two-day trial to compare nutrient removal capacity of woodchips and slag media beds was performed late in 2020. At Site D, a hybrid treatment swale (HTS) was designed and installed to capture a portion of the production runoff water to determine the effectiveness of a passive shallow swale instead of a complete hybrid treatment system (which generally requires a substantial footprint, power, and cost).

Figure 7a. Test bed layout (L) and applying fertilizer for the October 2020 trial (R).

Figure 7b. Media sections of the HTS (L) and the HTS full view (R).

Site A Media Bed Trial

- For the trial, the same solution was used as influent water (applied) on both trial beds. The beds were first saturated with irrigation water (no nutrients). Samples were taken immediately before fertilizer application (post H_2O), one hour after application (1h post) and one and two days after application (24h, 48h). No sample was available post H_2O application in the WC+S treatment.
- Both treatment beds resulted in significant reduction of nitrogen. Taking to account the dilution factor of the saturated beds, nitrate-N was removed by 17% and 51% in the WC and WC+S beds, respectively, and this is expected to improve as the woodchips mature.
- Total P also decreased to below detection levels for both treatments at 24 h Over the 48hr sampling period, the WC bed removed 72% of total P and WC+S removed 86% of total P from the effluent. A higher proportion of slag would improve P removal.
- In contrast chloride, which is not bound to any significant extent, was not reduced, indicating that the above calculations are conservative estimates of N and P binding in the beds.

- Analysis of the effluent pH was slightly higher in the WC+S trial bed (7.5 compared to 7.1), as was expected due to interaction of the water with slag (data not shown).
- We were not able to conduct longer trials, but these are needed to determine overall long-term effects. For example, there was indication that some K was also removed (data not shown).
- Samples taken over the whole season (June to October) from the collection drain for the whole production bed underlain with woodchips generally had very low concentrations of nitrate-N and total P.

Site D Hybrid Treatment Swale

Site D has both container and field nursery production within the catchment area leading to a new pond (constructed 2019). Fertilizer is applied to the fields with a coulter, and to the container pots either as incorporated media, or as a top-dress for smaller pot sizes (liners, 4-6") and in the 2nd year of 12+mo crops. There are two main tile drains, one from the field and the liner beds, and the second from the cold frames where most of the container stock is grown. Preliminary water sampling indicated that there was nutrient loading of the pond through these two drains, and the owner was supportive of implementing solutions to decrease the amount of nutrients reaching the pond. The hybrid treatment swale (HTS) was designed and installed to capture a portion of the water from these drains to determine the effectiveness of a passive shallow swale. Since both N and P were present in the drain water, media chosen included a woodchip cell (N removal) followed by a slag cell (P removal, screened to include 1/4" – 3/8" material). A final gravel section of the bed was included in the design to restore the potential biological oxygen demand to acceptable levels and lower the pH before discharge. The pond water quality was tracked in both this pond (West) as well as another pond on site (East) over the three years as the ponds continued to receive some nutrients from production activities.

Pond Benchmarking

- For the ponds, water quality fluctuated over each year, but in general, the nutrient levels in the main (west) were fairly high in 2020 and 2022, with a slight drop in most nutrients (except sulfate-S) in 2021. The east pond, sampled only during 2020 and 2021 seasons, had much higher sulfate-S and conductivity levels compared to the west pond.
- Biological activity in the ponds as measured with the YSI indicated that chlorophyll a levels in the west pond were quite high in the summer 2020, and peaked again in the summer of 2021 and 2022. While phycocyanin levels started out low each spring, levels increased over the three years (although there was significant variability in the data).

- In comparing the quality of the water directly entering the pond through the drain, nutrient levels increased or were stable (total and ortho-P, K, sulfate-S). Chlorophyll *a* levels were low in the drain water, but interestingly, one sample captured in late summer 2022 had moderate levels of phycocyanin.
- In 2020 the peak chlorophyll concentrations in the west pond corresponded to a population of very small unicellular algae (unidentified) in early September, and second smaller peak corresponded to brown flagellates (likely cryptomonads)
- In 2021 there were minimal populations observed microscopically initially, but by the end of September, cyanobacteria became the dominant group (*Anabaena* or *Aphanizomenon*, and *Oscillatoria*). This corresponded with the strong peak of phycocyanin measured at that time. Note that even though nitrate-N levels were generally below detection levels, *Anabaena* and *Aphanizomenon* have the ability to fix atmospheric nitrogen to support their growth.
- In 2022, unicellular green algae dominated in mid-August, but by early September cyanobacteria again dominated (*Aphanizomenon* and fine *Oscillatoria*). By early October, *Apanizomenon* still dominated the population with a variety of other algae present. Again, this corresponded to the relative peaks in chlorophyll and phycocyanin.
- The buildup of phytoplankton populations in the west pond would indicate a decline in water quality over the 3 years of the study.

<u>HTS</u>

- Sample points for the HTS included the influent (the drain water entering the HTS), and samples taken after each media cell (post cell 1, 2 and 3). Results were averaged for each sampling point over each year of sampling.
- Influent levels of nitrate-N and total and ortho-P were significant, but dropped after the water travelled through the HTS.
- Nitrate-N decreased in 2021 by more than 85% after moving through the woodchip cell, reaching the detection limit of the laboratory, and over 65% in 2022, (Note: The swale was not completed until late spring of 2021 so there is no post cell 1, 2, or 3 data in 2020).
- Total P decreased slightly in 2021 by approximately 30% after the woodchip cell but not in 2021. However total P was significantly lower after the slag cell (approx. 60% in 2021 and 70% in 2022). Ortho-P values (dissolved reactive portion of P) were analysed separately by the laboratory, and reported values were often higher than total P (as measured by ion-coupling plasma technology, or ICP). Ortho-P levels also

decreased in some cases, up to 56% by the woodchips in 2021, and a further 45% after the slag cell. However, in 2022 the numbers are difficult to interpret, with slight increases in ortho-P after the woodchip cell and a 44% decrease in ortho-P after the slag cell.

Overall Recommendations:

Shallow woodchip media beds have clear potential for removal of nitrate-N from fertilizer and production leachate prior to reaching a watercourse. There is evidence from this and previous trials (Hybrid Treatment Systems, Soil Resource Group, 2014-2018) that when P levels are high, woodchips can bind a portion. The application of this technology to commercial operations should be promoted as a best management practice to prevent nutrient runoff from reaching the environment. Shallow hybrid treatment swales, acting passively with a gentle slope, have incredible potential to remove nitrate-N and P from outdoor field production water. Water quality exiting the HTS in this study was still exceeded commonly accepted guidelines for P but met the requirement for N. Design adjustments for shallow systems need to be tailored to each site's specific inputs, layout and ultimate discharge quality desired. These systems do not require any plumbing, however, still require a significant footprint along the edge of field, depending on the complexity of the media choices.

General Recommendations

Standard practices for irrigation pond management (e.g., aeration alone) are not sufficient to maintain water quality at an acceptable level throughout the growing season. In this study, selected technologies improved pond water quality over existing levels to increase suitability for re-use on crops as well as minimizing the impact on the environment.

The amount of existing organic matter in the sediment and nutrient loading occurring must be factored into the solutions considered for managing pond water quality. It is perhaps simplest to consider the types of solutions for new ponds separately from existing ponds that have a build-up of organic matter.

For new ponds, the primary objective is the "keep the pond clean". This concept appears so simple, but in reality, re-capture ponds are intentionally collecting leachate and runoff from a mix of areas and activities. Outdoor production can be fertilized with soluble and controlled (slow) release fertilizers, there can be residual fertilizer and nutrients coming from product in staging yards; plus, water can move both over the land (surface runoff) and through subsurface drainage systems. Capturing and managing the water quality of each of these potential sources prior to reaching the pond can be challenging, so upstream best management practices that consider fertilizer choices, rates and timing of application, as well as irrigation practices to limit runoff and subsurface flow are critical. Prior to reaching ponds, cover crops or other vegetated areas can help mitigate nutrient flow to pond by holding back water and uptake of nutrients. In this study, both under-plant media beds (woodchips with and without slag) and an edge-of-field hybrid treatment swale were successful in decreasing the key nutrients N and P (although how to remove K and S is still a big mystery). It is important to remember that even very low levels of nutrient inputs can quickly deteriorate water quality in a pond. Nutrient analysis alone is not always the most accurate way to assess overall pond health.

For older ponds that have sediments that are holding nutrients, organic matter, and potentially spores or dormant forms of nuisance cyanobacteria and algae, a range of in-pond treatments must be considered *in addition to the prevention of additional nutrient loading*. Promising treatments include aeration (e.g., nanobubblers for deeper ponds, traditional airstones for shallow or small ponds), and covering ponds, either with physical covers or plantings. Physical covers are expensive, but do not require continual harvesting and maintenance. Polishing of the water through use of aquatic vegetation also may have value, but with low-nutrient level ponds, their effectiveness may be limited as a one-stop solution. However, plantings of rooted aquatic vegetation (e.g., *Pontedaria*) around the shoreline may help keep the water nutrient levels low, but periodic harvesting of some of the biomass is recommended. It is most likely that a combination of technologies will work better – for example using a cover combined with aeration, so that further growth of phytoplankton is inhibited, and aerobic degradation of sediment organic matter can continue and gradually improve the health of the pond over time.

Acknowledgements

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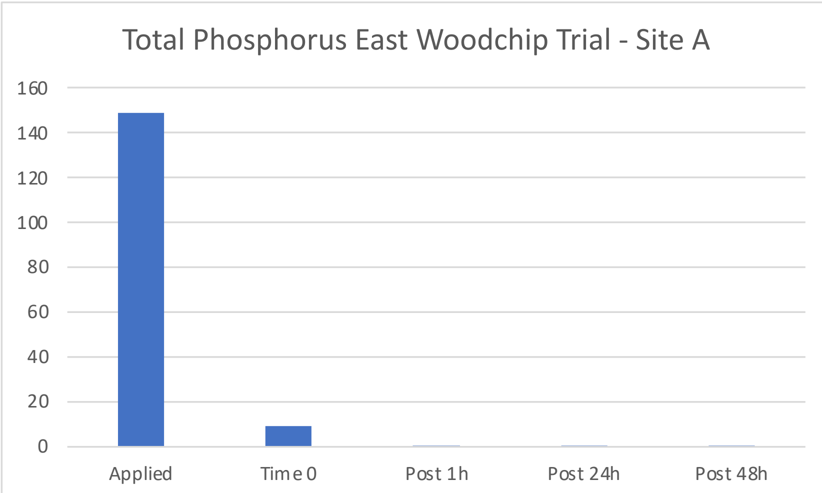
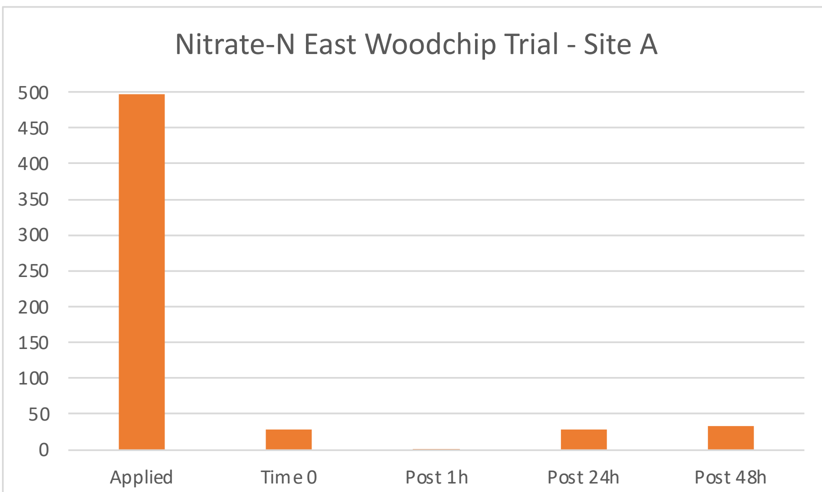
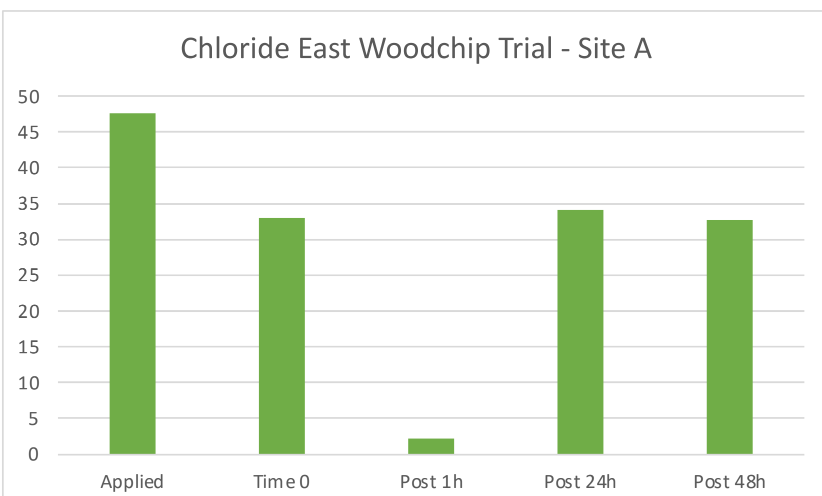
Appendix 1 – Site A Selected Results

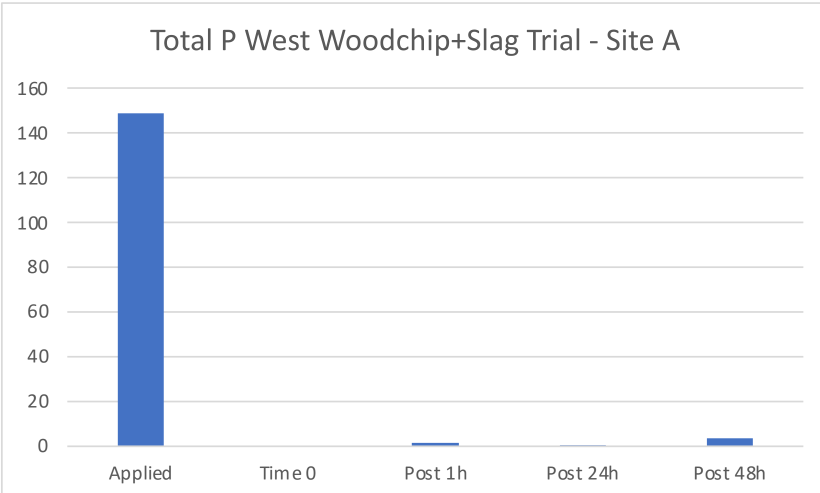
Woodchip trial bed, chloride shows movement of fertilizer through bed

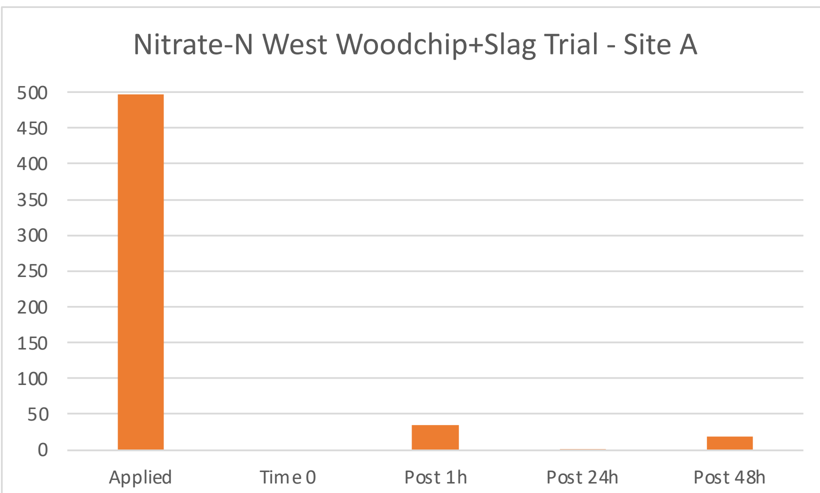


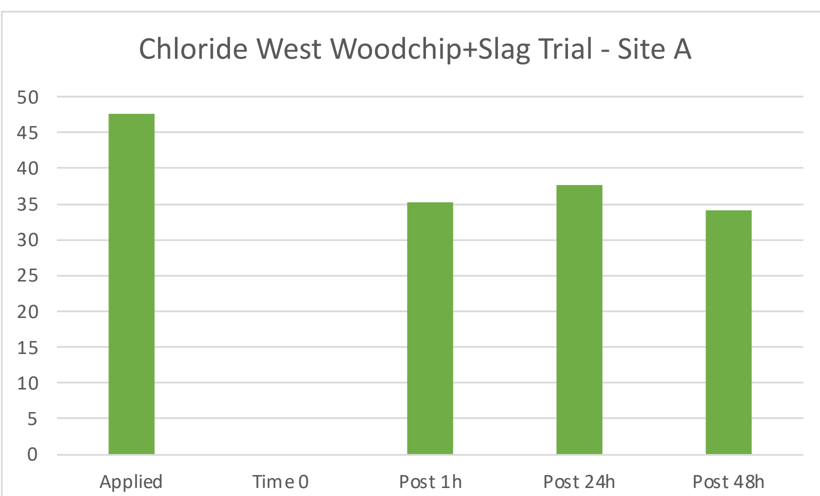




Woodchip plus slag trial bed, chloride shows movement of fertilizer through bed (note, no sample from this bed immediately after applying fertilizer)

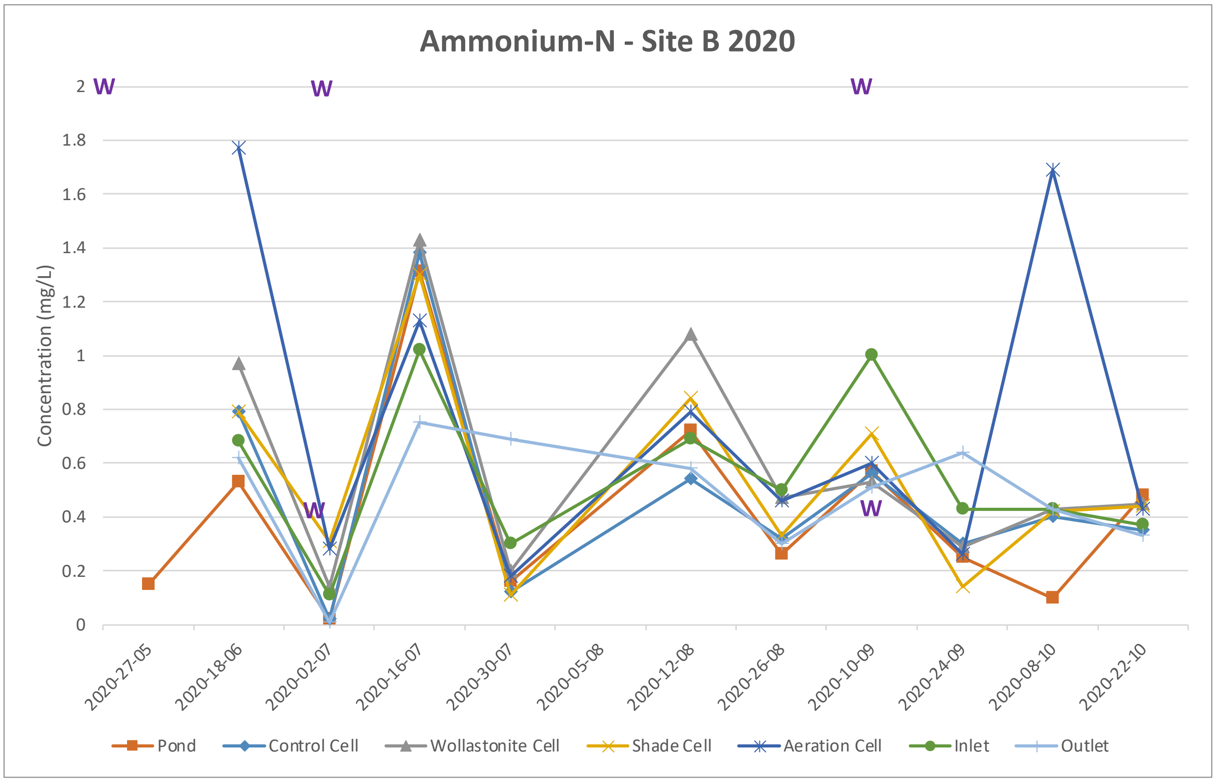


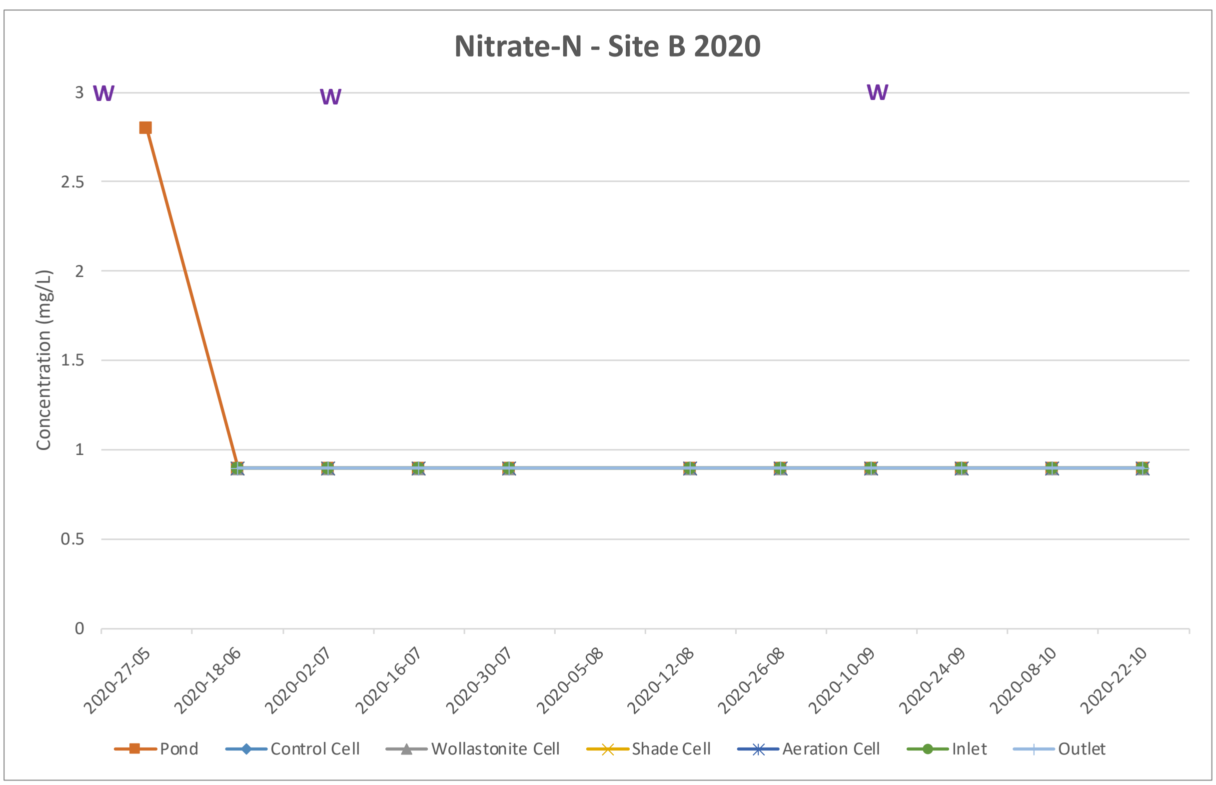


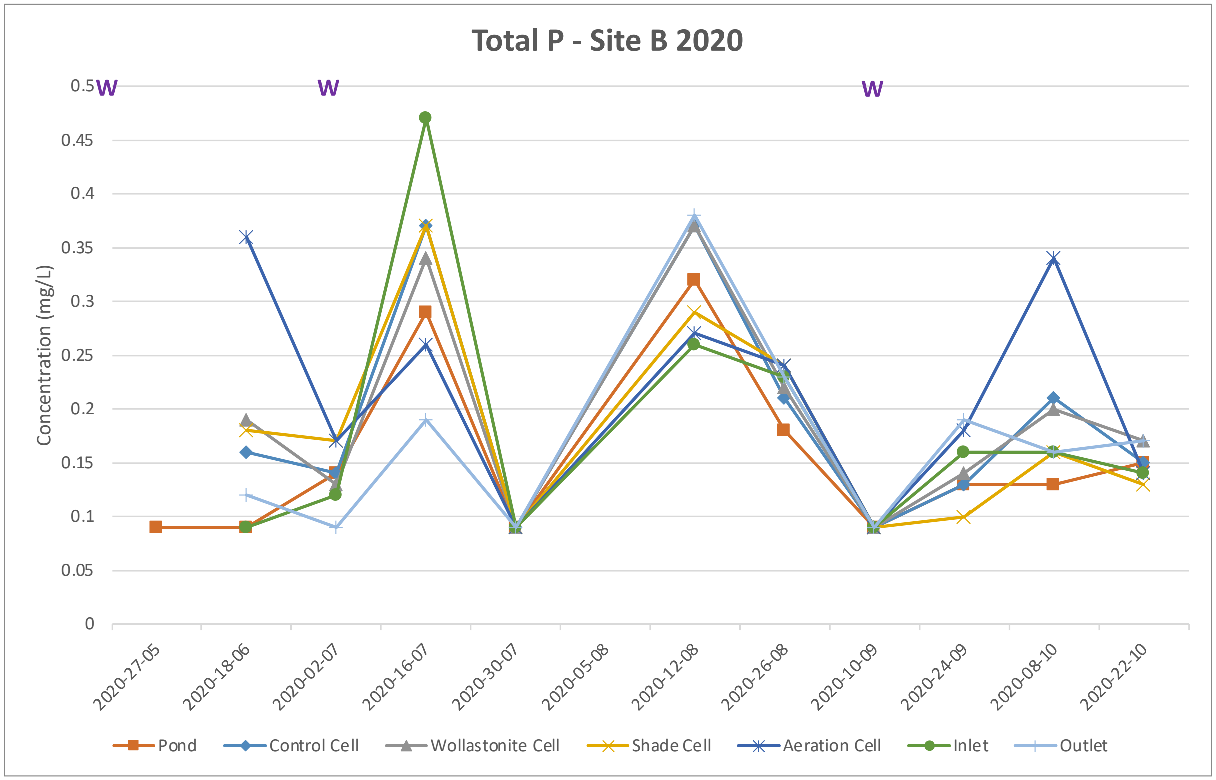


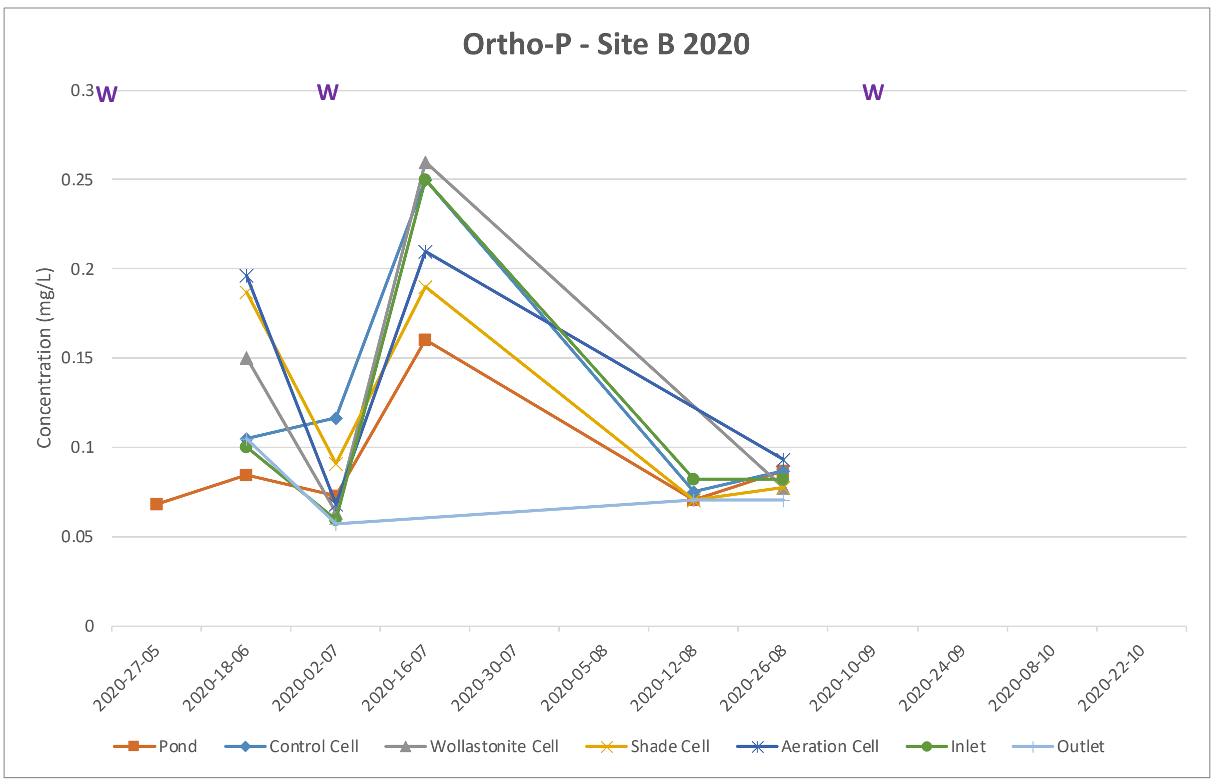
Appendix 2 – Site B Selected Results

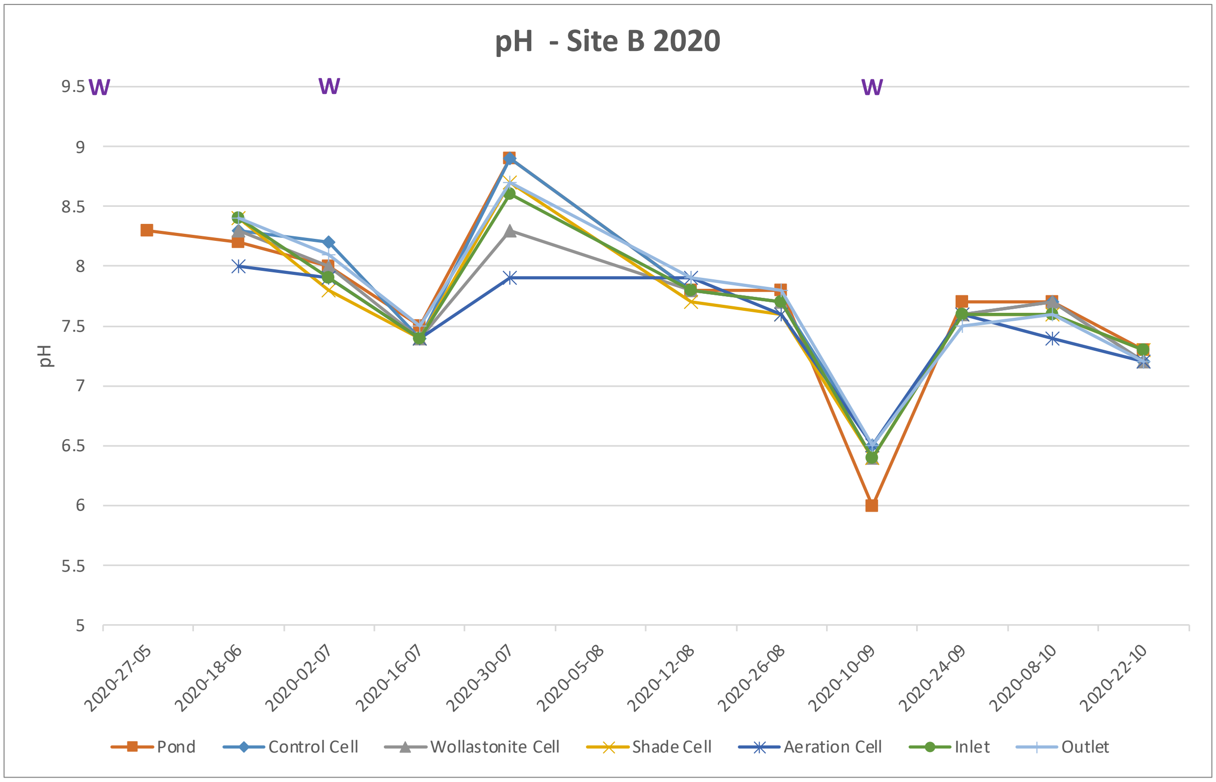
2020 mesocosms



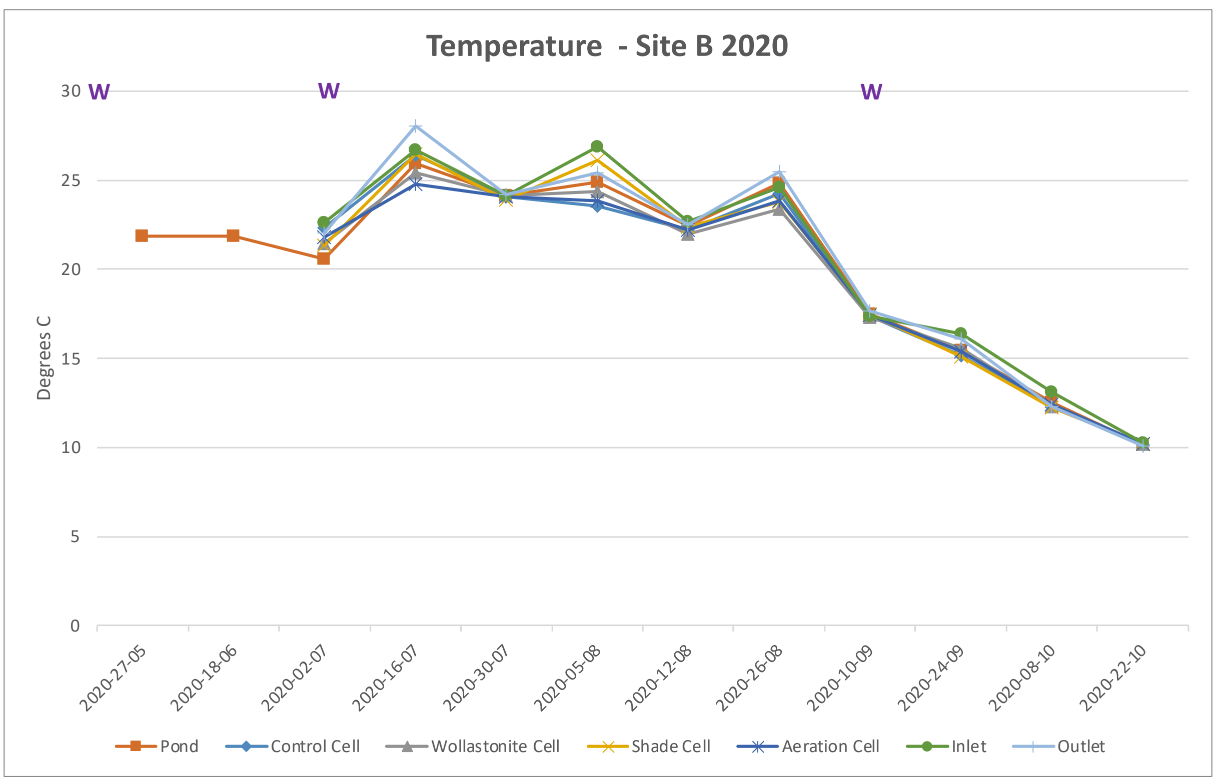



Total P - Site B 2020
W
W
W
Concentration (mg/L)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2020-27-05
2020-18-06
2020-02-07
2020-16-07
2020-30-07
2020-05-08
2020-12-08
2020-26-08
2020-10-09
2020-24-09
2020-08-10
2020-22-10
Pond
Control Cell
Wollastonite Cell
Shade Cell
Aeration Cell
Inlet
Outlet

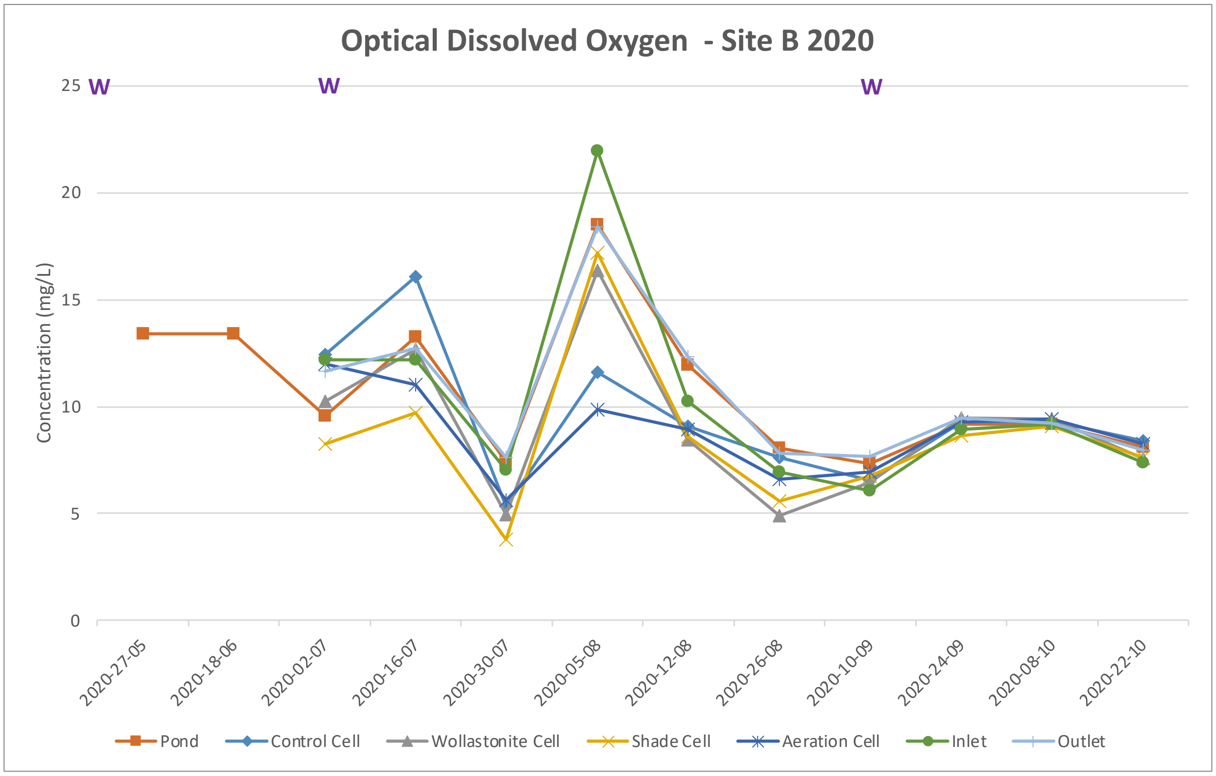

Ortho-P - Site B 2020
W
W
W
Concentration (mg/L)
0.3
0.25
0.2
0.15
0.1
0.05
0
2020-27-05
2020-18-06
2020-02-07
2020-16-07
2020-30-07
2020-05-08
2020-12-08
2020-26-08
2020-10-09
2020-24-09
2020-08-10
2020-22-10
Pond
Control Cell
Wollastonite Cell
Shade Cell
Aeration Cell
Inlet
Outlet



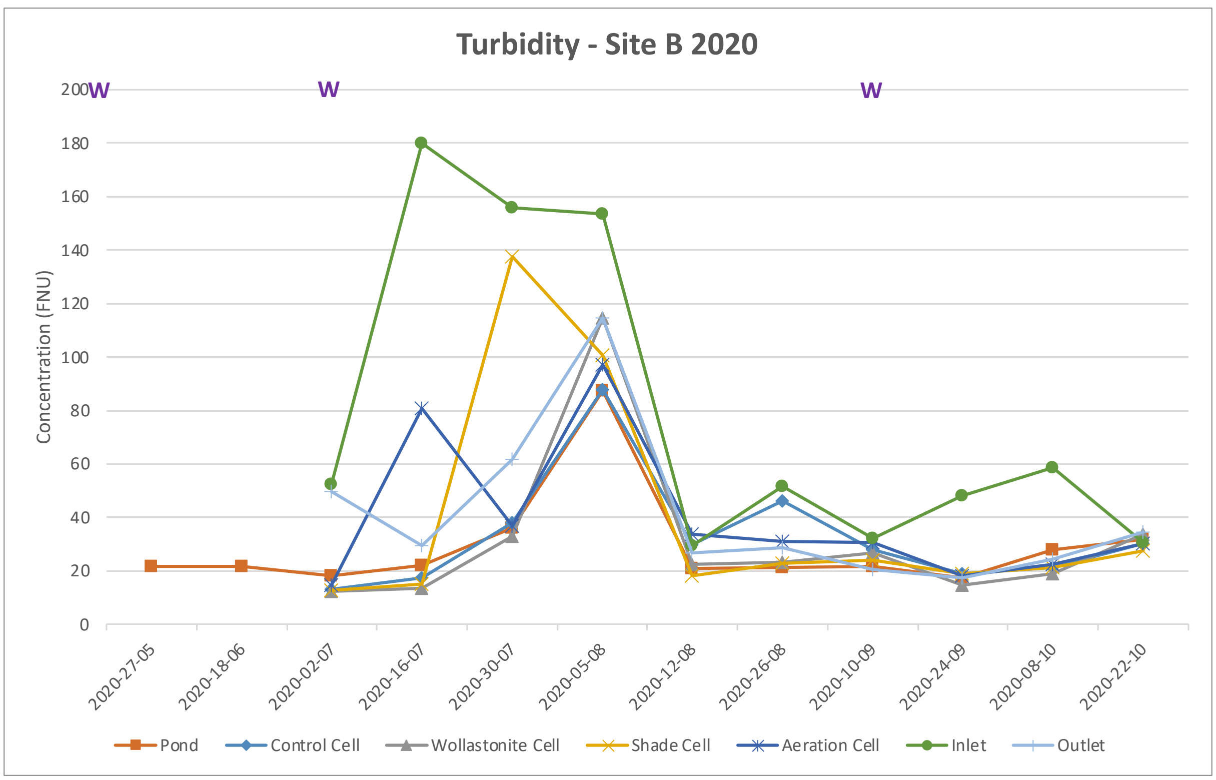
pH - Site B 2020
W
W
W
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
pH
2020-27-05
2020-18-06
2020-02-07
2020-16-07
2020-30-07
2020-05-08
2020-12-08
2020-26-08
2020-10-09
2020-24-09
2020-08-10
2020-22-10
Pond
Control Cell
Wollastonite Cell
Shade Cell
Aeration Cell
Inlet
Outlet



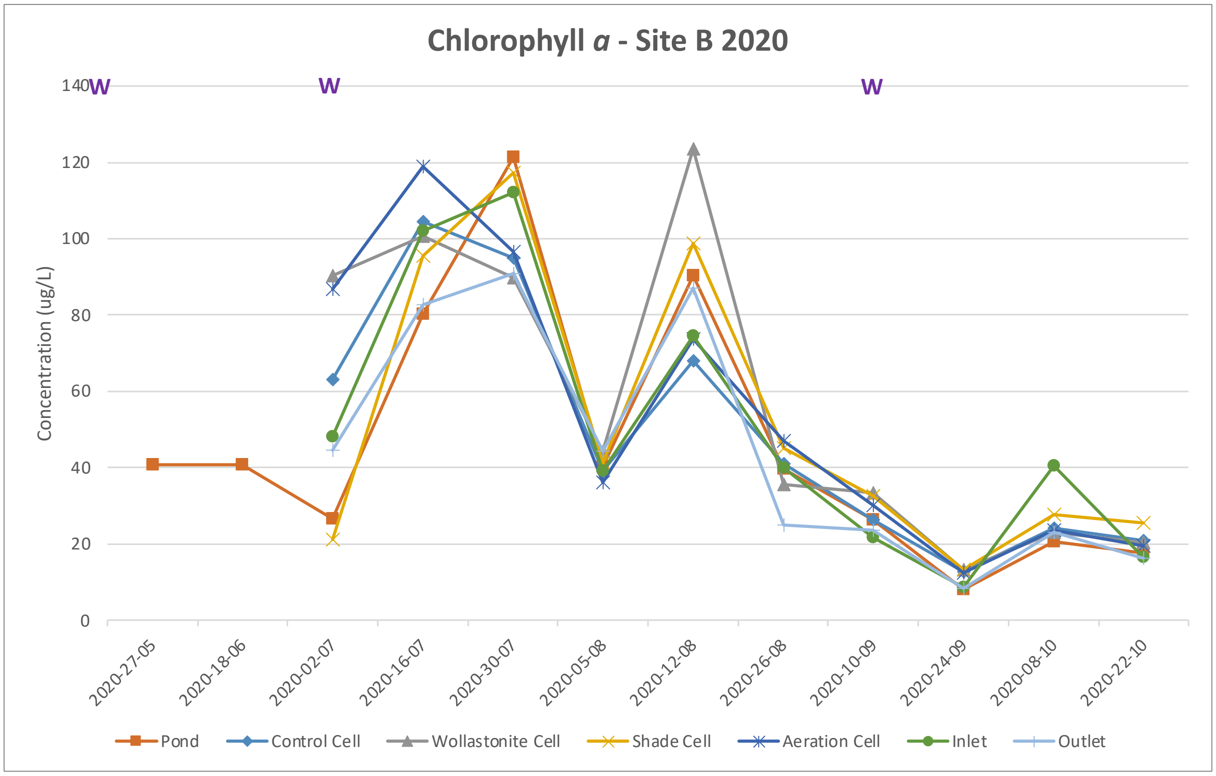
Temperature - Site B 2020
W
W
W
30
25
20
15
10
5
0
Degrees C
2020-27-05
2020-18-06
2020-02-07
2020-16-07
2020-30-07
2020-05-08
2020-12-08
2020-26-08
2020-10-09
2020-24-09
2020-08-10
2020-22-10
Pond
Control Cell
Wollastonite Cell
Shade Cell
Aeration Cell
Inlet
Outlet



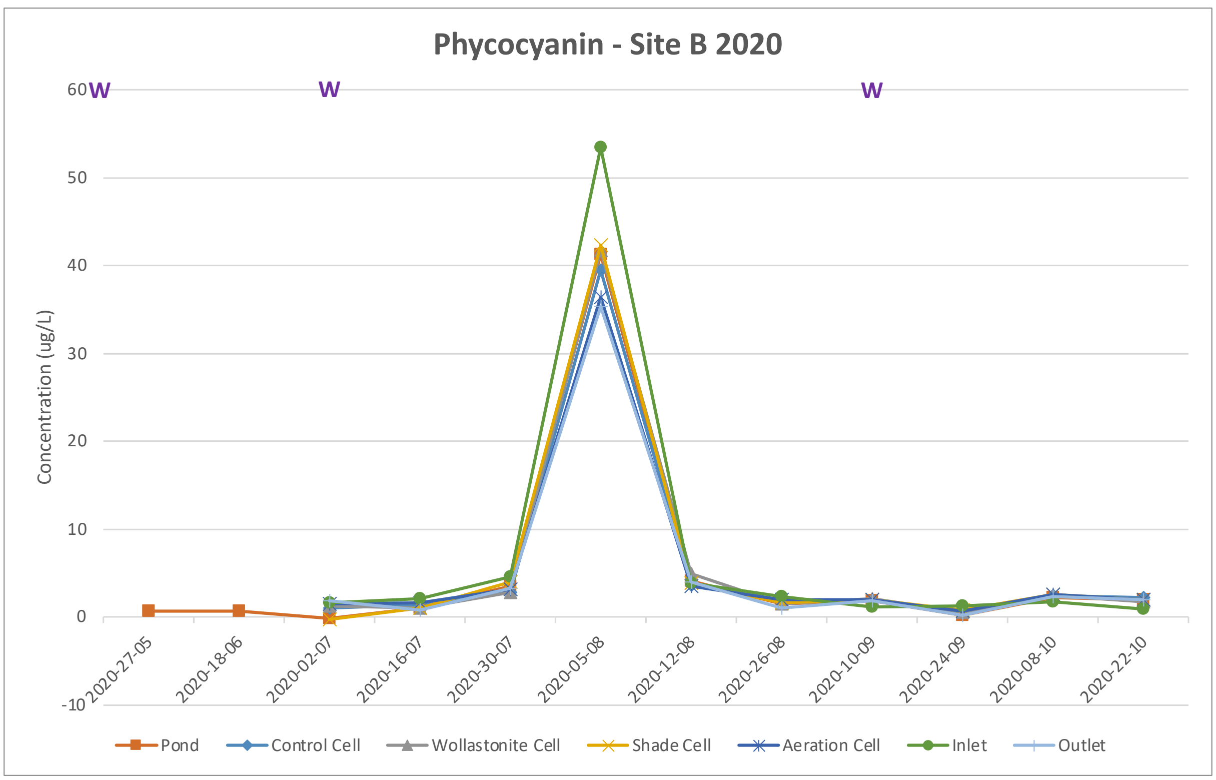
Optical Dissolved Oxygen - Site B 2020
Concentration (mg/L)
W
W
W
0
5
10
15
20
25
2020-27-05
2020-18-06
2020-02-07
2020-16-07
2020-30-07
2020-05-08
2020-12-08
2020-26-08
2020-10-09
2020-24-09
2020-08-10
2020-22-10
Pond
Control Cell
Wollastonite Cell
Shade Cell
Aeration Cell
Inlet
Outlet



Turbidity - Site B 2020
Concentration (FNU)
W
W
W
0
20
40
60
80
100
120
140
160
180
200
2020-27-05
2020-18-06
2020-02-07
2020-16-07
2020-30-07
2020-05-08
2020-12-08
2020-26-08
2020-10-09
2020-24-09
2020-08-10
2020-22-10
Pond
Control Cell
Wollastonite Cell
Shade Cell
Aeration Cell
Inlet
Outlet

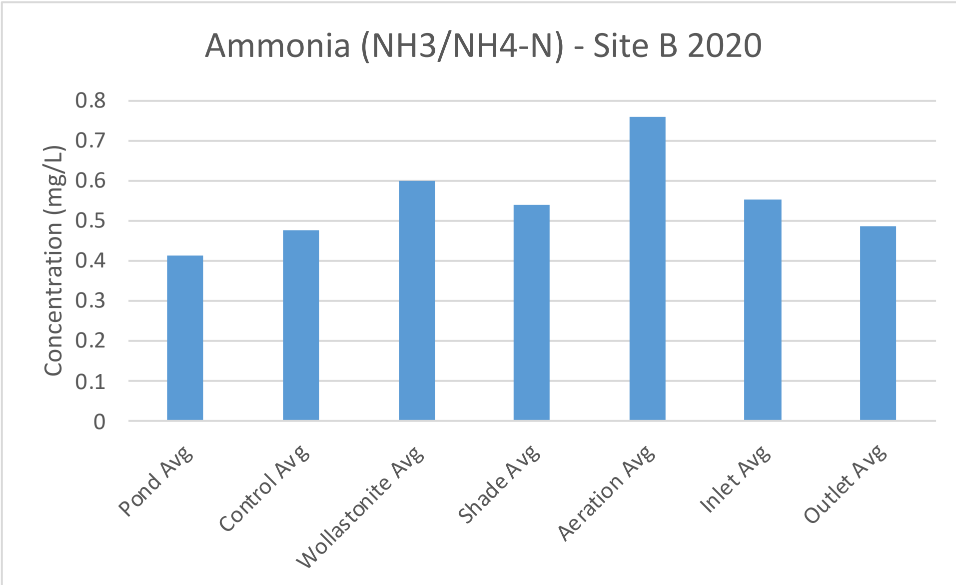


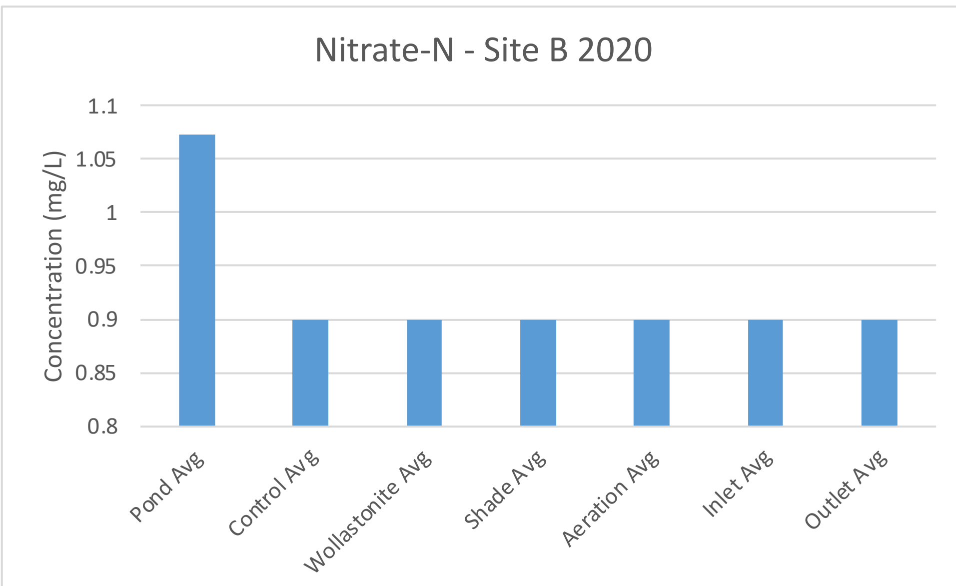
Chlorophyll a - Site B 2020
W
W
W
140
120
100
80
60
40
20
0
Concentration (ug/L)
2020-27-05
2020-18-06
2020-02-07
2020-16-07
2020-30-07
2020-05-08
2020-12-08
2020-26-08
2020-10-09
2020-24-09
2020-08-10
2020-22-10
Pond
Control Cell
Wollastonite Cell
Shade Cell
Aeration Cell
Inlet
Outlet

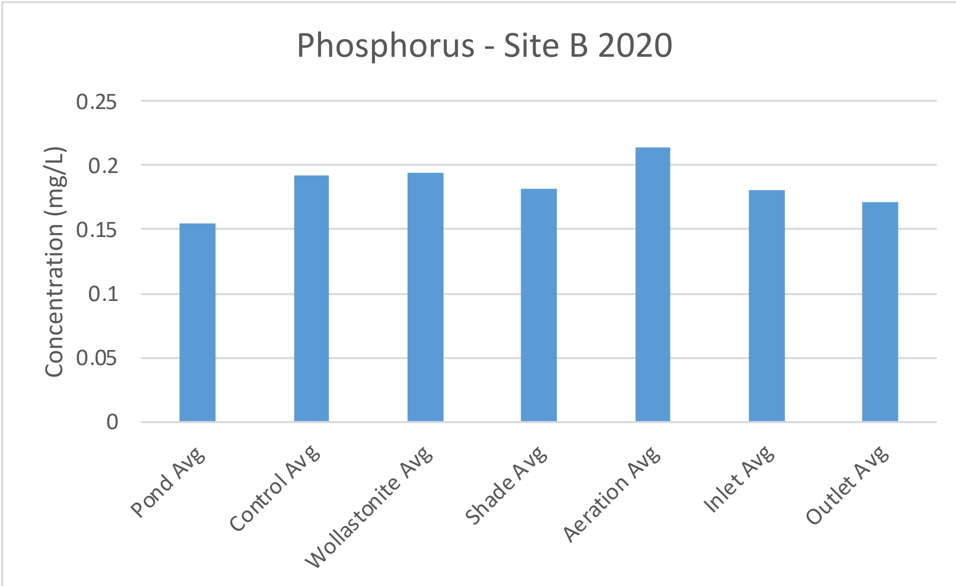


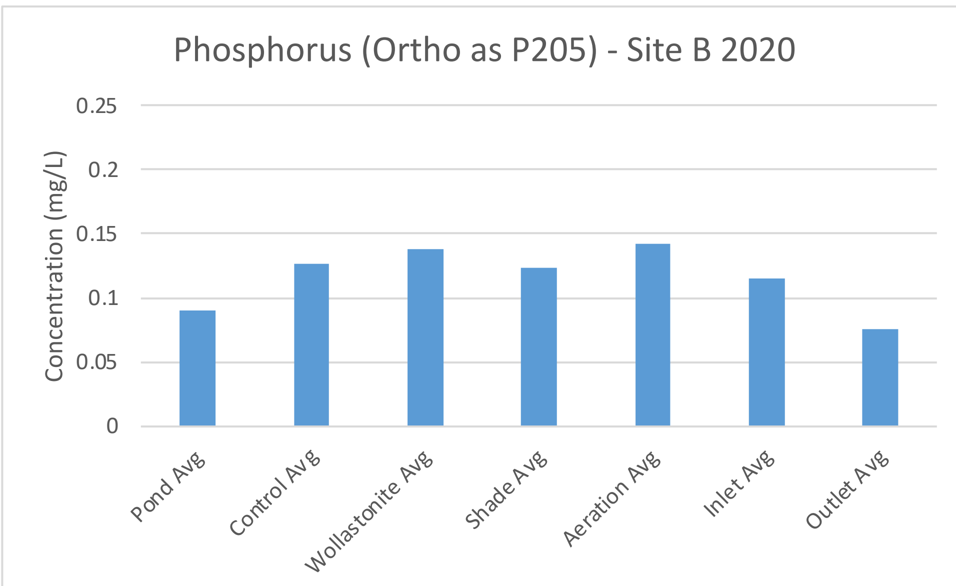
Phycocyanin - Site B 2020
W
W
W
60
50
40
30
20
10
0
-10
Concentration (ug/L)
2020-27-05
2020-18-06
2020-02-07
2020-16-07
2020-30-07
2020-05-08
2020-12-08
2020-26-08
2020-10-09
2020-24-09
2020-08-10
2020-22-10
Pond
Control Cell
Wollastonite Cell
Shade Cell
Aeration Cell
Inlet
Outlet

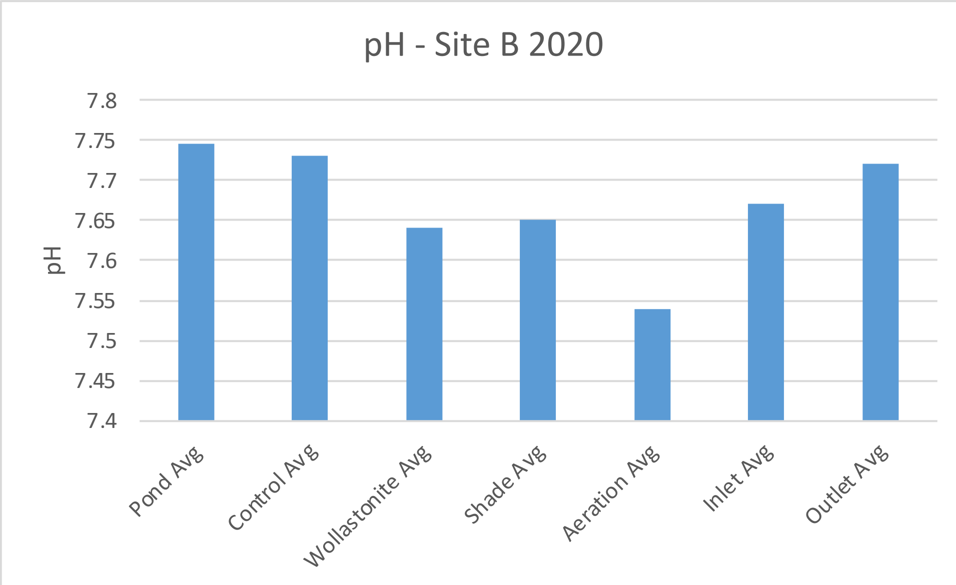
2020 Averages Site B

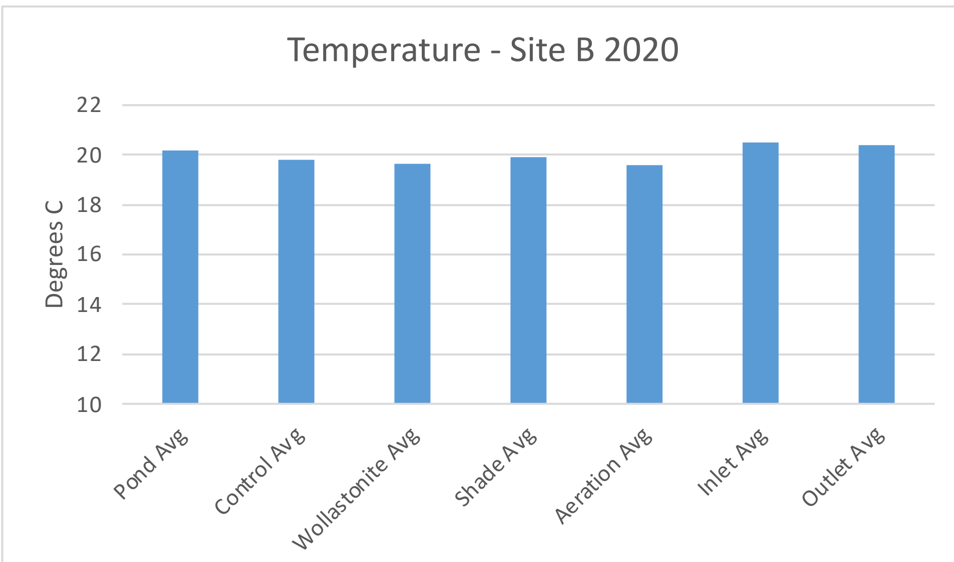


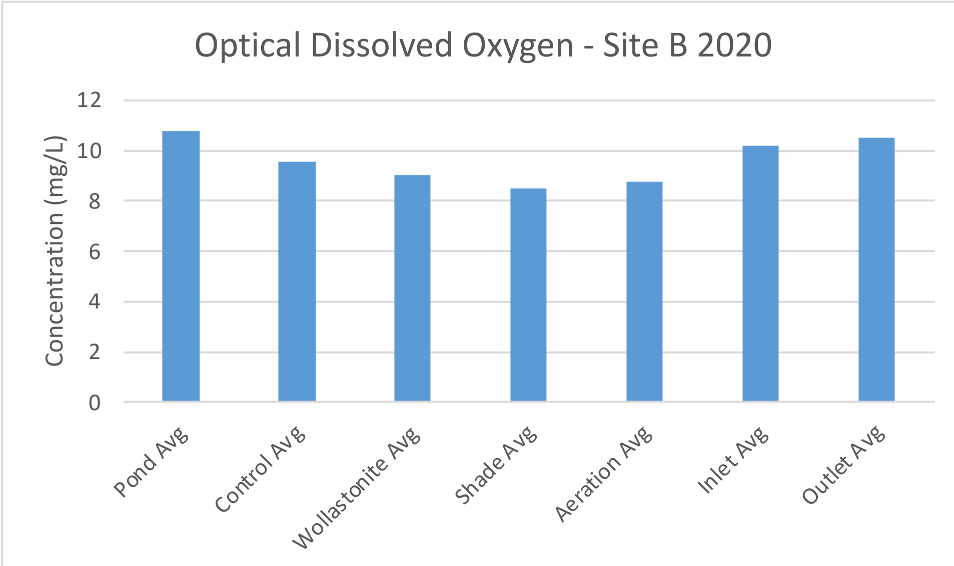


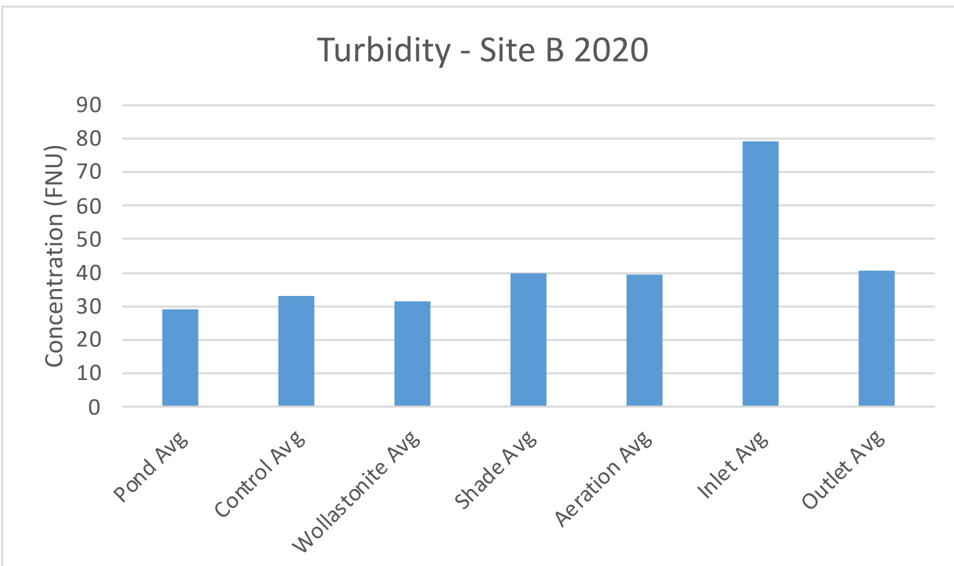

Phosphorus - Site B 2020
Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
Pond Avg
Control Avg
Wollastonite Avg
Shade Avg
Aeration Avg
Inlet Avg
Outlet Avg

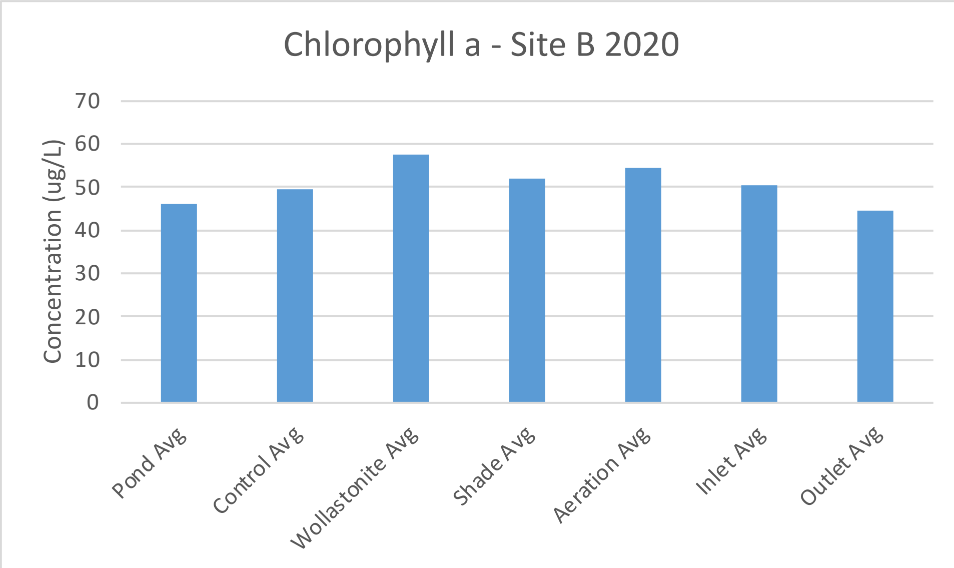

Phosphorus (Ortho as P205) - Site B 2020
Concentration (mg/L)
0.25
0.2
0.15
0.1
0.05
0
Pond Avg
Control Avg
Wollastonite Avg
Shade Avg
Aeration Avg
Inlet Avg
Outlet Avg


pH - Site B 2020
pH
7.8
7.75
7.7
7.65
7.6
7.55
7.5
7.45
7.4
Pond Avg
Control Avg
Wollastonite Avg
Shade Avg
Aeration Avg
Inlet Avg
Outlet Avg

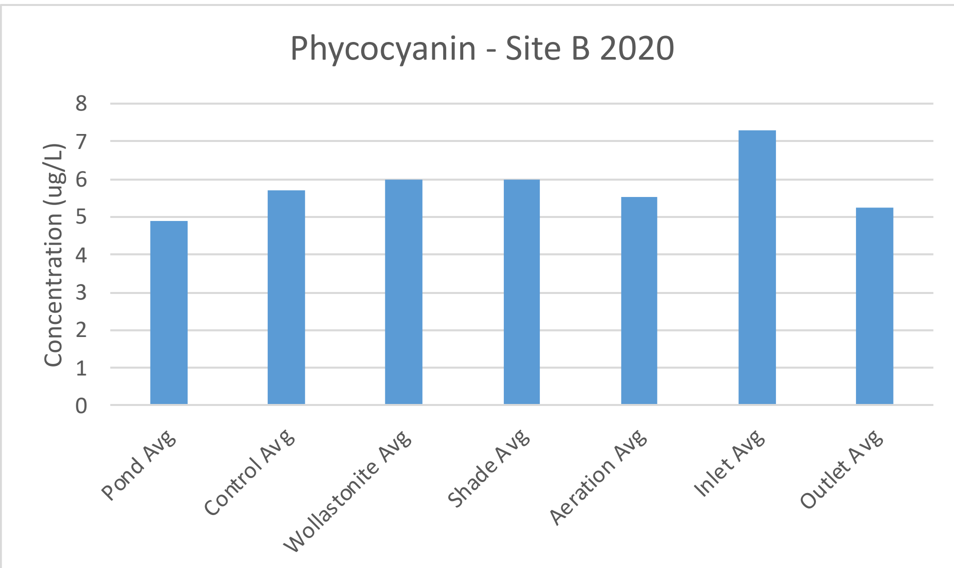

Temperature - Site B 2020
Degrees C
22
20
18
16
14
12
10
Pond Avg
Control Avg
Wollastonite Avg
Shade Avg
Aeration Avg
Inlet Avg
Outlet Avg


Optical Dissolved Oxygen - Site B 2020
Concentration (mg/L)
0
2
4
6
8
10
12
Pond Avg
Control Avg
Wollastonite Avg
Shade Avg
Aeration Avg
Inlet Avg
Outlet Avg


Turbidity - Site B 2020
Concentration (FNU)
0
10
20
30
40
50
60
70
80
90
Pond Avg
Control Avg
Wollastonite Avg
Shade Avg
Aeration Avg
Inlet Avg
Outlet Avg

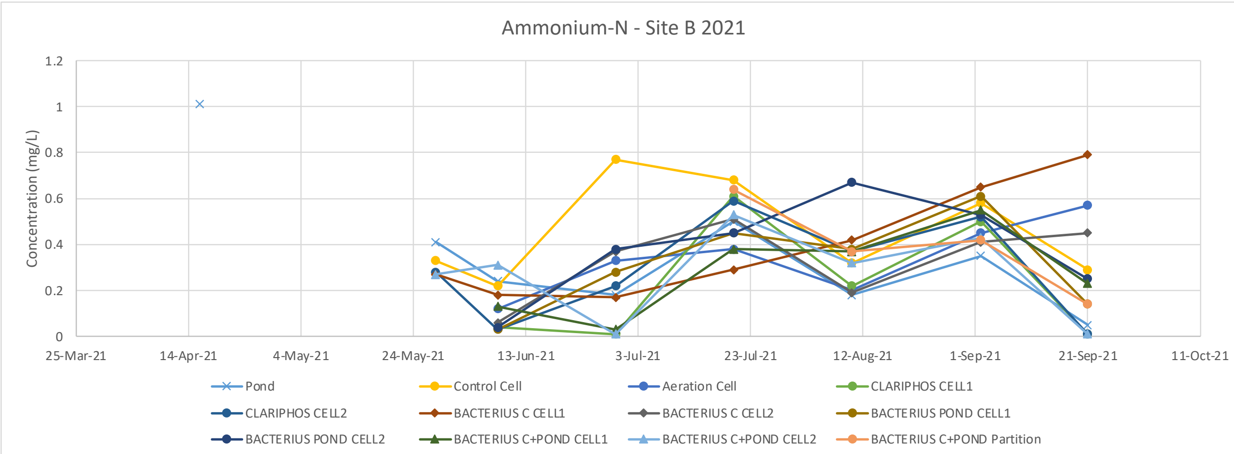


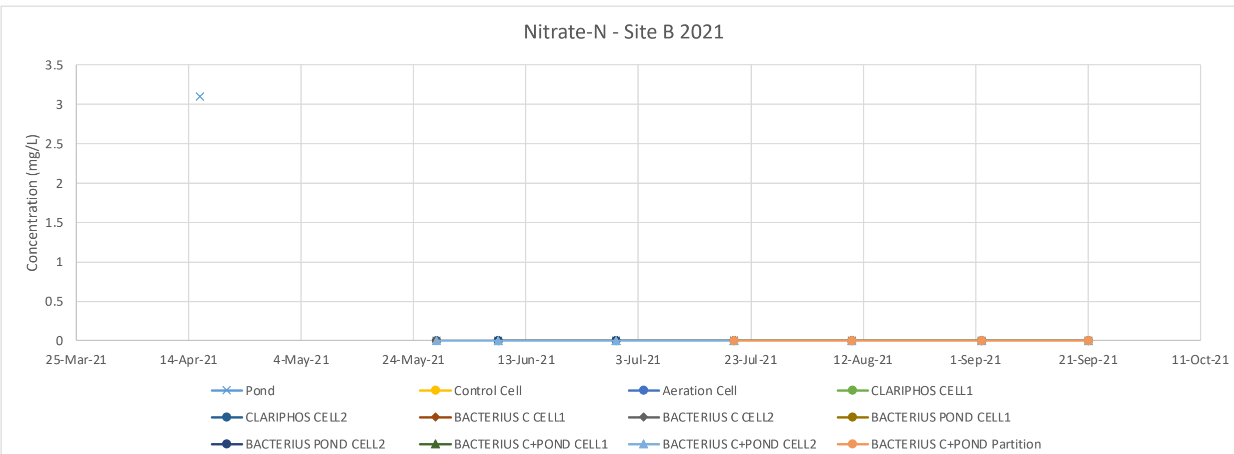
Chlorophyll a - Site B 2020
Concentration (ug/L)
0
10
20
30
40
50
60
70
Pond Avg
Control Avg
Wollastonite Avg
Shade Avg
Aeration Avg
Inlet Avg
Outlet Avg

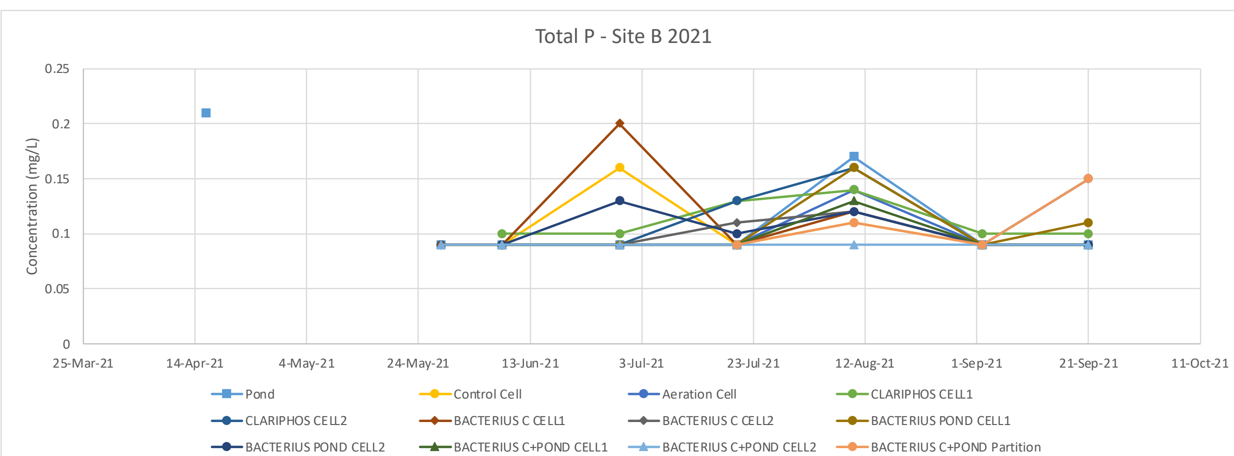


Phycocyanin - Site B 2020
Concentration (ug/L)
0
1
2
3
4
5
6
7
8
Pond Avg
Control Avg
Wollastonite Avg
Shade Avg
Aeration Avg
Inlet Avg
Outlet Avg

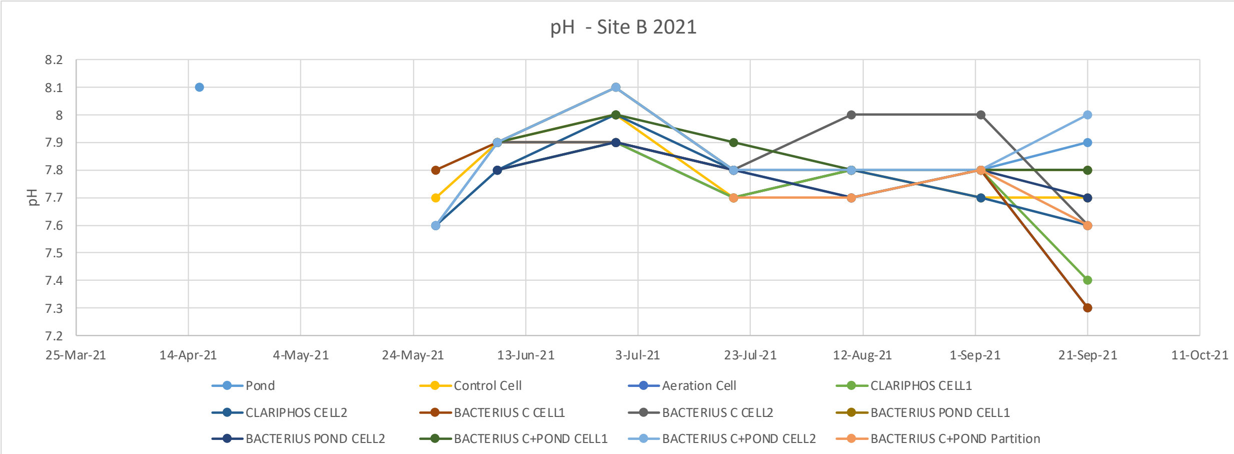
2021 mesocosms (first by date, then averages follow the in/out graphs by date)

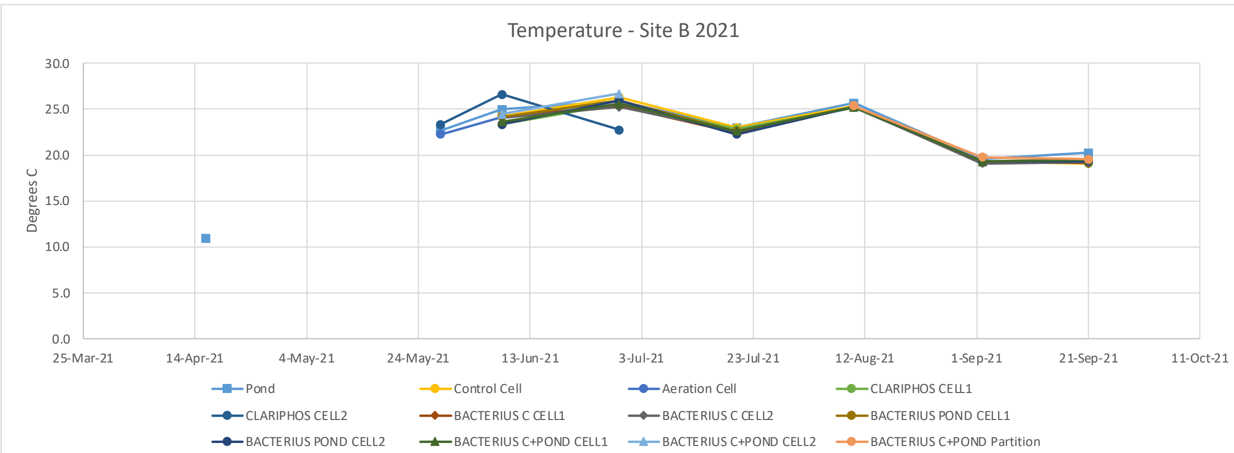


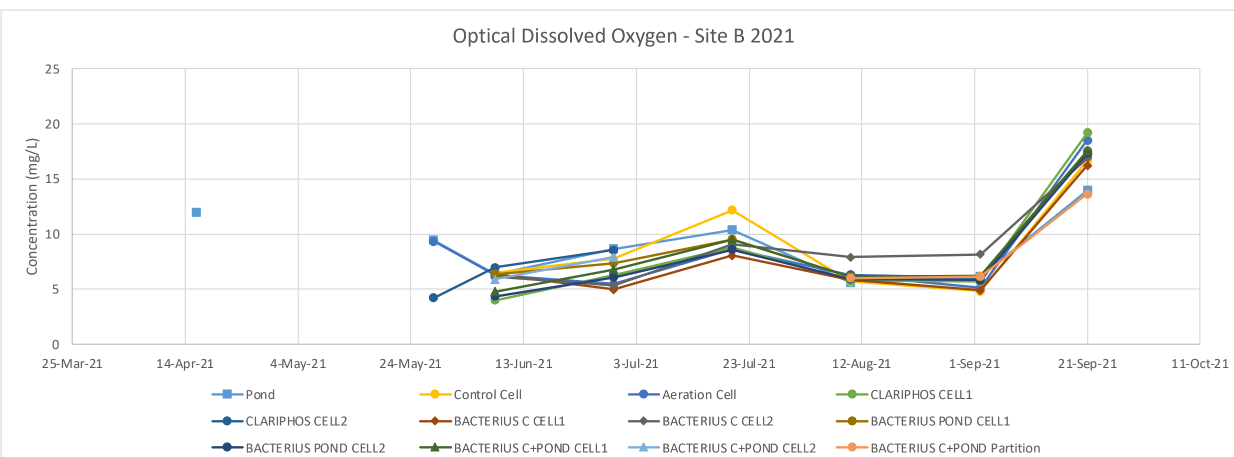


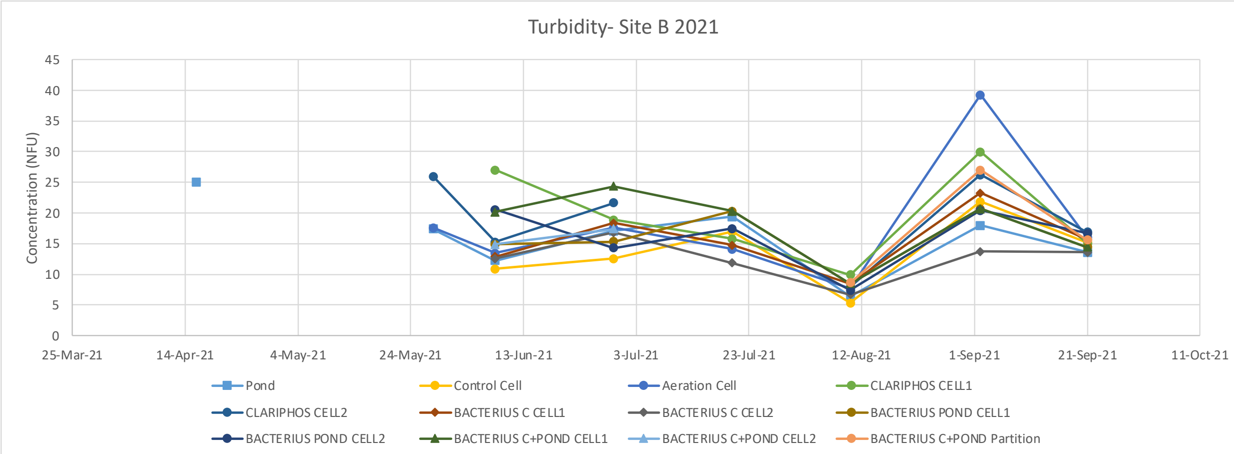


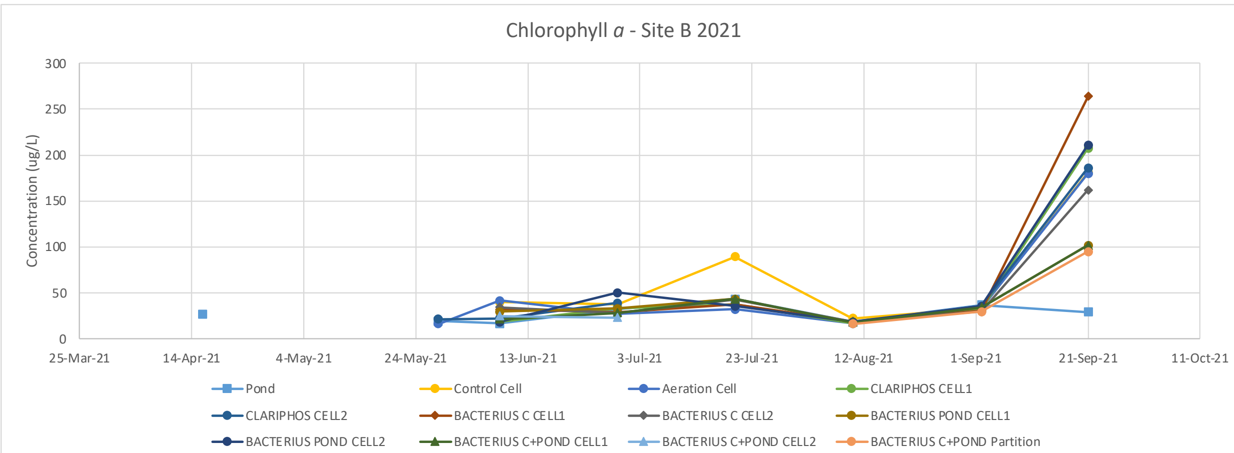
Ortho-P all below detection limit (BDL), data not shown

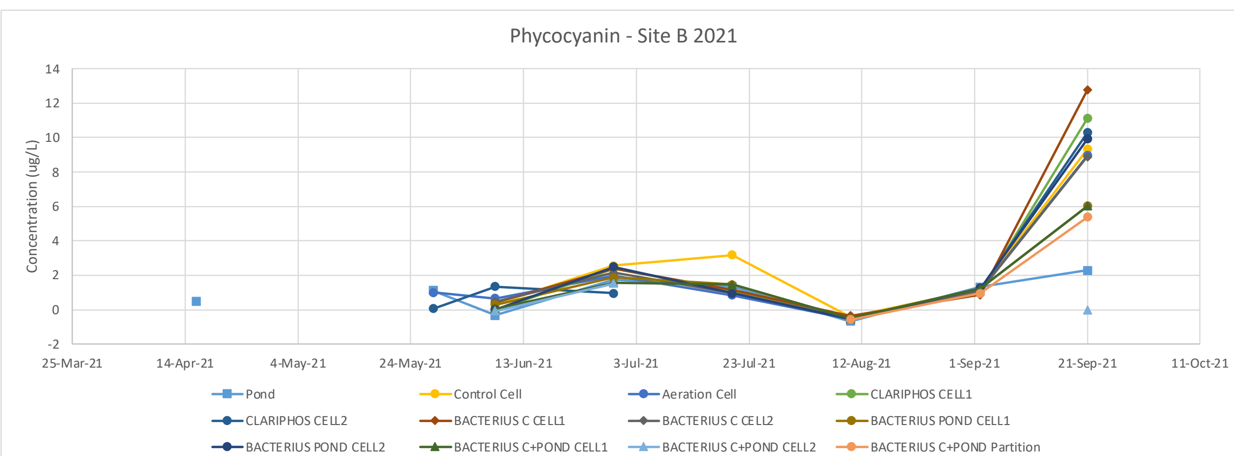

pH - Site B 2021
pH
8.2
8.1
8
7.9
7.8
7.7
7.6
7.5
7.4
7.3
7.2
25-Mar-21
14-Apr-21
4-May-21
24-May-21
13-Jun-21
3-Jul-21
23-Jul-21
12-Aug-21
1-Sep-21
21-Sep-21
11-Oct-21
Pond
Control Cell
Aeration Cell
CLARIPHOS CELL1
CLARIPHOS CELL2
BACTERIUS C CELL1
BACTERIUS C CELL2
BACTERIUS POND CELL1
BACTERIUS POND CELL2
BACTERIUS C+POND CELL1
BACTERIUS C+POND CELL2
BACTERIUS C+POND Partition


Temperature - Site B 2021
Degrees C
30.0
25.0
20.0
15.0
10.0
5.0
0.0
25-Mar-21
14-Apr-21
4-May-21
24-May-21
13-Jun-21
3-Jul-21
23-Jul-21
12-Aug-21
1-Sep-21
21-Sep-21
11-Oct-21
Pond
Control Cell
Aeration Cell
CLARIPHOS CELL1
CLARIPHOS CELL2
BACTERIUS C CELL1
BACTERIUS C CELL2
BACTERIUS POND CELL1
BACTERIUS POND CELL2
BACTERIUS C+POND CELL1
BACTERIUS C+POND CELL2
BACTERIUS C+POND Partition

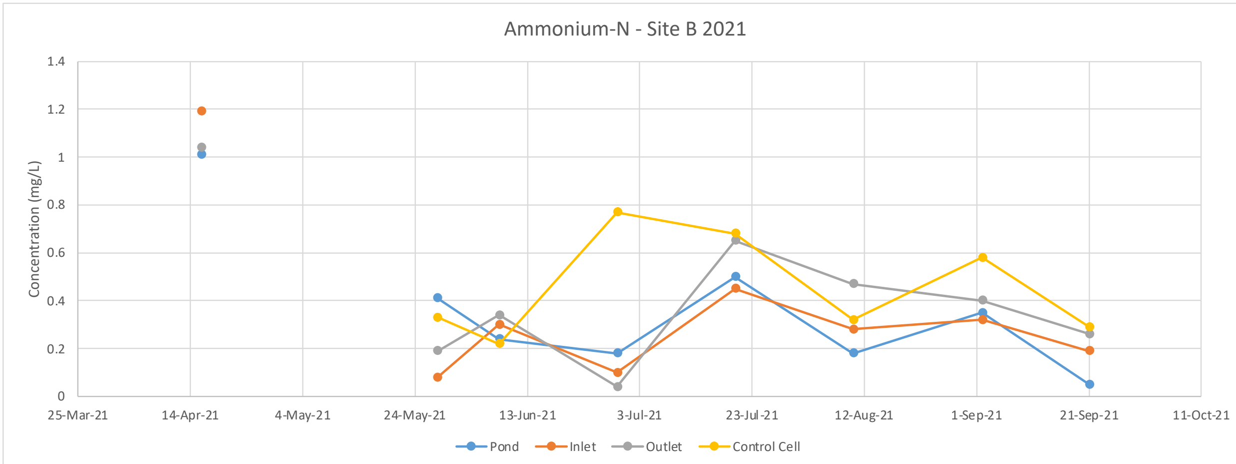

Optical Dissolved Oxygen - Site B 2021
Concentration (mg/L)
25
20
15
10
5
0
25-Mar-21
14-Apr-21
4-May-21
24-May-21
13-Jun-21
3-Jul-21
23-Jul-21
12-Aug-21
1-Sep-21
21-Sep-21
11-Oct-21
Pond
Control Cell
Aeration Cell
CLARIPHOS CELL1
CLARIPHOS CELL2
BACTERIUS C CELL1
BACTERIUS C CELL2
BACTERIUS POND CELL1
BACTERIUS POND CELL2
BACTERIUS C+POND CELL1
BACTERIUS C+POND CELL2
BACTERIUS C+POND Partition

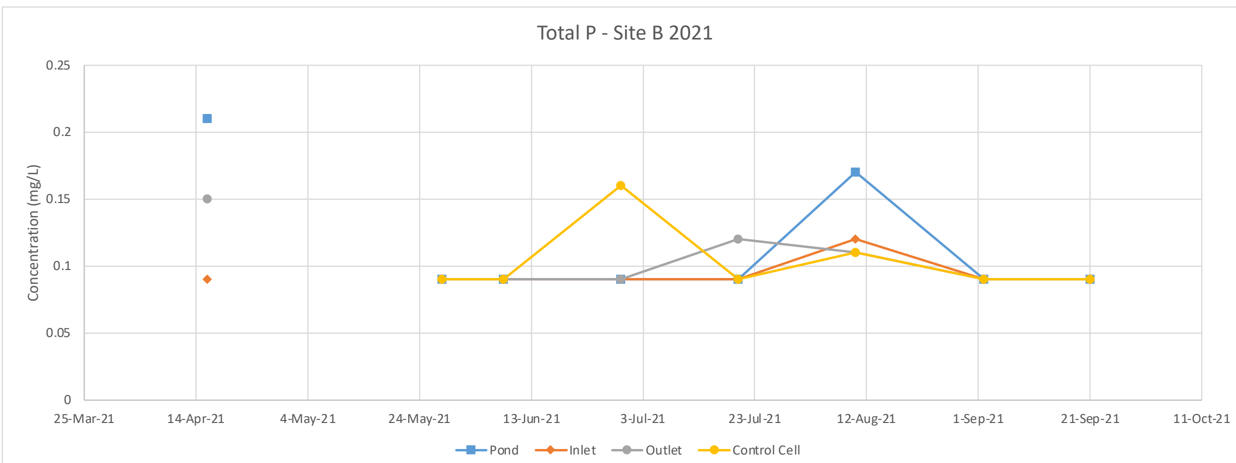

Turbidity- Site B 2021
Concentration (NFU)
45
40
35
30
25
20
15
10
5
0
25-Mar-21
14-Apr-21
4-May-21
24-May-21
13-Jun-21
3-Jul-21
23-Jul-21
12-Aug-21
1-Sep-21
21-Sep-21
11-Oct-21
Pond
Control Cell
Aeration Cell
CLARIPHOS CELL1
CLARIPHOS CELL2
BACTERIUS C CELL1
BACTERIUS C CELL2
BACTERIUS POND CELL1
BACTERIUS POND CELL2
BACTERIUS C+POND CELL1
BACTERIUS C+POND CELL2
BACTERIUS C+POND Partition


Chlorophyll *a* - Site B 2021
Concentration (ug/L)
300
250
200
150
100
50
0
25-Mar-21
14-Apr-21
4-May-21
24-May-21
13-Jun-21
3-Jul-21
23-Jul-21
12-Aug-21
1-Sep-21
21-Sep-21
11-Oct-21
Pond
Control Cell
Aeration Cell
CLARIPHOS CELL1
CLARIPHOS CELL2
BACTERIUS C CELL1
BACTERIUS C CELL2
BACTERIUS POND CELL1
BACTERIUS POND CELL2
BACTERIUS C+POND CELL1
BACTERIUS C+POND CELL2
BACTERIUS C+POND Partition

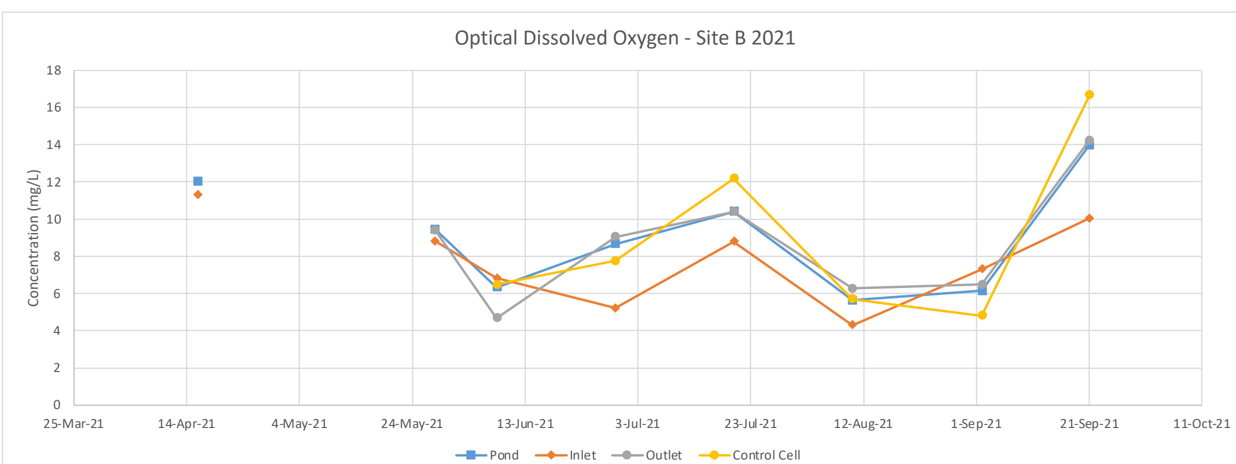

Phycocyanin - Site B 2021
Concentration (ug/L)
14
12
10
8
6
4
2
0
-2
25-Mar-21
14-Apr-21
4-May-21
24-May-21
13-Jun-21
3-Jul-21
23-Jul-21
12-Aug-21
1-Sep-21
21-Sep-21
11-Oct-21
Pond
Control Cell
Aeration Cell
CLARIPHOS CELL1
CLARIPHOS CELL2
BACTERIUS C CELL1
BACTERIUS C CELL2
BACTERIUS POND CELL1
BACTERIUS POND CELL2
BACTERIUS C+POND CELL1
BACTERIUS C+POND CELL2
BACTERIUS C+POND Partition

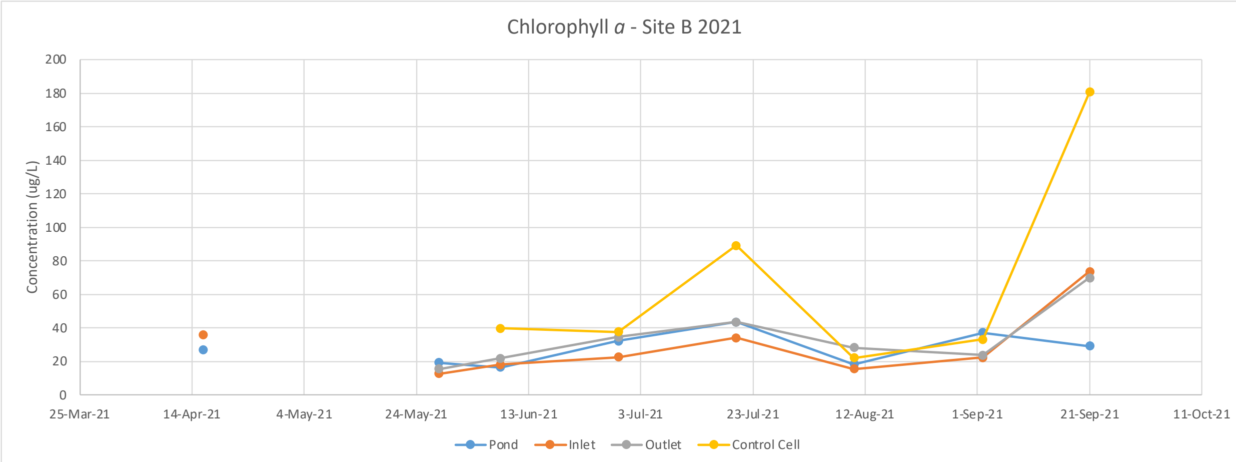
2021 in/out vs pond, control mesocosm (by date, averages follow) – selected data only

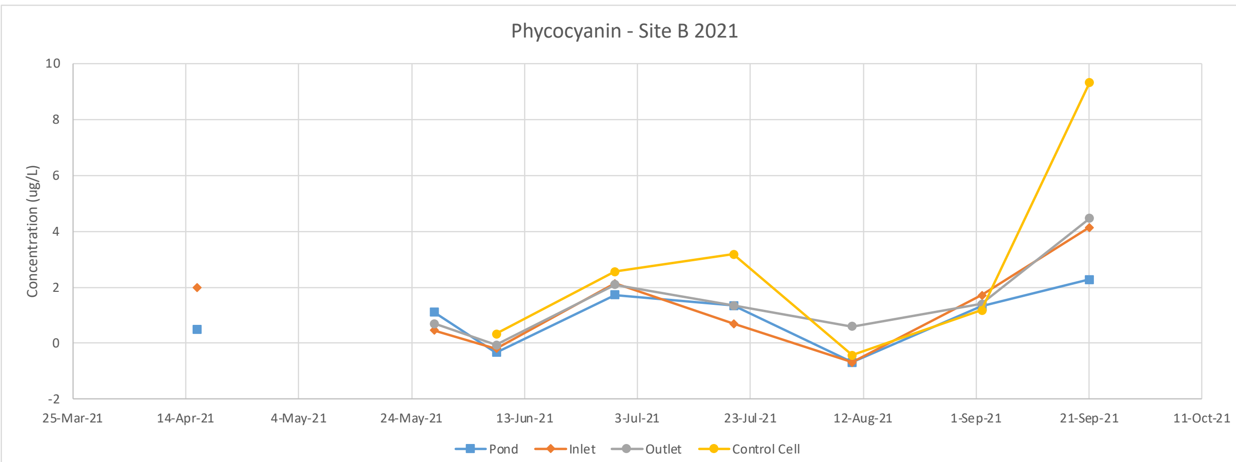




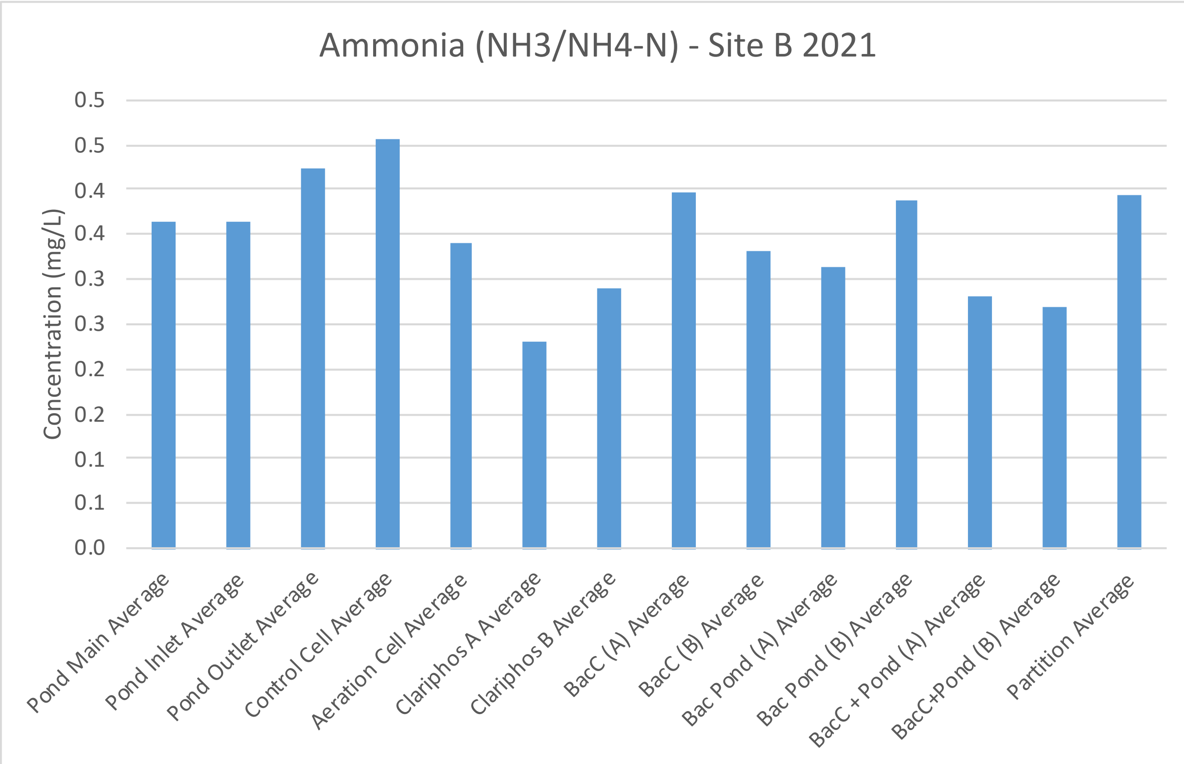
Ortho P all BDL, data not shown



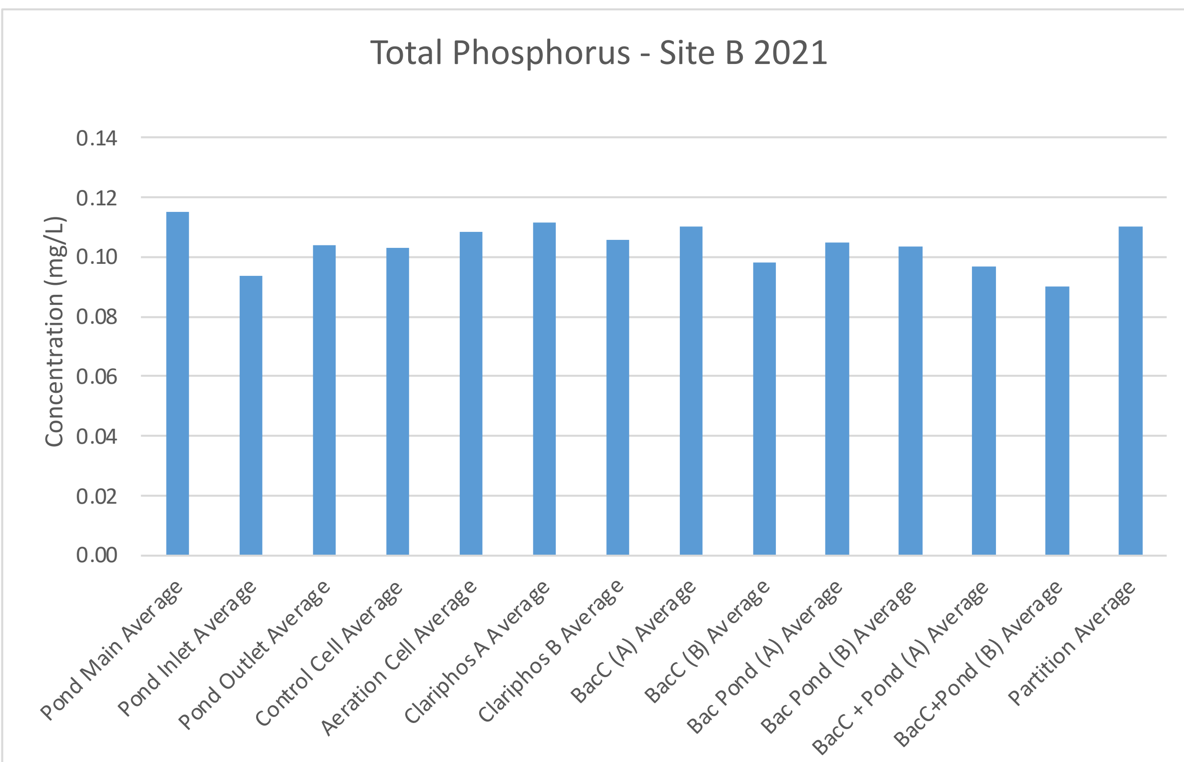

Chlorophyll a - Site B 2021
Concentration (ug/L)
200
180
160
140
120
100
80
60
40
20
0
25-Mar-21
14-Apr-21
4-May-21
24-May-21
13-Jun-21
3-Jul-21
23-Jul-21
12-Aug-21
1-Sep-21
21-Sep-21
11-Oct-21
Pond
Inlet
Outlet
Control Cell


Phycocyanin - Site B 2021
Concentration (ug/L)
10
8
6
4
2
0
-2
25-Mar-21
14-Apr-21
4-May-21
24-May-21
13-Jun-21
3-Jul-21
23-Jul-21
12-Aug-21
1-Sep-21
21-Sep-21
11-Oct-21
Pond
Inlet
Outlet
Control Cell

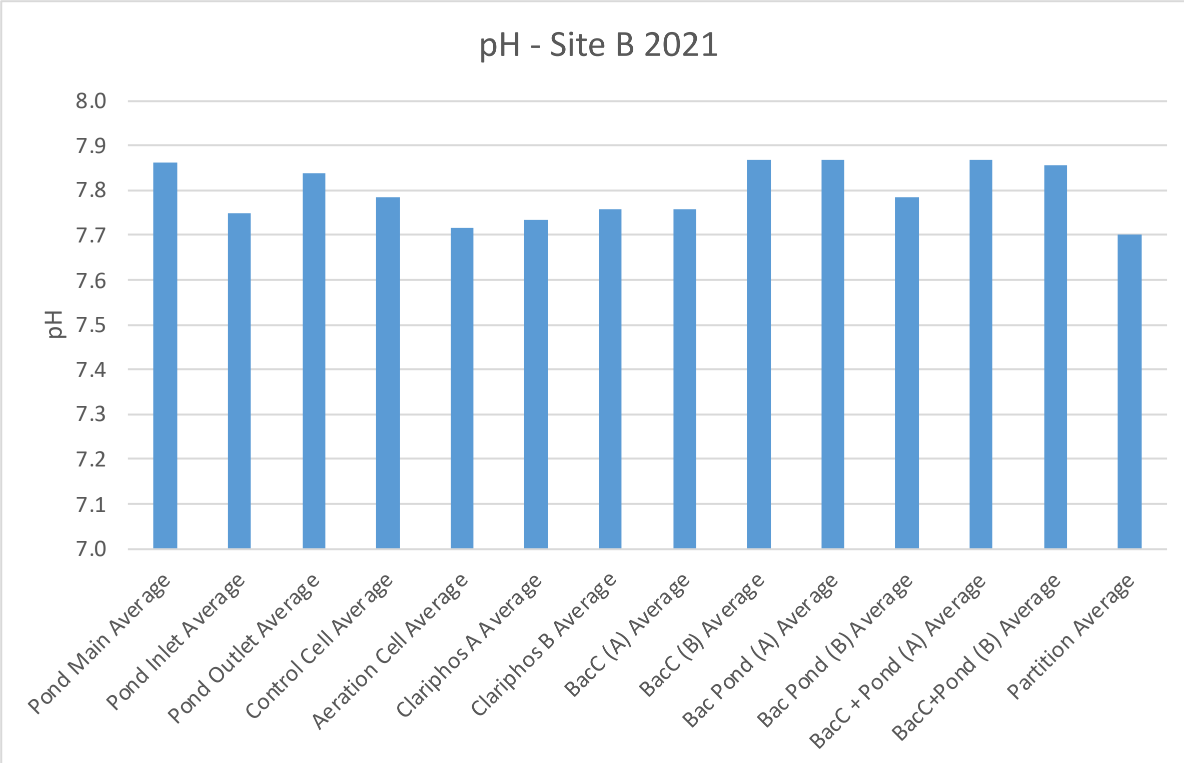
Averages of all B treatments in 2021

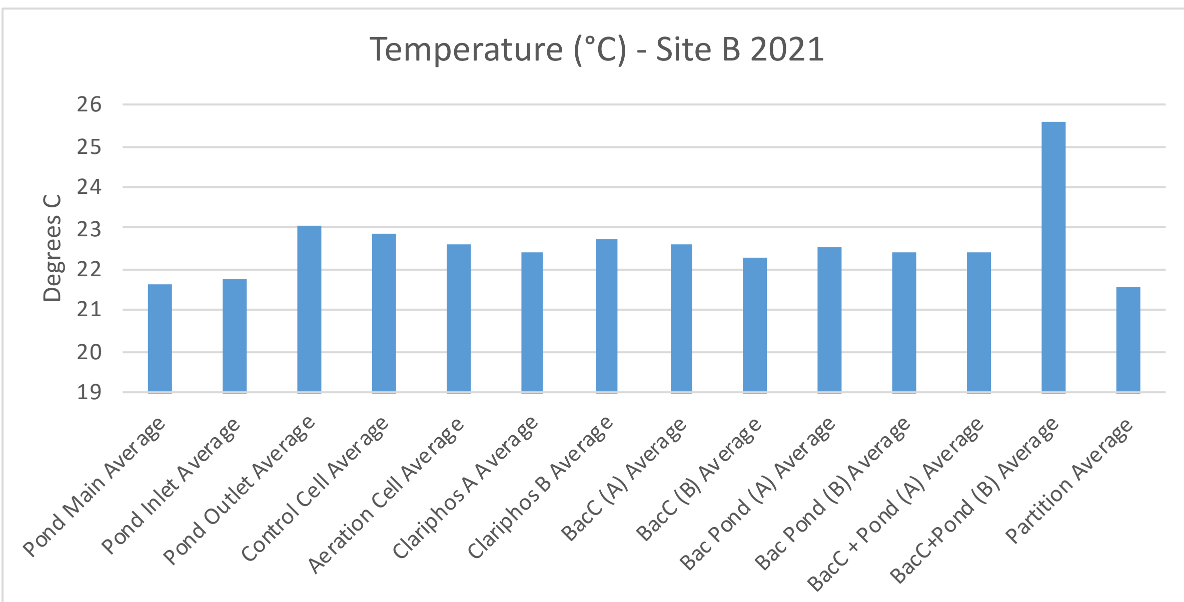


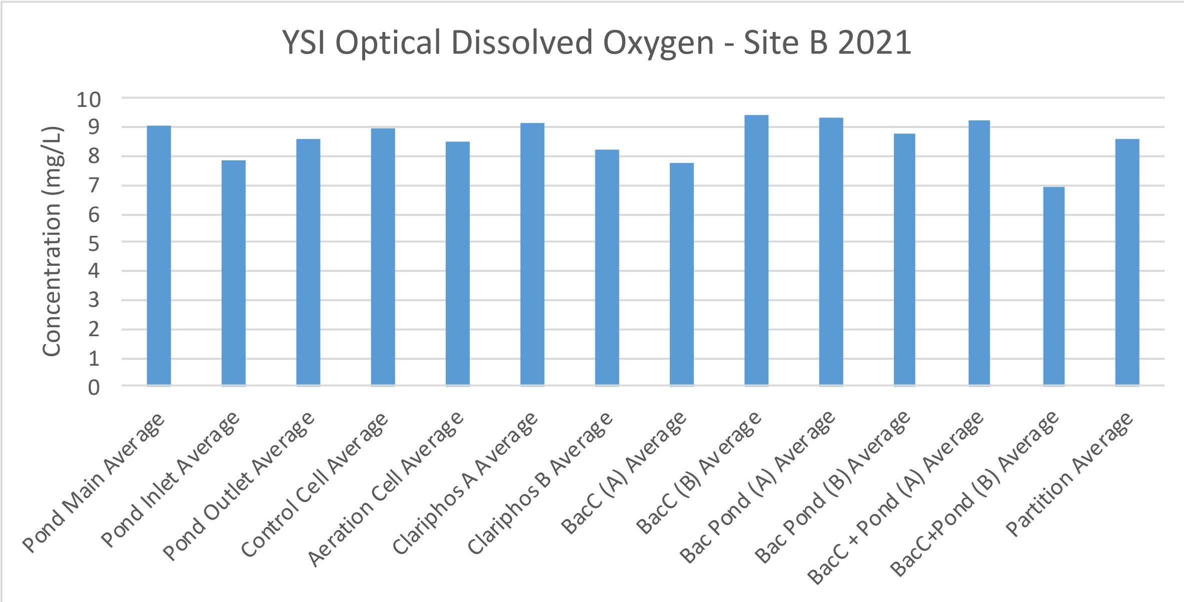
Nitrate all BDL

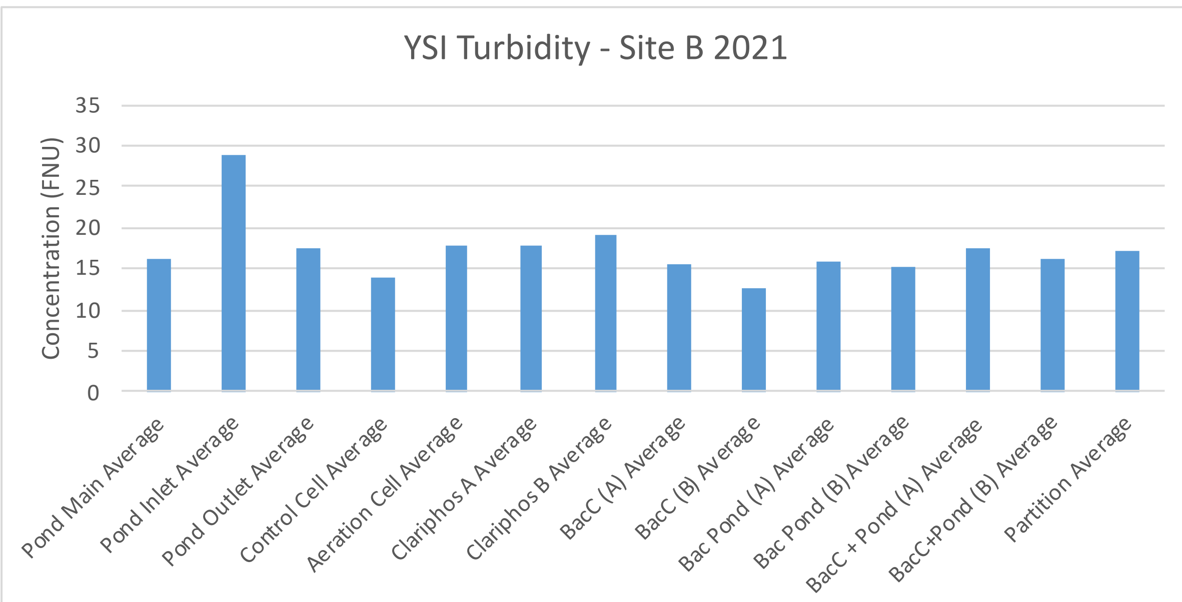


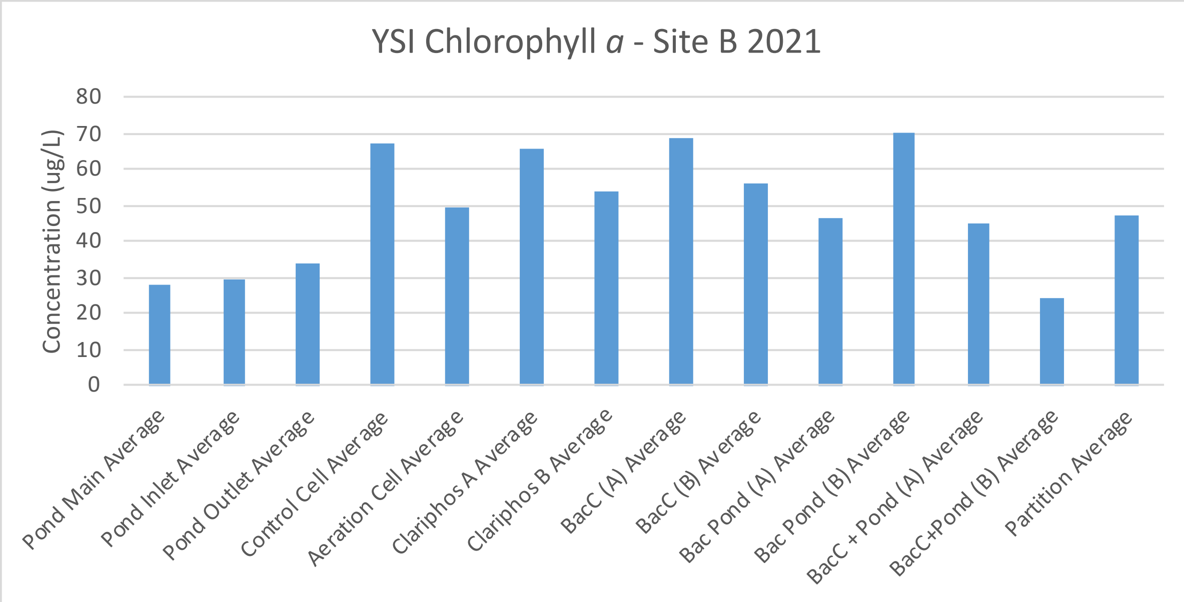
No ortho-P – all BDL or no sample

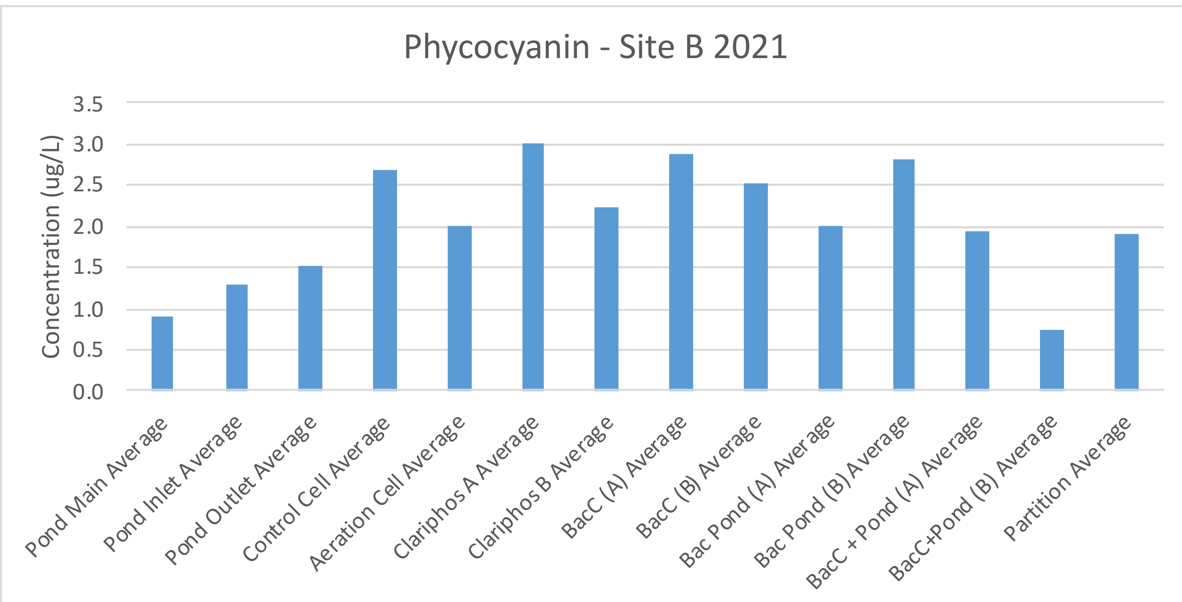





YSI Optical Dissolved Oxygen - Site B 2021
Concentration (mg/L)
0
1
2
3
4
5
6
7
8
9
10
Pond Main Average
Pond Inlet Average
Pond Outlet Average
Control Cell Average
Aeration Cell Average
Clariphos A Average
Clariphos B Average
BacC (A) Average
BacC (B) Average
Bac Pond (A) Average
Bac Pond (B) Average
BacC + Pond (A) Average
BacC+Pond (B) Average
Partition Average

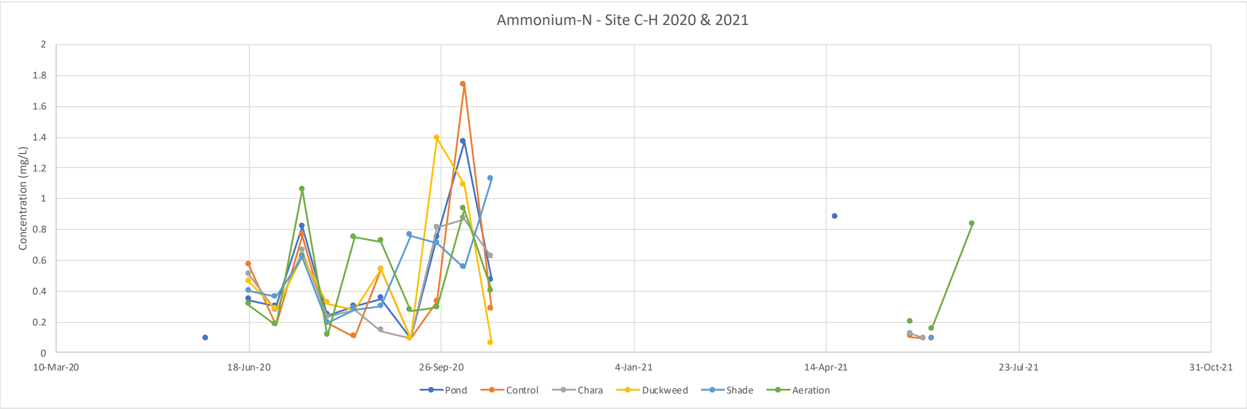

YSI Turbidity - Site B 2021
Concentration (FNU)
0
5
10
15
20
25
30
35
Pond Main Average
Pond Inlet Average
Pond Outlet Average
Control Cell Average
Aeration Cell Average
Clariphos A Average
Clariphos B Average
BacC (A) Average
BacC (B) Average
Bac Pond (A) Average
Bac Pond (B) Average
BacC + Pond (A) Average
BacC+Pond (B) Average
Partition Average


YSI Chlorophyll a - Site B 2021
Concentration (ug/L)
80
70
60
50
40
30
20
10
0
Pond Main Average
Pond Inlet Average
Pond Outlet Average
Control Cell Average
Aeration Cell Average
Clariphos A Average
Clariphos B Average
BacC (A) Average
BacC (B) Average
Bac Pond (A) Average
Bac Pond (B) Average
BacC + Pond (A) Average
BacC+Pond (B) Average
Partition Average

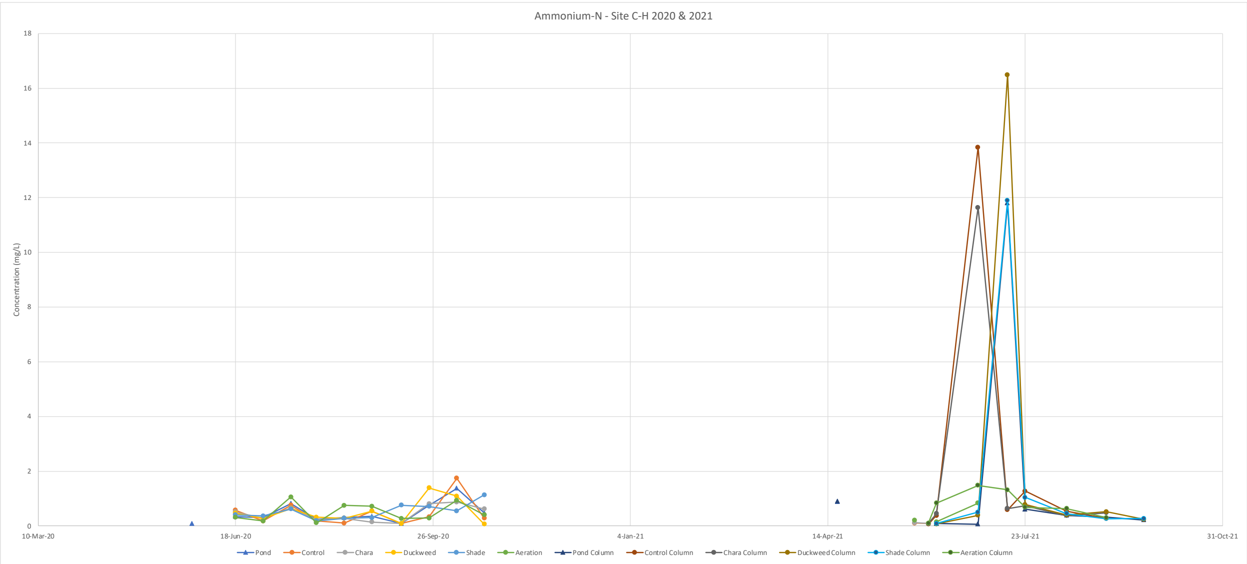

Phycocyanin - Site B 2021
Concentration (ug/L)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Pond Main Average
Pond Inlet Average
Pond Outlet Average
Control Cell Average
Aeration Cell Average
Clariphos A Average
Clariphos B Average
BacC (A) Average
BacC (B) Average
Bac Pond (A) Average
Bac Pond (B) Average
BacC + Pond (A) Average
BacC+Pond (B) Average
Partition Average

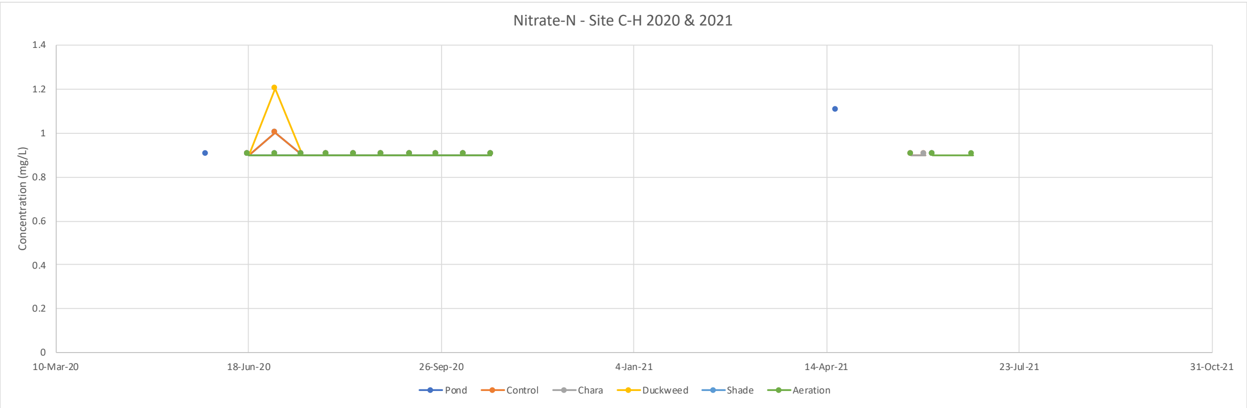
Appendix C-H – Site C-H Selected Results

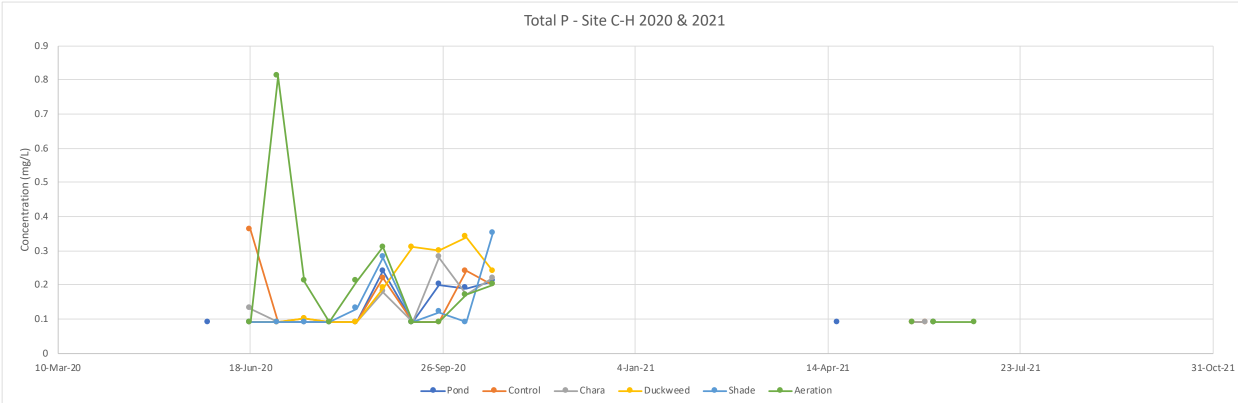
Surface only 2020 and 2021 (the column data is hard to visualize if included)

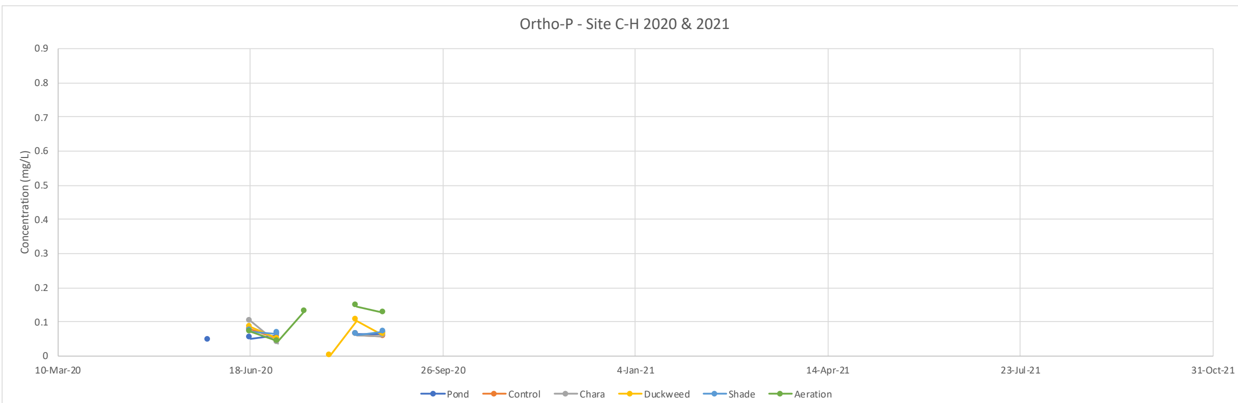


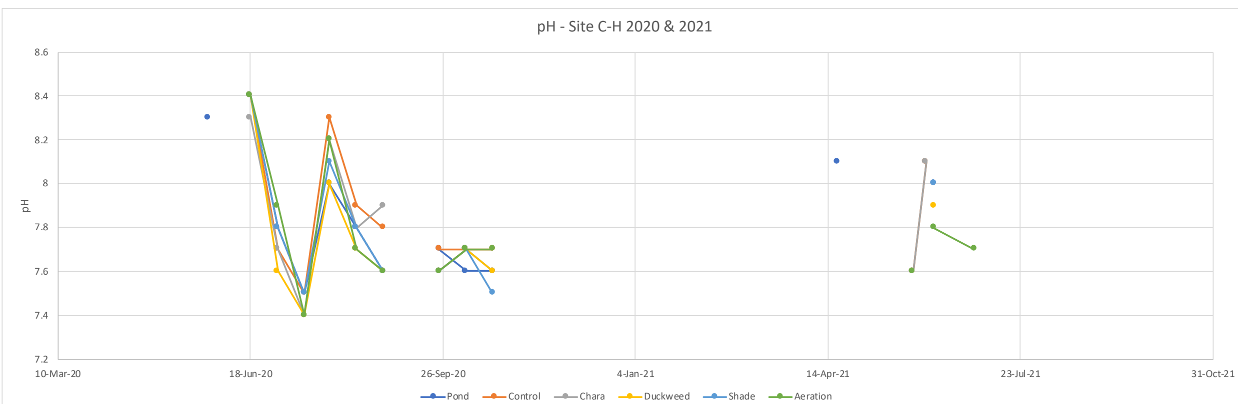
Ammonium-N with column data

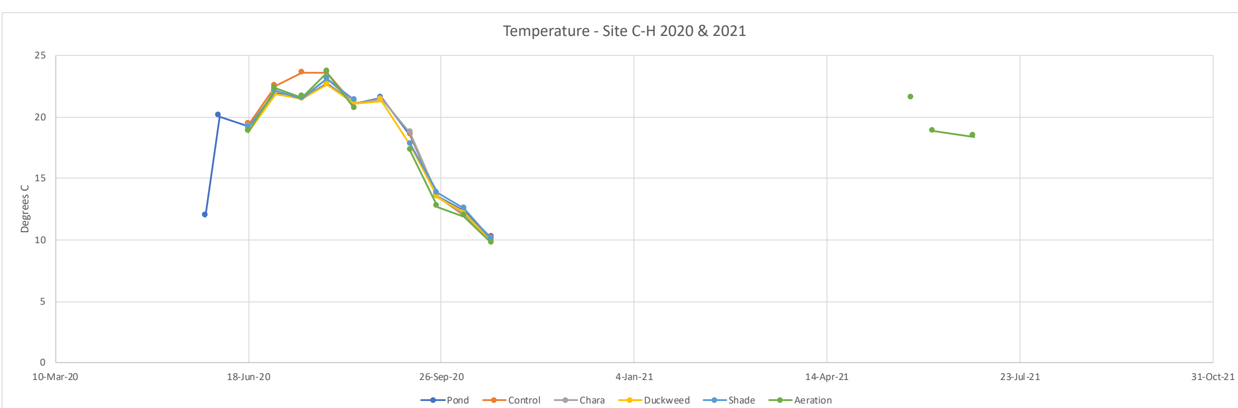


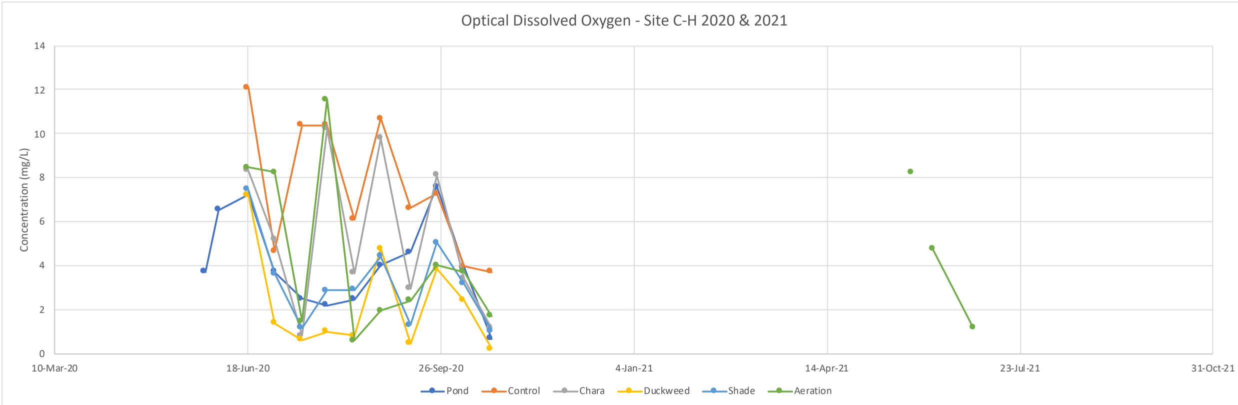



Total P - Site C-H 2020 & 2021
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
Pond
Control
Chara
Duckweed
Shade
Aeration

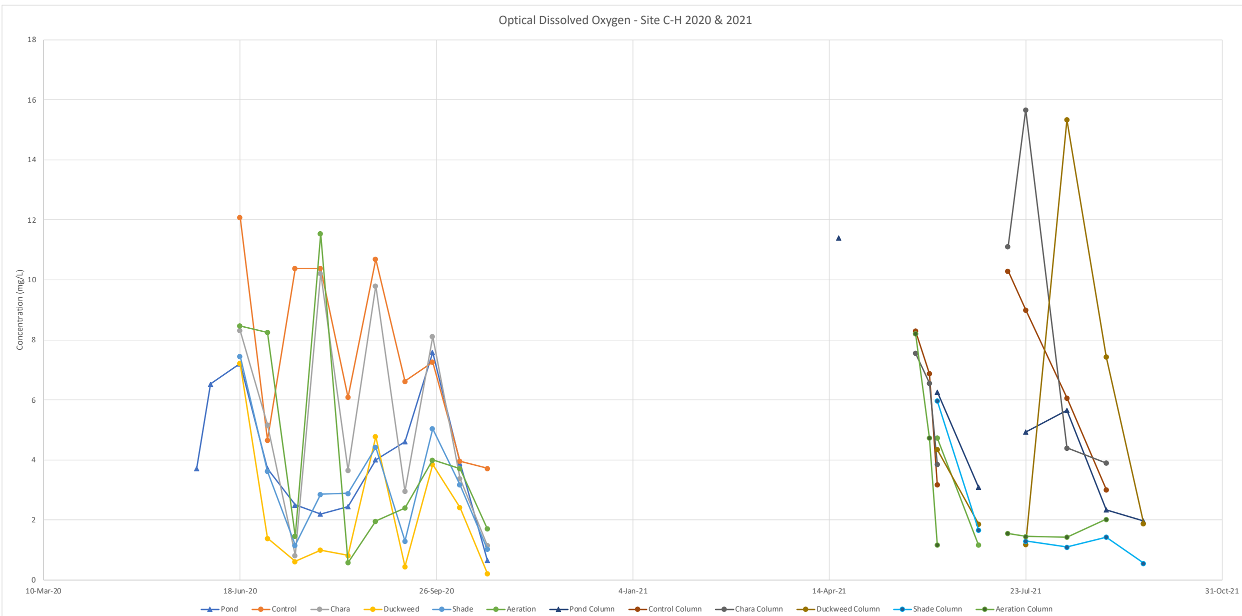

Ortho-P - Site C-H 2020 & 2021
Concentration (mg/L)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
Pond
Control
Chara
Duckweed
Shade
Aeration

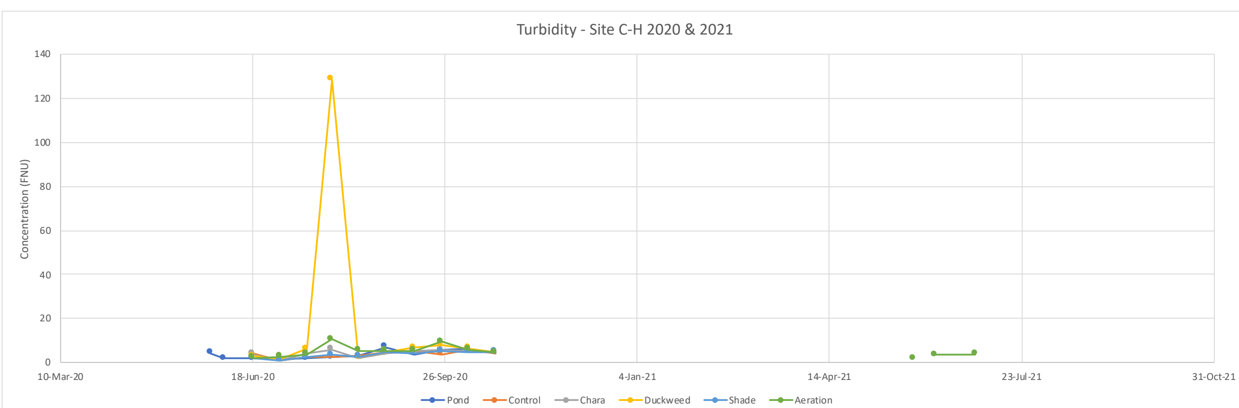

pH - Site C-H 2020 & 2021
pH
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
Pond
Control
Chara
Duckweed
Shade
Aeration

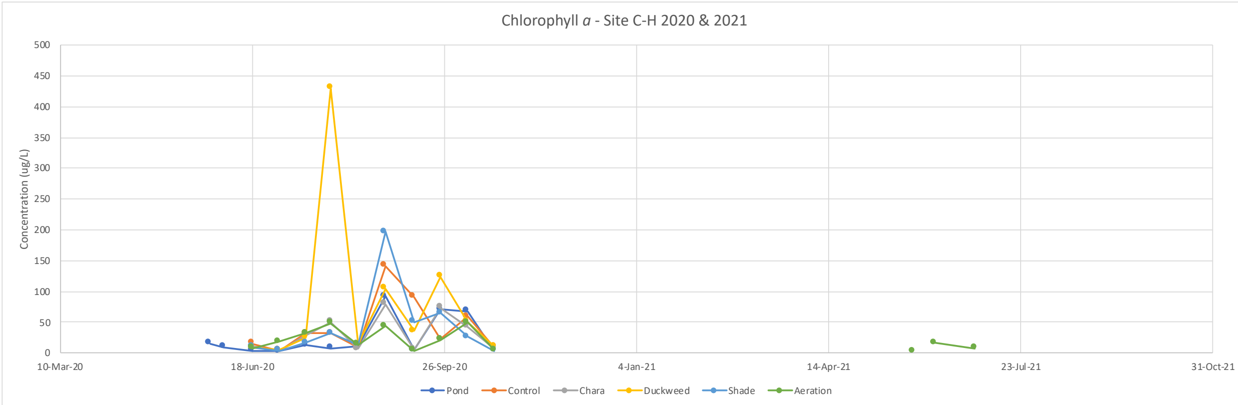

Temperature - Site C-H 2020 & 2021
Degrees C
25
20
15
10
5
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
Pond
Control
Chara
Duckweed
Shade
Aeration

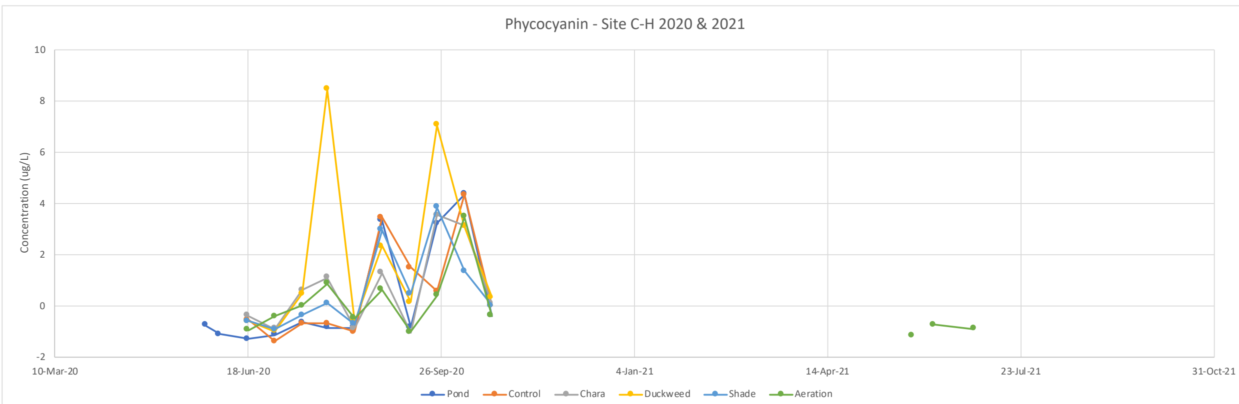


ODO with column data

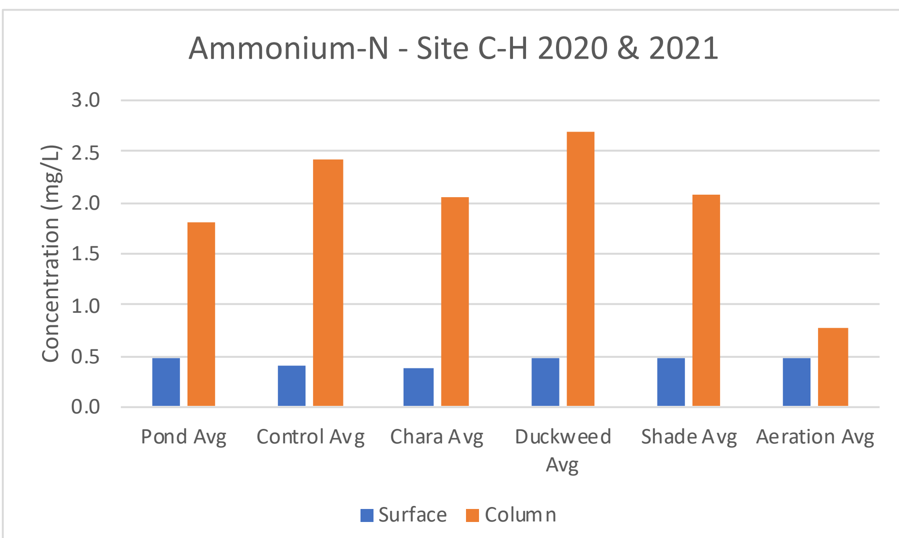


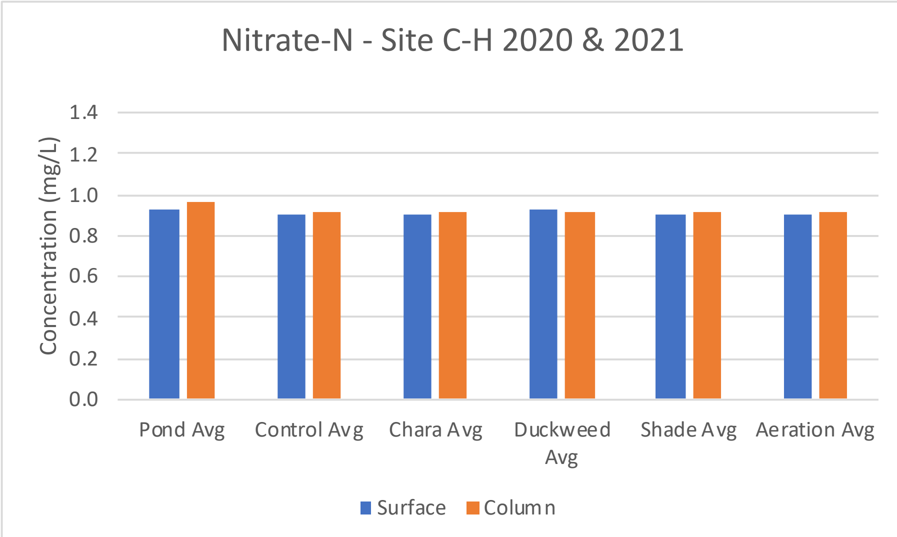


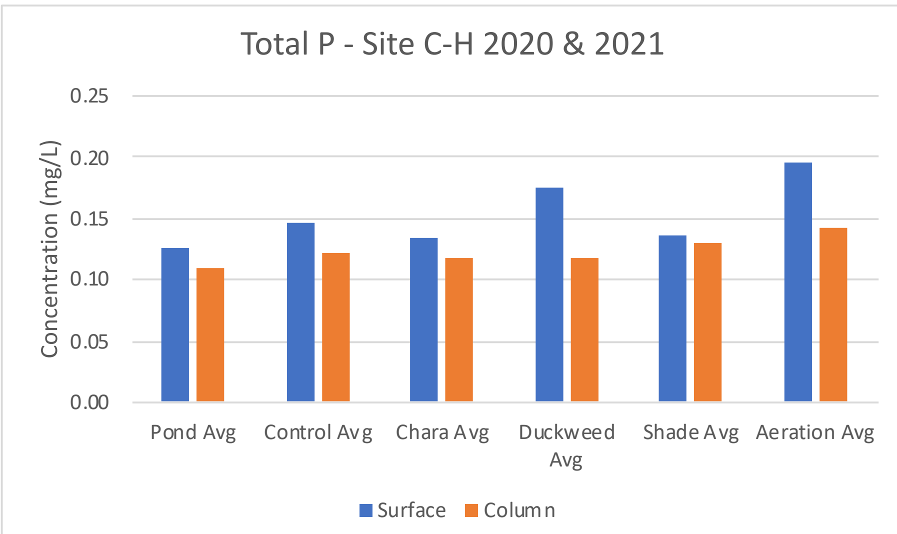


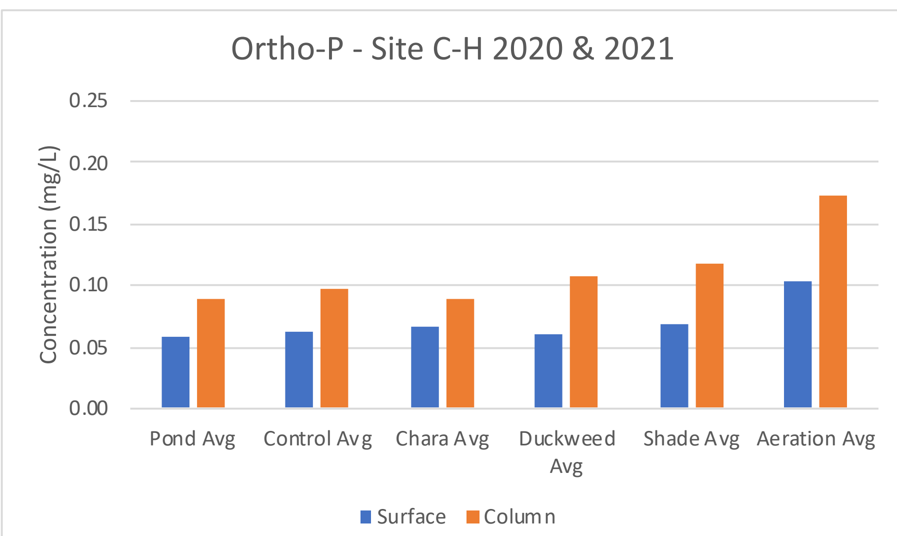


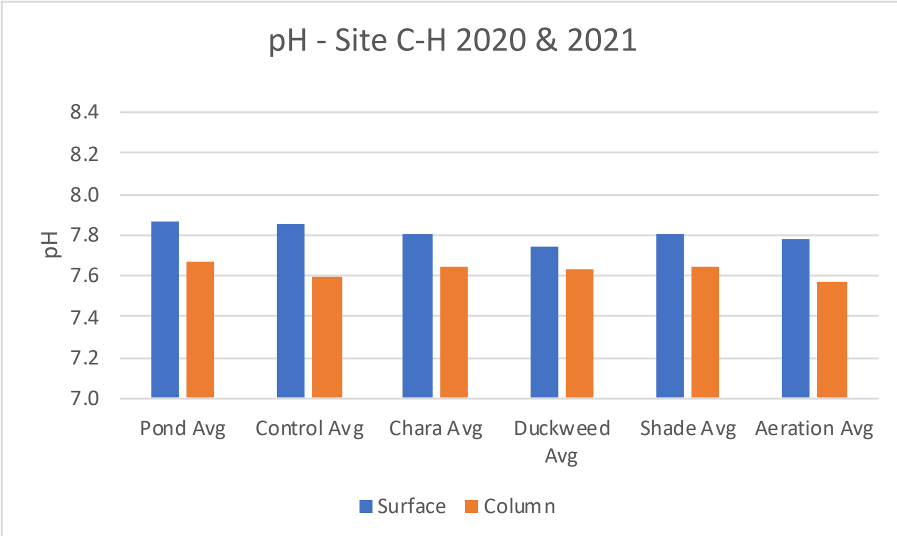
Averages 2020/2021 with both surface and column data (only Pond has April/May data)

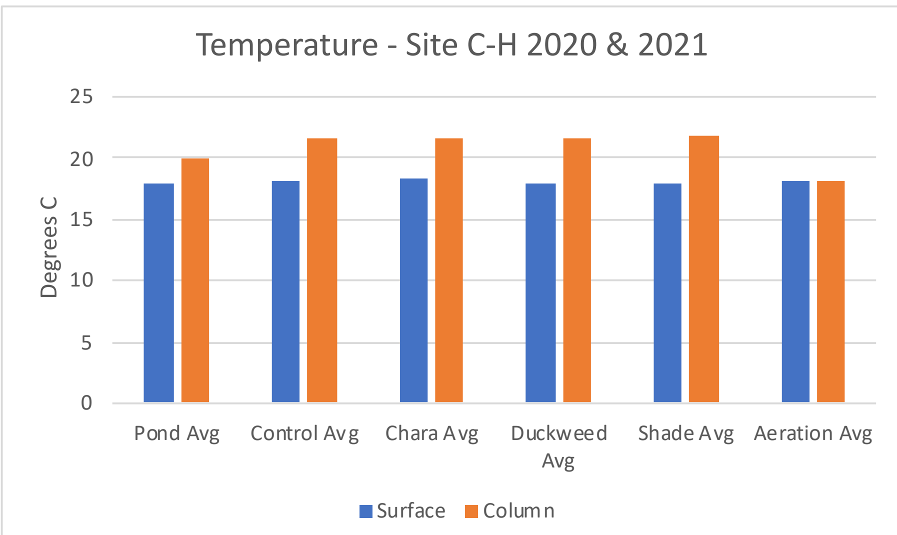


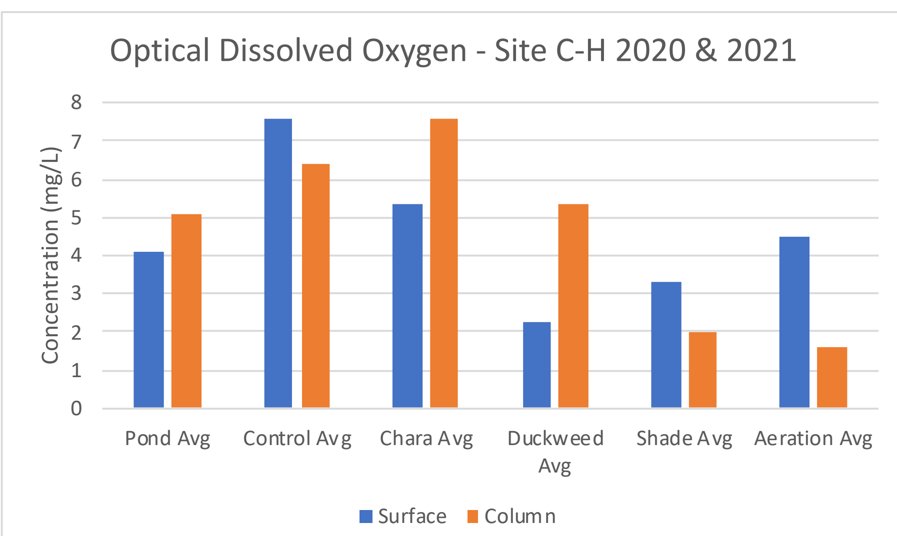

Nitrate-N - Site C-H 2020 & 2021
Concentration (mg/L)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column

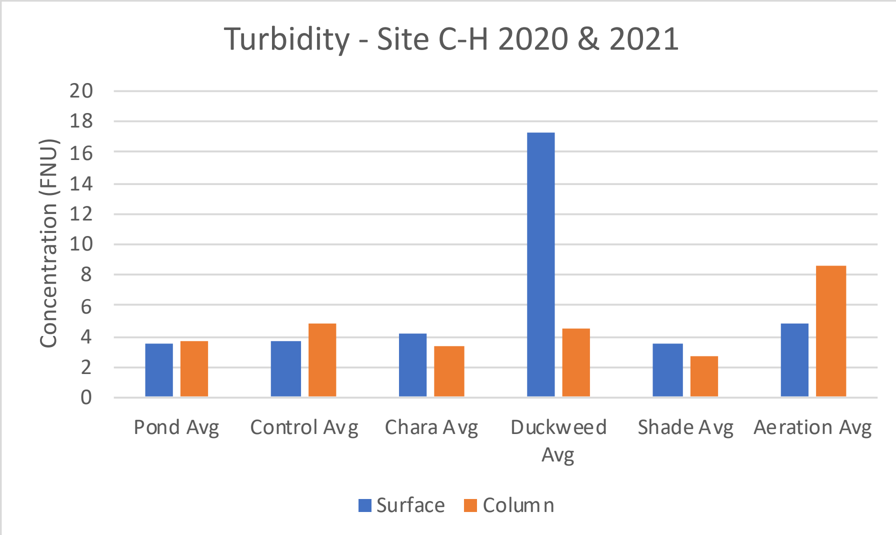

Total P - Site C-H 2020 & 2021
Concentration (mg/L)
0.25
0.20
0.15
0.10
0.05
0.00
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column

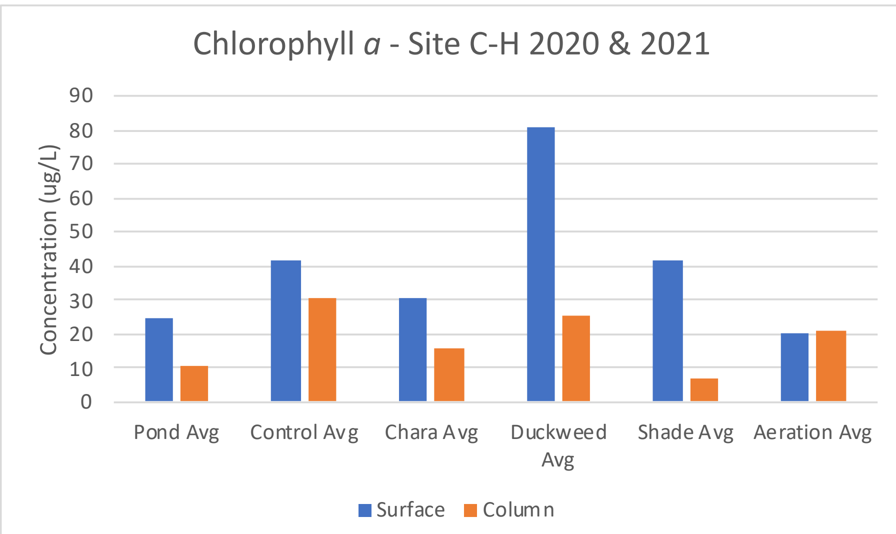

Ortho-P - Site C-H 2020 & 2021
Concentration (mg/L)
0.25
0.20
0.15
0.10
0.05
0.00
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column

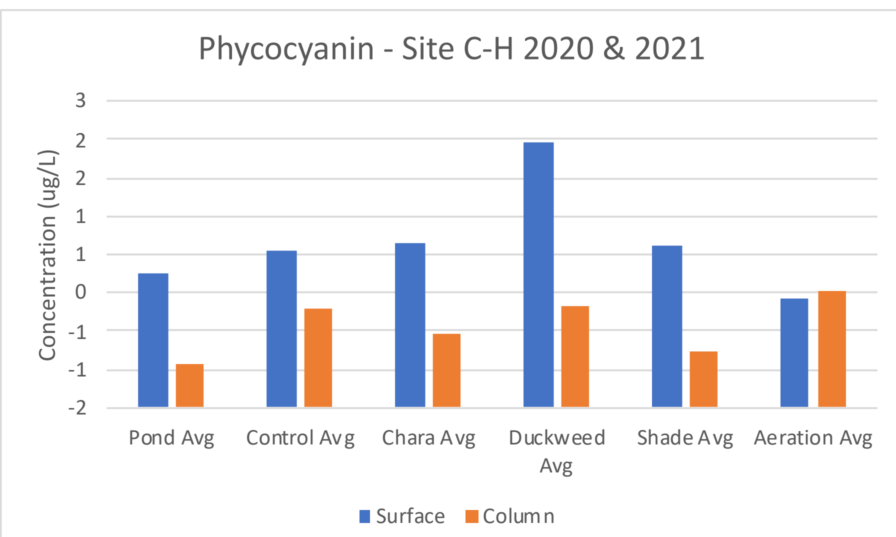

pH - Site C-H 2020 & 2021
pH
8.4
8.2
8.0
7.8
7.6
7.4
7.2
7.0
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column


Temperature - Site C-H 2020 & 2021
Degrees C
25
20
15
10
5
0
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column

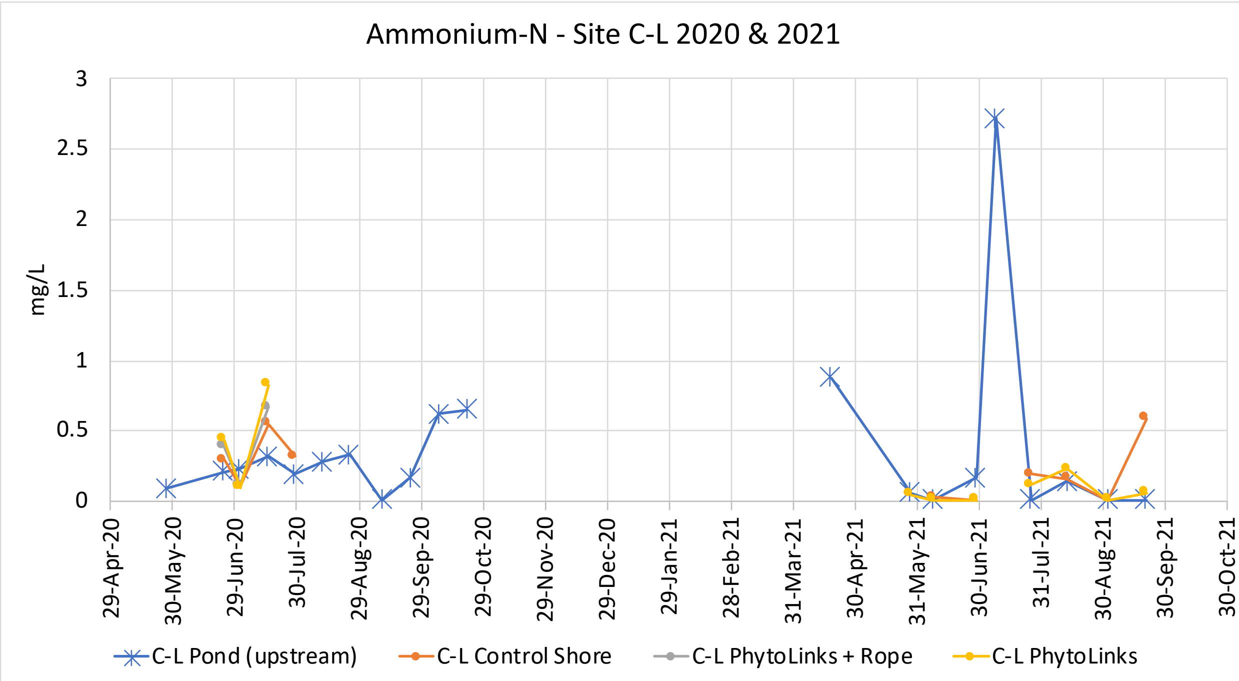

Optical Dissolved Oxygen - Site C-H 2020 & 2021
Concentration (mg/L)
8
7
6
5
4
3
2
1
0
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column

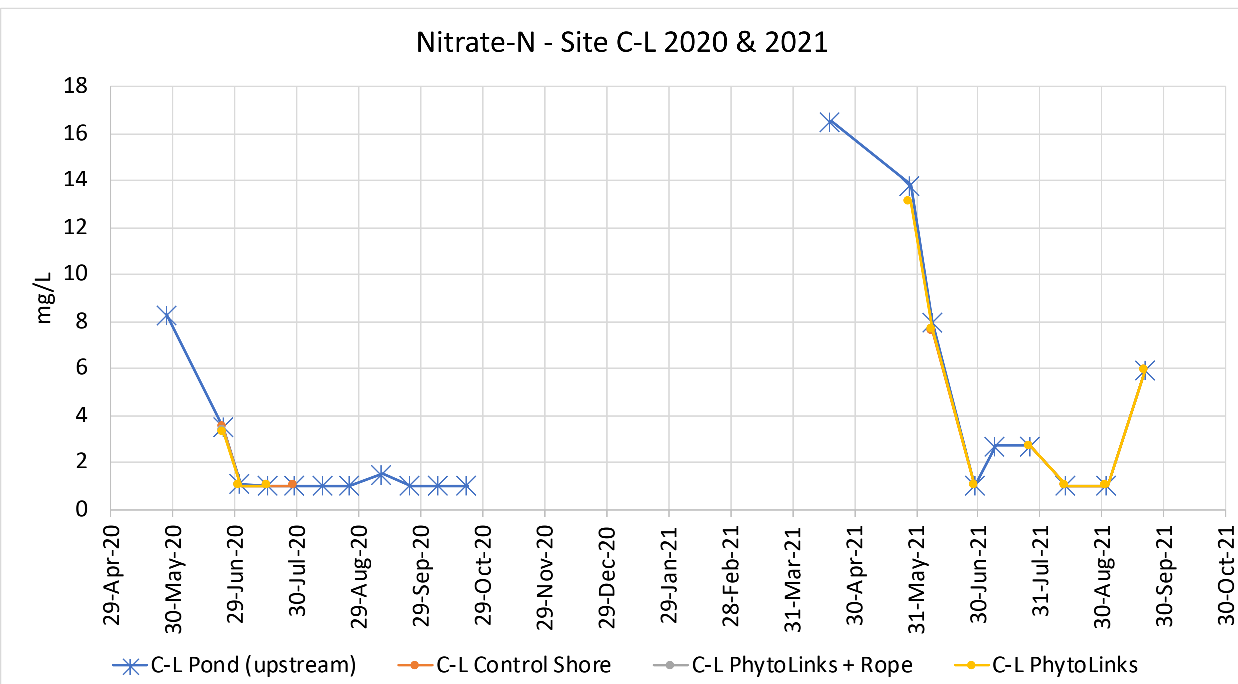

Turbidity - Site C-H 2020 & 2021
Concentration (FNU)
20
18
16
14
12
10
8
6
4
2
0
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column

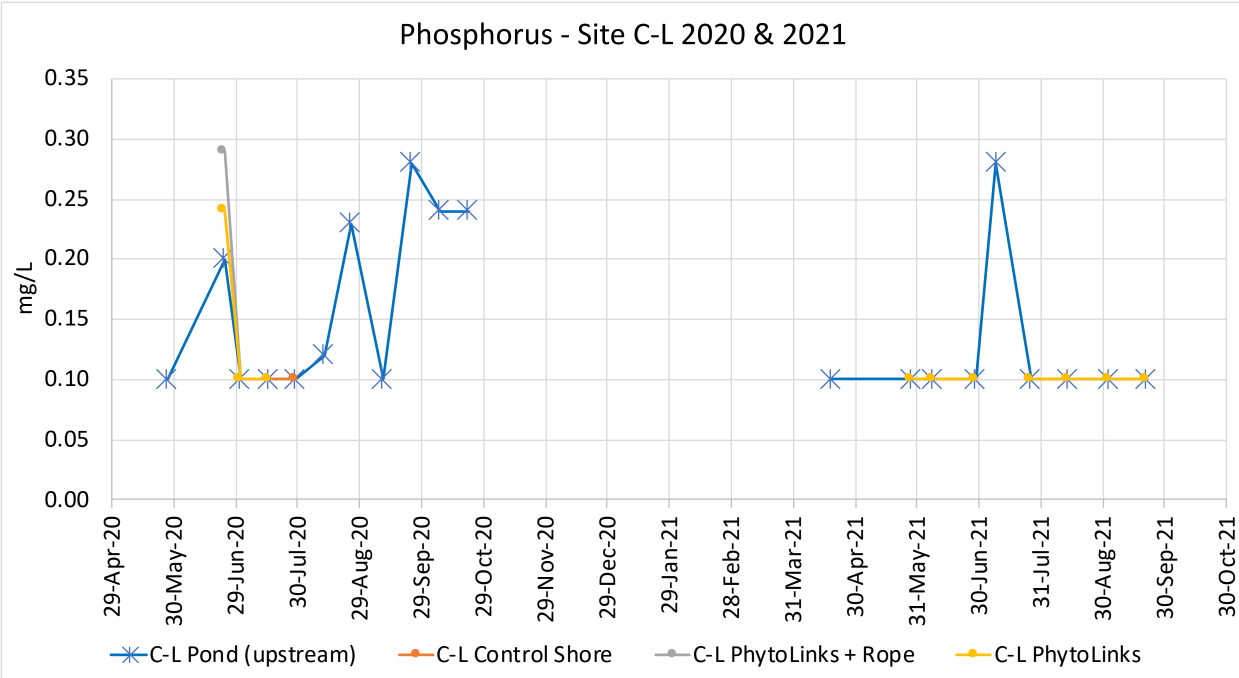

Chlorophyll *a* - Site C-H 2020 & 2021
Concentration (ug/L)
90
80
70
60
50
40
30
20
10
0
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column

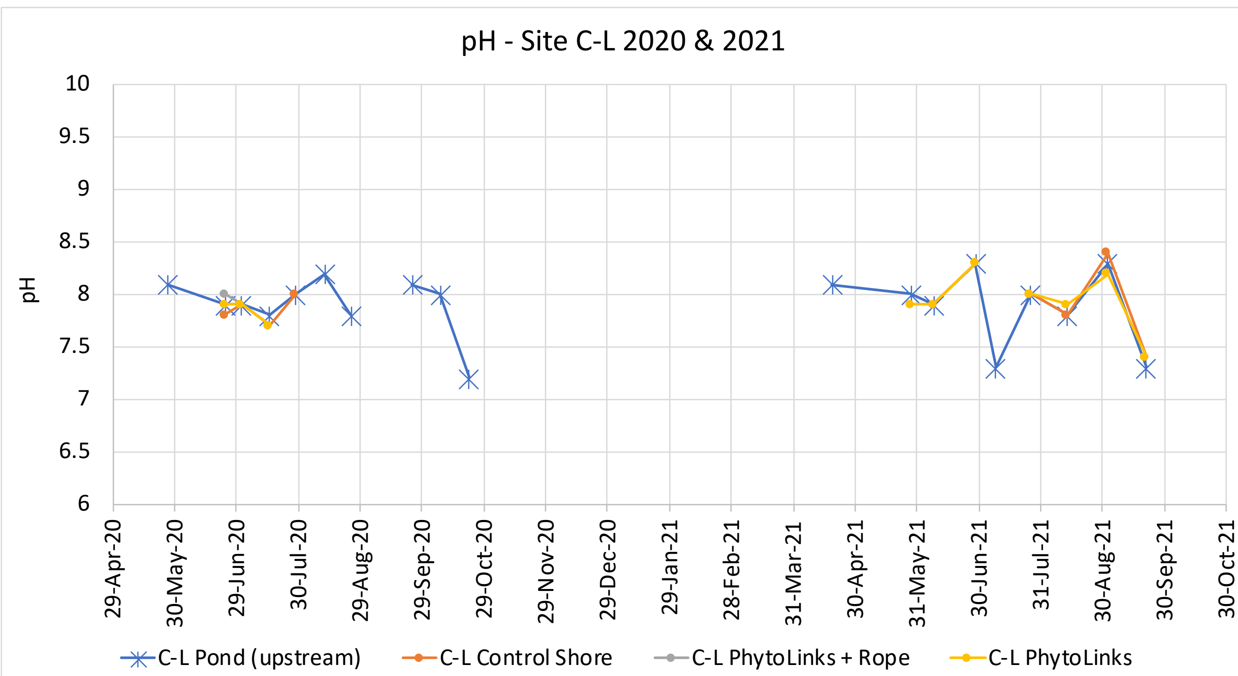

Phycocyanin - Site C-H 2020 & 2021
Concentration (ug/L)
3
2
2
1
1
0
-1
-1
-2
Pond Avg
Control Avg
Chara Avg
Duckweed Avg
Shade Avg
Aeration Avg
Surface
Column

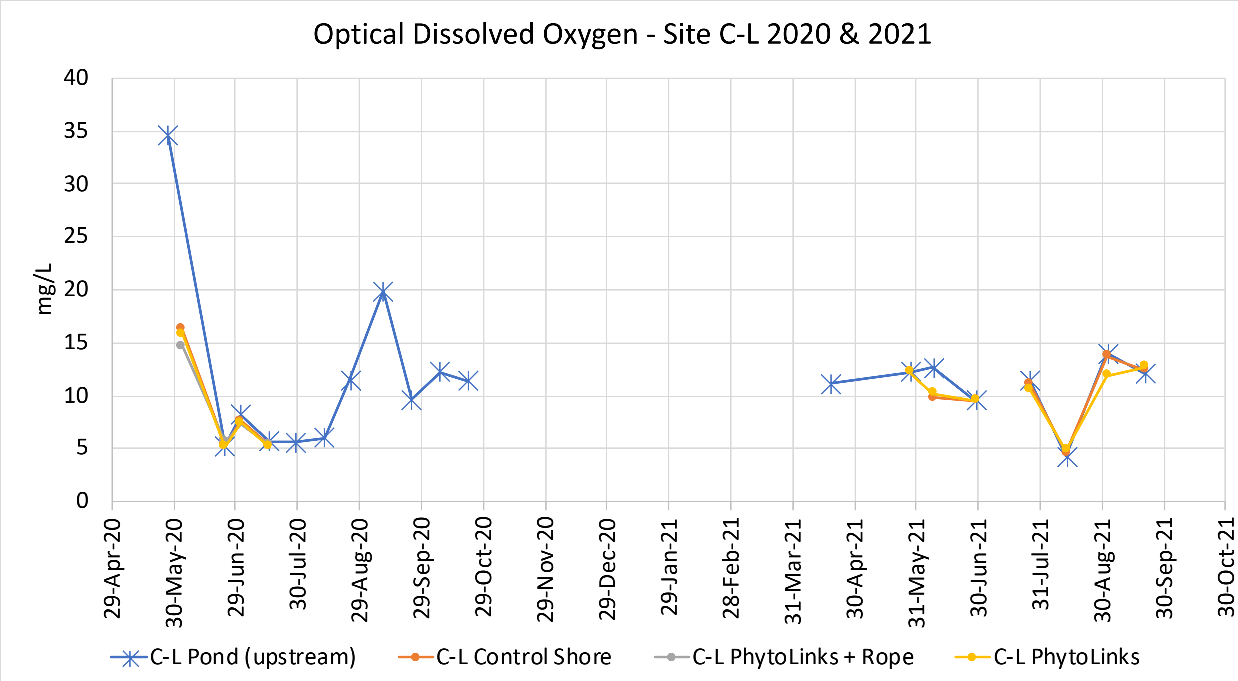
Appendix C-L – Site C-L Selected Results

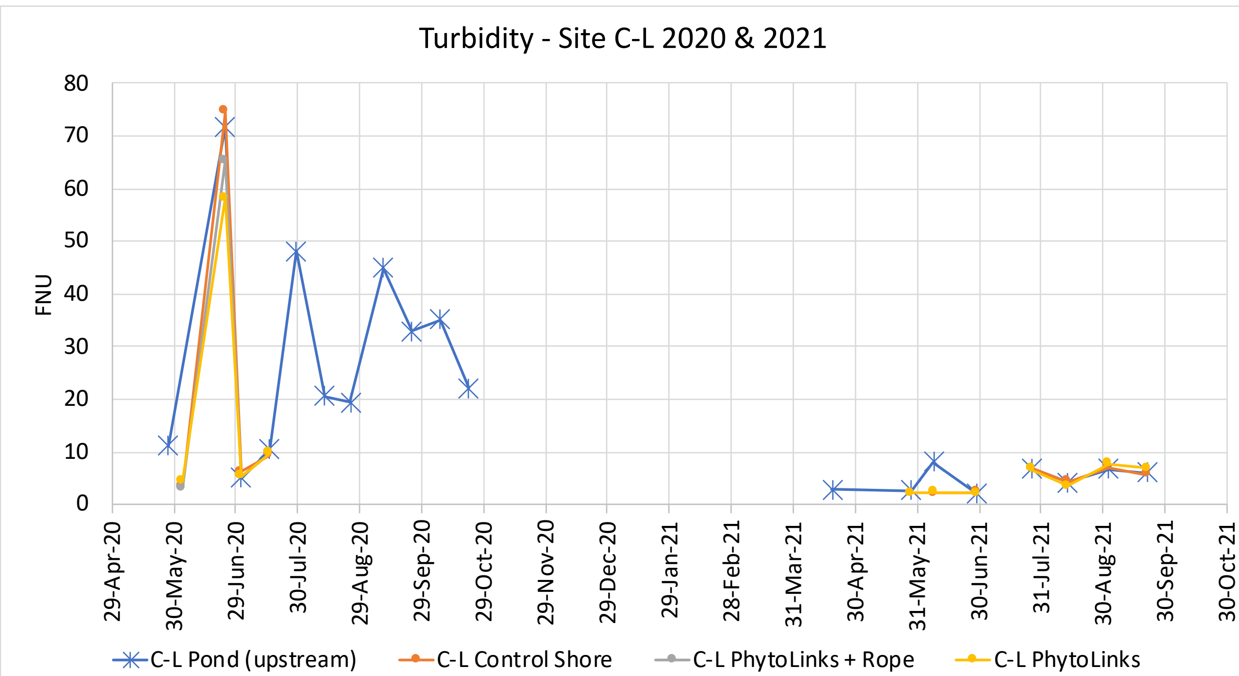


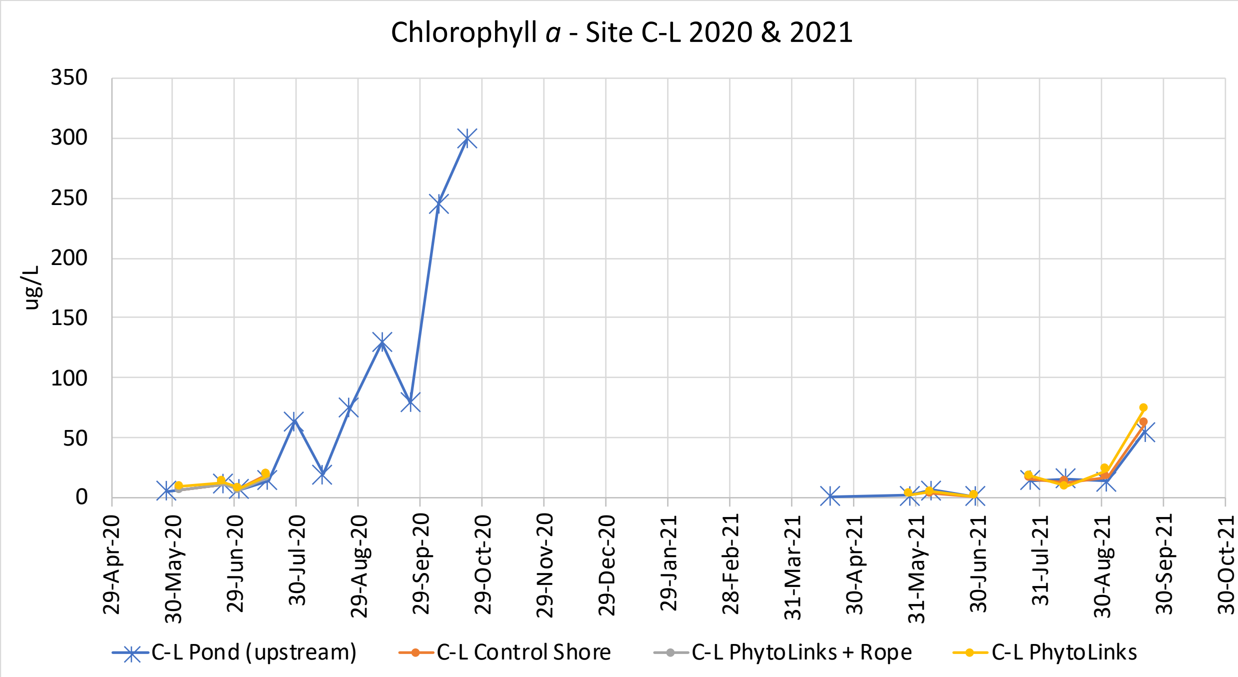



Phosphorus - Site C-L 2020 & 2021
mg/L
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
29-Apr-20
30-May-20
29-Jun-20
30-Jul-20
29-Aug-20
29-Sep-20
29-Oct-20
29-Nov-20
29-Dec-20
29-Jan-21
28-Feb-21
31-Mar-21
30-Apr-21
31-May-21
30-Jun-21
31-Jul-21
30-Aug-21
30-Sep-21
30-Oct-21
C-L Pond (upstream)
C-L Control Shore
C-L PhytoLinks + Rope
C-L PhytoLinks

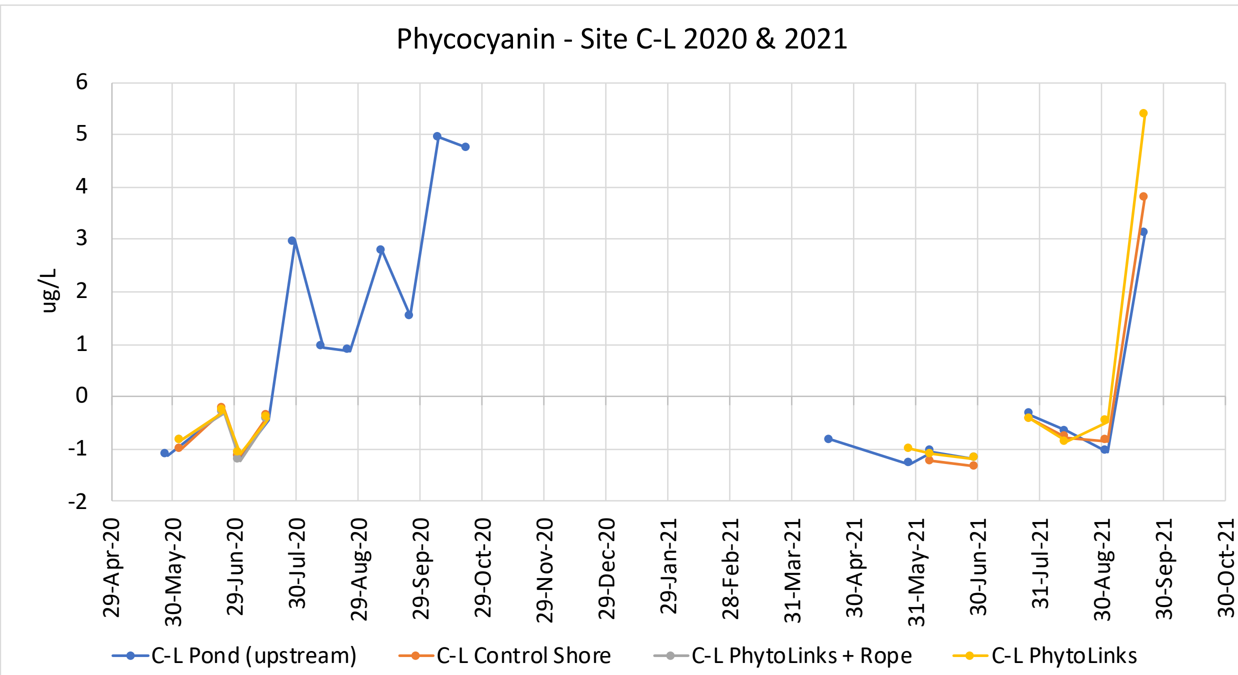

pH - Site C-L 2020 & 2021
pH
10
9.5
9
8.5
8
7.5
7
6.5
6
29-Apr-20
30-May-20
29-Jun-20
30-Jul-20
29-Aug-20
29-Sep-20
29-Oct-20
29-Nov-20
29-Dec-20
29-Jan-21
28-Feb-21
31-Mar-21
30-Apr-21
31-May-21
30-Jun-21
31-Jul-21
30-Aug-21
30-Sep-21
30-Oct-21
C-L Pond (upstream)
C-L Control Shore
C-L PhytoLinks + Rope
C-L PhytoLinks


Optical Dissolved Oxygen - Site C-L 2020 & 2021
mg/L
40
35
30
25
20
15
10
5
0
29-Apr-20
30-May-20
29-Jun-20
30-Jul-20
29-Aug-20
29-Sep-20
29-Oct-20
29-Nov-20
29-Dec-20
29-Jan-21
28-Feb-21
31-Mar-21
30-Apr-21
31-May-21
30-Jun-21
31-Jul-21
30-Aug-21
30-Sep-21
30-Oct-21
C-L Pond (upstream)
C-L Control Shore
C-L PhytoLinks + Rope
C-L PhytoLinks


Turbidity - Site C-L 2020 & 2021
FNU
80
70
60
50
40
30
20
10
0
29-Apr-20
30-May-20
29-Jun-20
30-Jul-20
29-Aug-20
29-Sep-20
29-Oct-20
29-Nov-20
29-Dec-20
29-Jan-21
28-Feb-21
31-Mar-21
30-Apr-21
31-May-21
30-Jun-21
31-Jul-21
30-Aug-21
30-Sep-21
30-Oct-21
C-L Pond (upstream)
C-L Control Shore
C-L PhytoLinks + Rope
C-L PhytoLinks



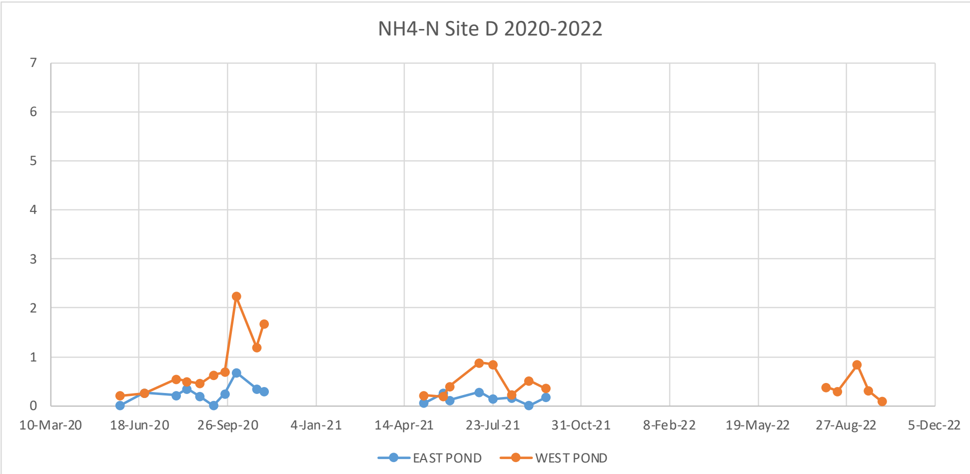
Chlorophyll a - Site C-L 2020 & 2021
ug/L
350
300
250
200
150
100
50
0
29-Apr-20
30-May-20
29-Jun-20
30-Jul-20
29-Aug-20
29-Sep-20
29-Oct-20
29-Nov-20
29-Dec-20
29-Jan-21
28-Feb-21
31-Mar-21
30-Apr-21
31-May-21
30-Jun-21
31-Jul-21
30-Aug-21
30-Sep-21
30-Oct-21
C-L Pond (upstream)
C-L Control Shore
C-L PhytoLinks + Rope
C-L PhytoLinks

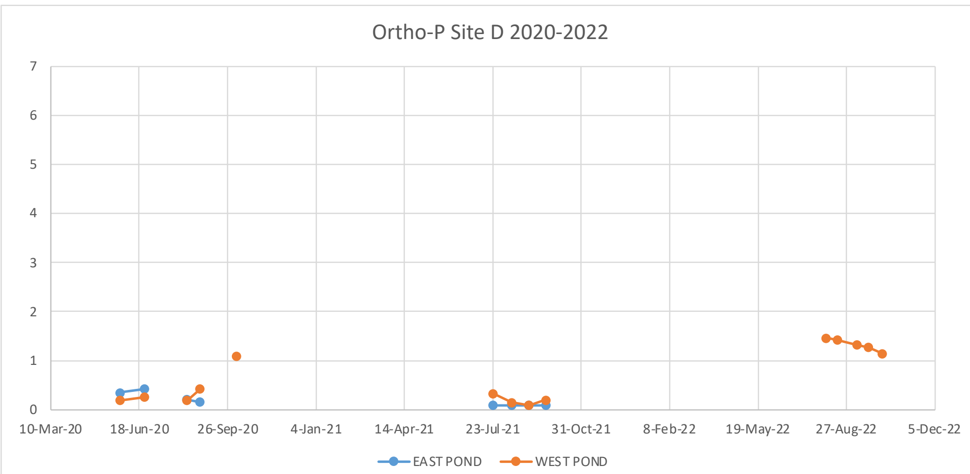


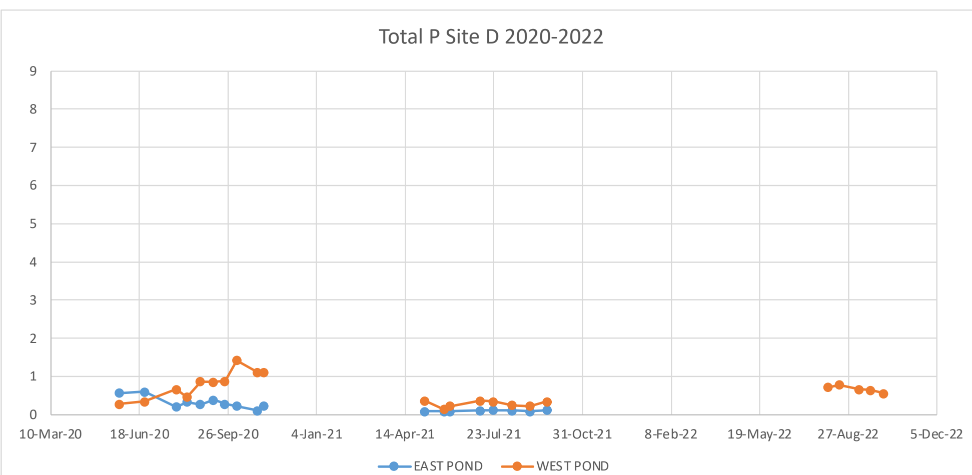
Phycocyanin - Site C-L 2020 & 2021
ug/L
6
5
4
3
2
1
0
-1
-2
29-Apr-20
30-May-20
29-Jun-20
30-Jul-20
29-Aug-20
29-Sep-20
29-Oct-20
29-Nov-20
29-Dec-20
29-Jan-21
28-Feb-21
31-Mar-21
30-Apr-21
31-May-21
30-Jun-21
31-Jul-21
30-Aug-21
30-Sep-21
30-Oct-21
C-L Pond (upstream)
C-L Control Shore
C-L PhytoLinks + Rope
C-L PhytoLinks

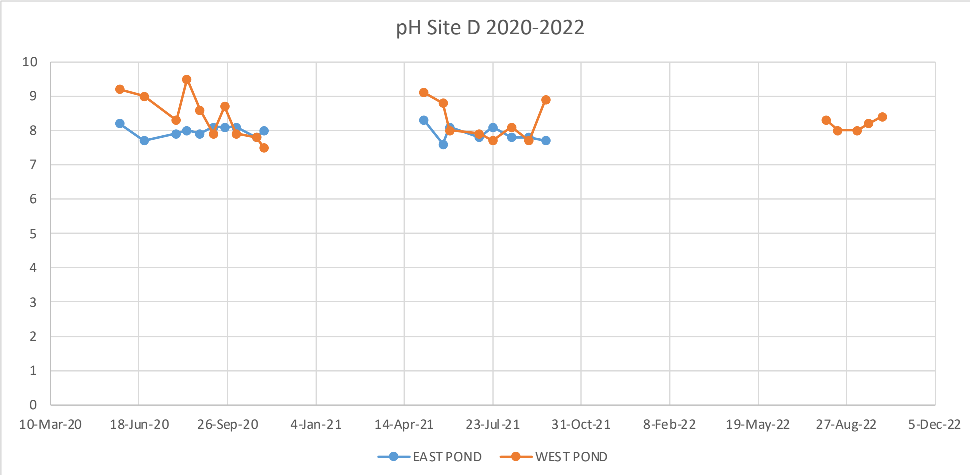
Appendix D – Site D Selected Results

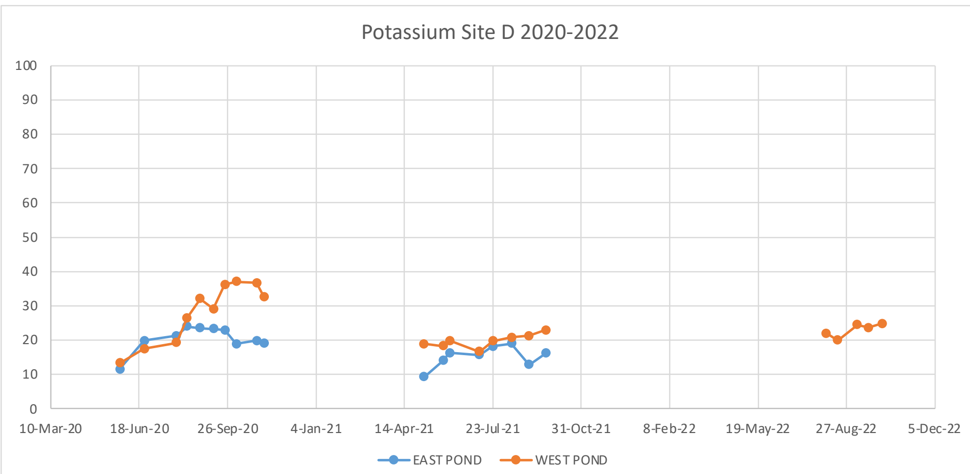
Comparison of West and East ponds

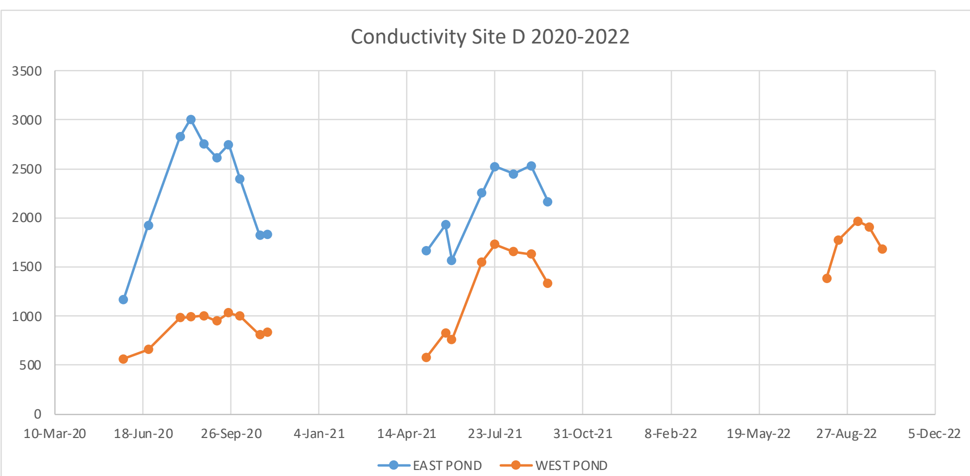


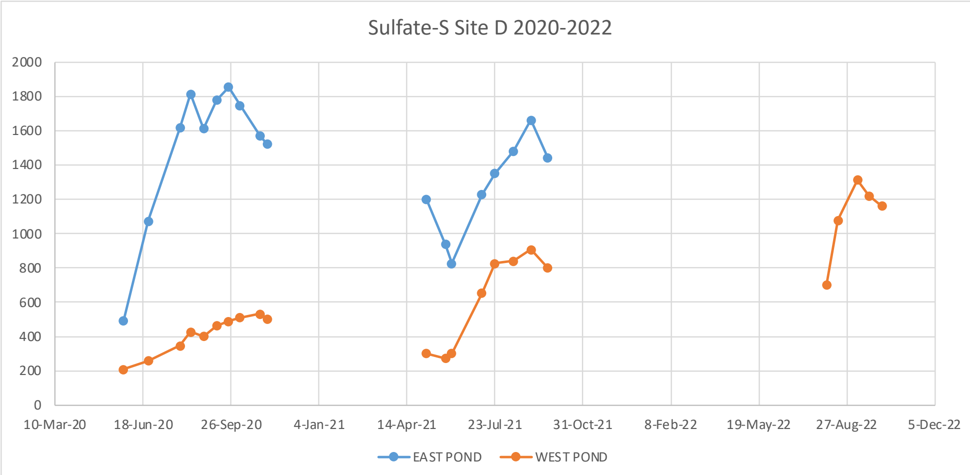


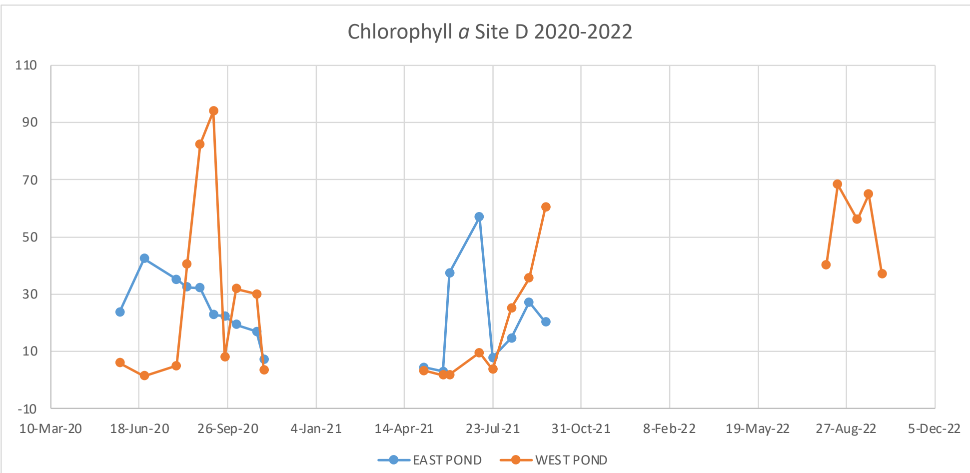


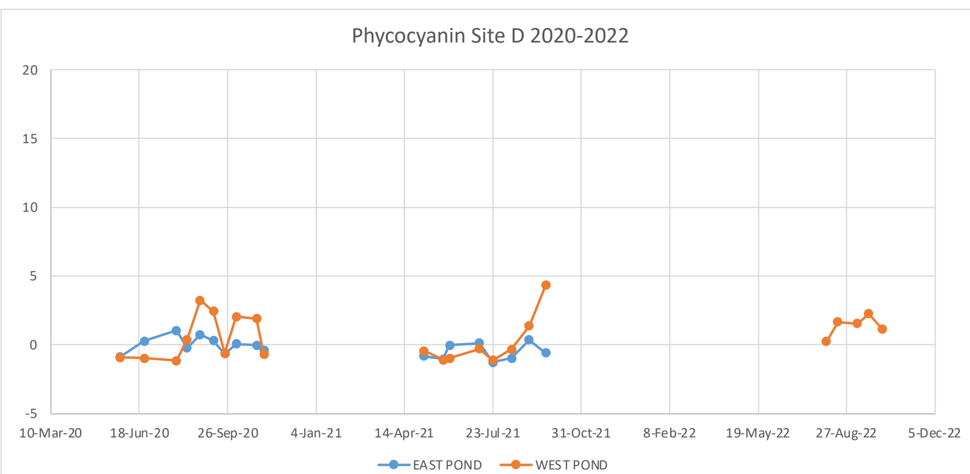

pH Site D 2020-2022
10
9
8
7
6
5
4
3
2
1
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
EAST POND
WEST POND


Potassium Site D 2020-2022
100
90
80
70
60
50
40
30
20
10
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
EAST POND
WEST POND

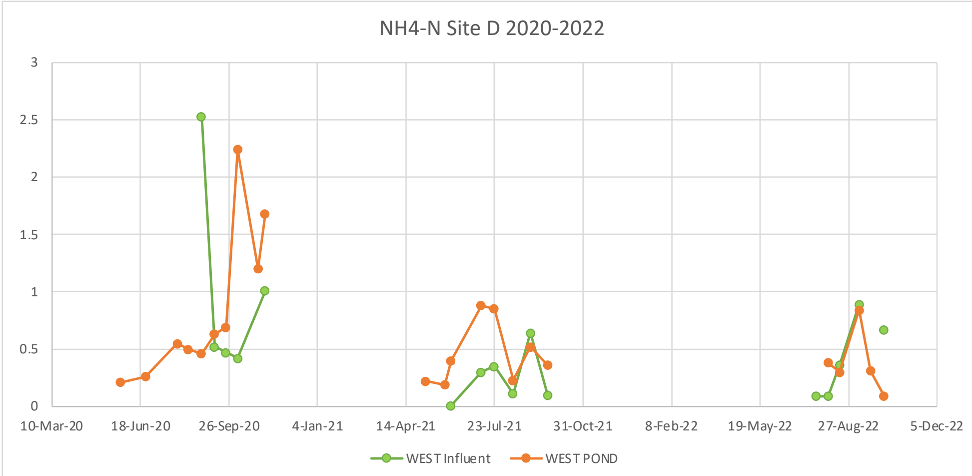

Conductivity Site D 2020-2022
3500
3000
2500
2000
1500
1000
500
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
EAST POND
WEST POND

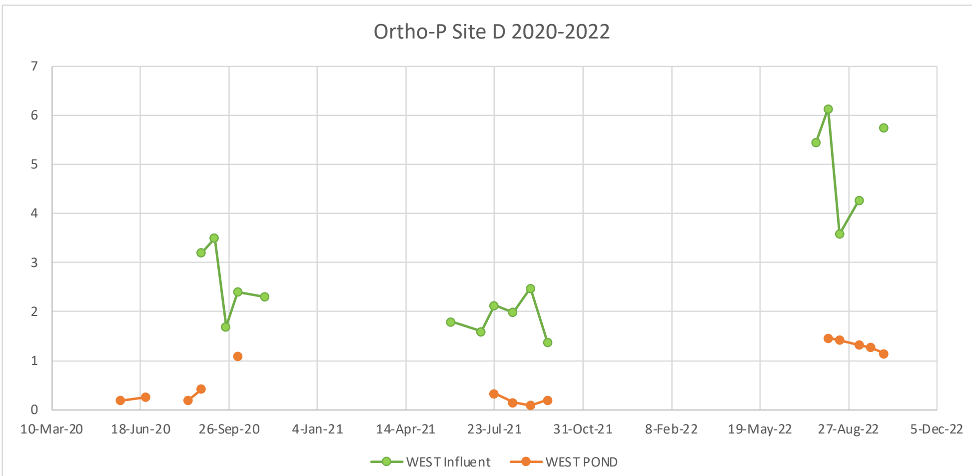

Sulfate-S Site D 2020-2022
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
EAST POND
WEST POND

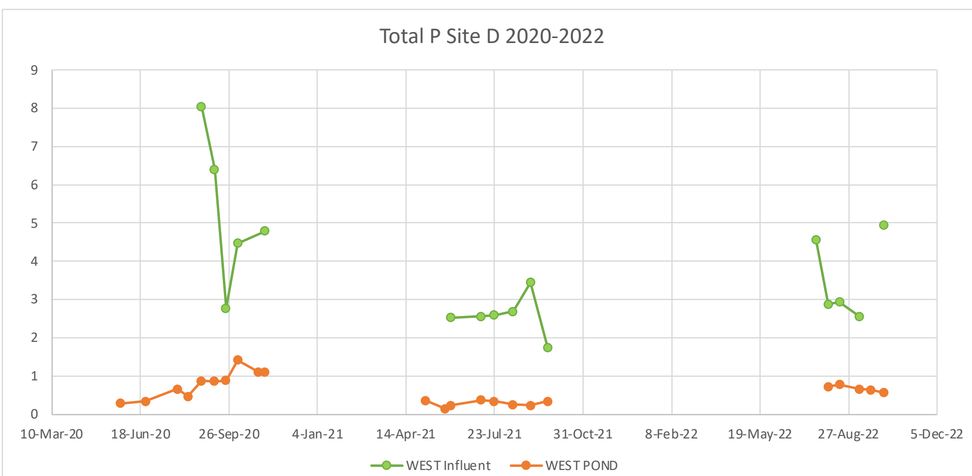

Chlorophyll *a* Site D 2020-2022
110
90
70
50
30
10
-10
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
EAST POND
WEST POND

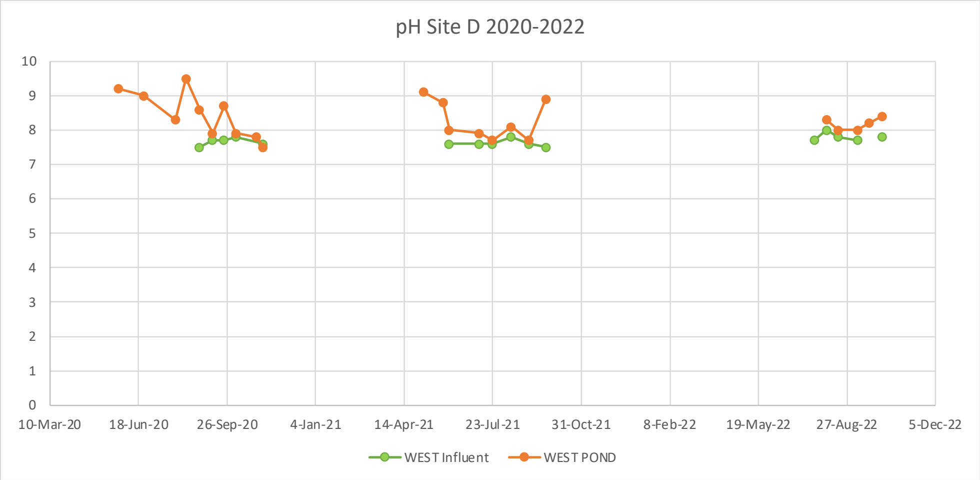

Phycocyanin Site D 2020-2022
20
15
10
5
0
-5
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
EAST POND
WEST POND

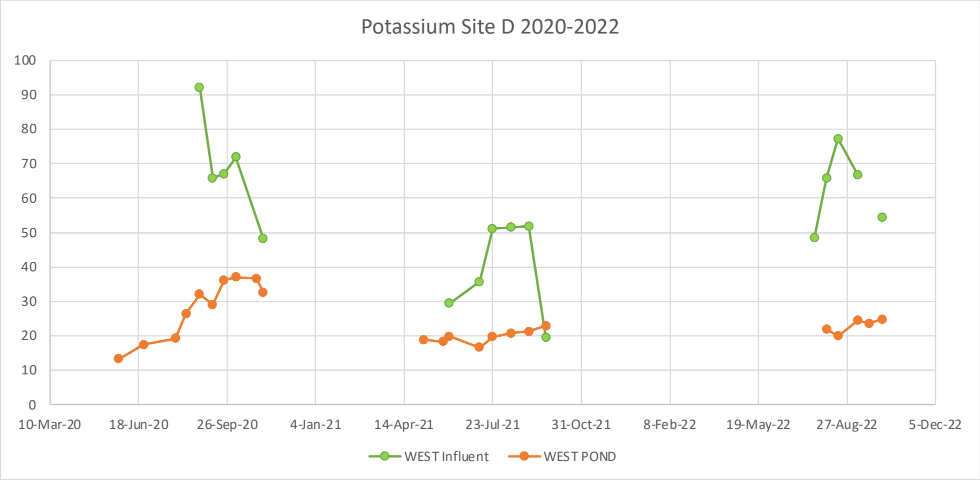
Comparison of West pond drain (influent into pond) and the West pond



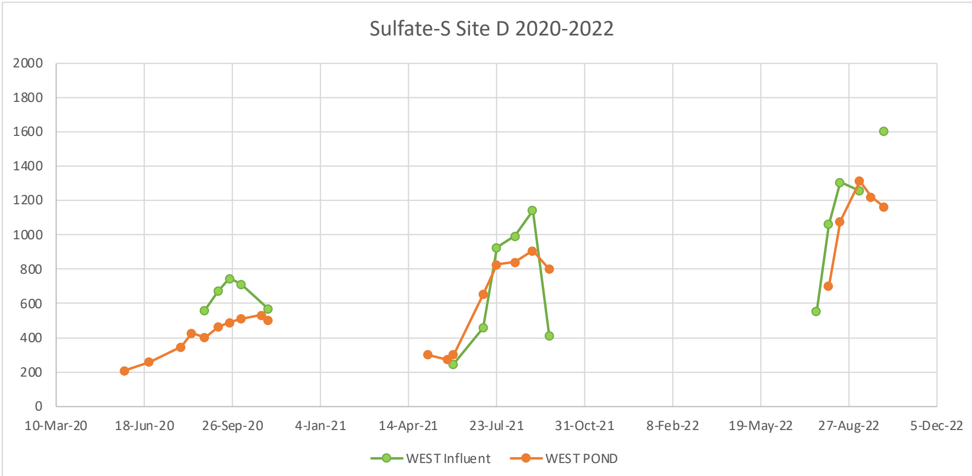


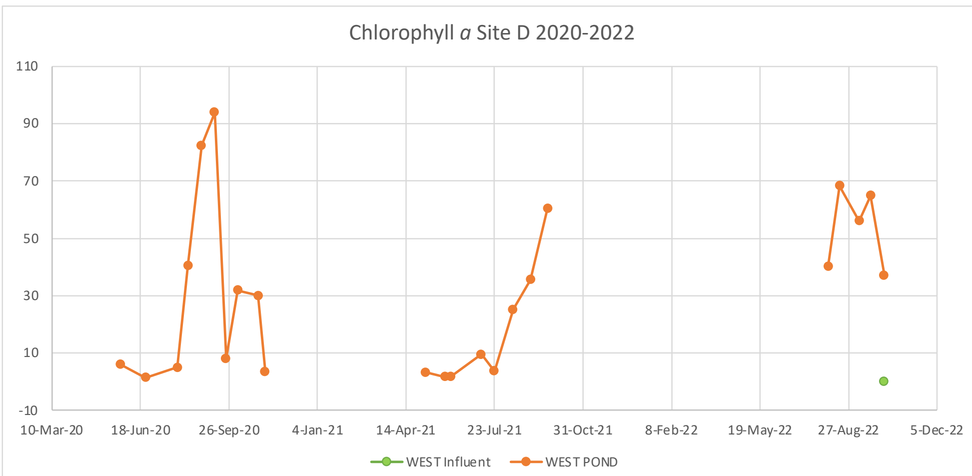


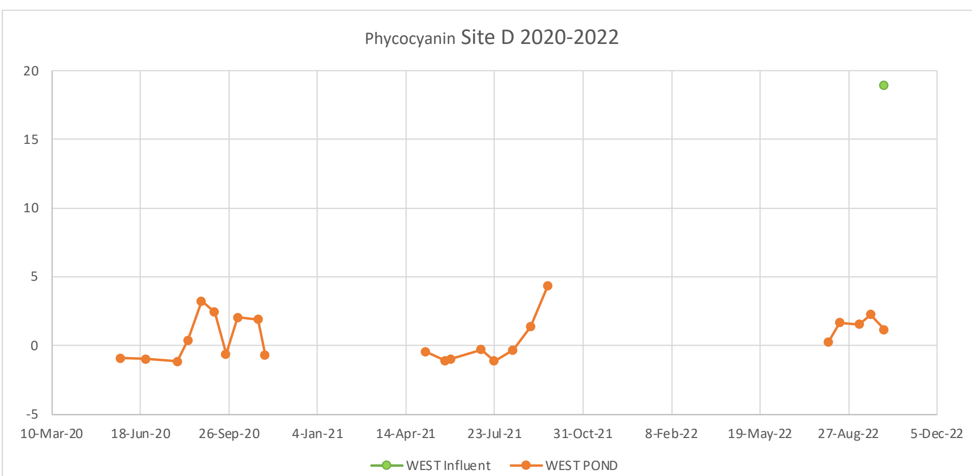

pH Site D 2020-2022
10
9
8
7
6
5
4
3
2
1
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
WEST Influent
WEST POND


Potassium Site D 2020-2022
100
90
80
70
60
50
40
30
20
10
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
WEST Influent
WEST POND

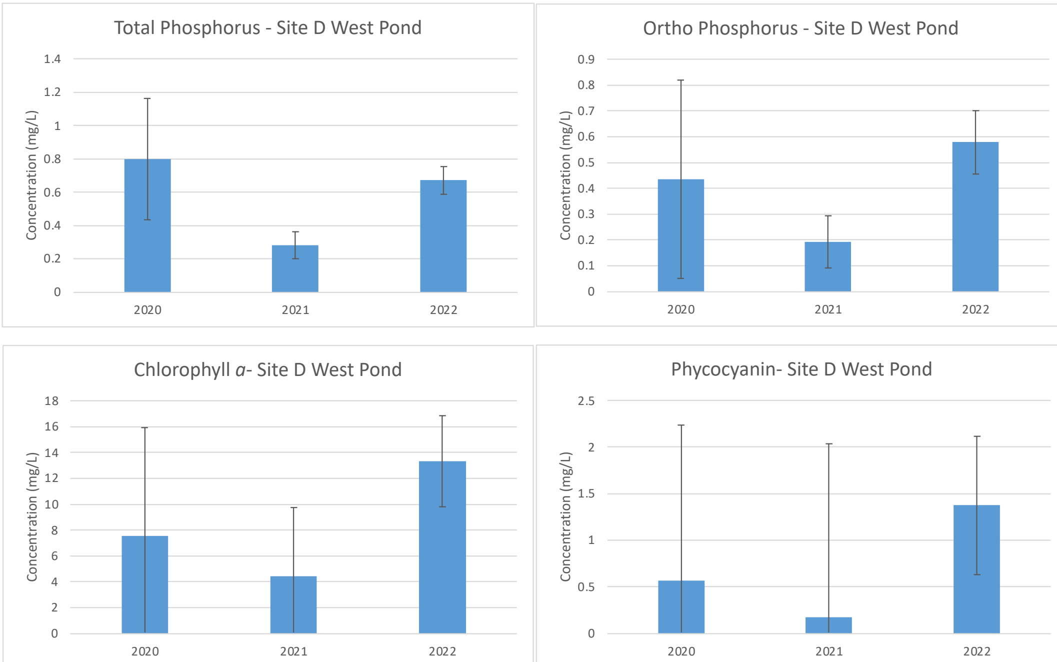

Conductivity Site D 2020-2022
3500
3000
2500
2000
1500
1000
500
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
WEST Influent
WEST POND


Sulfate-S Site D 2020-2022
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
WEST Influent
WEST POND

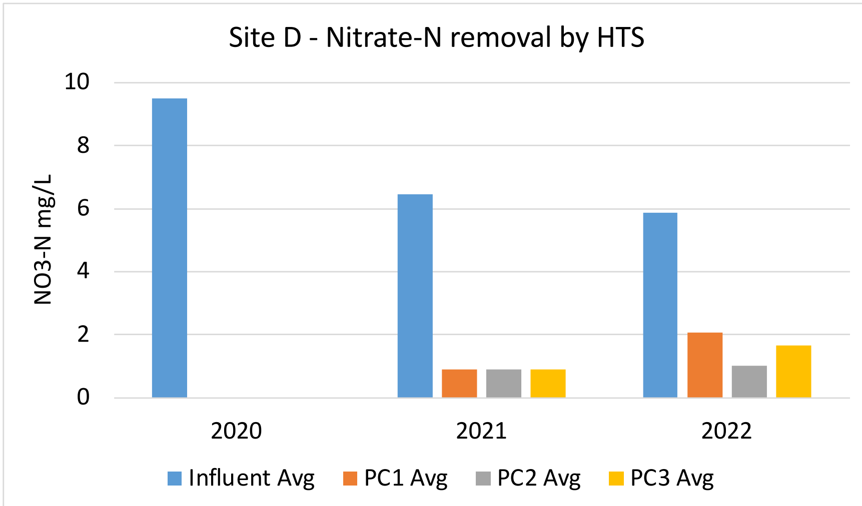

Chlorophyll a Site D 2020-2022
110
90
70
50
30
10
-10
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
WEST Influent
WEST POND

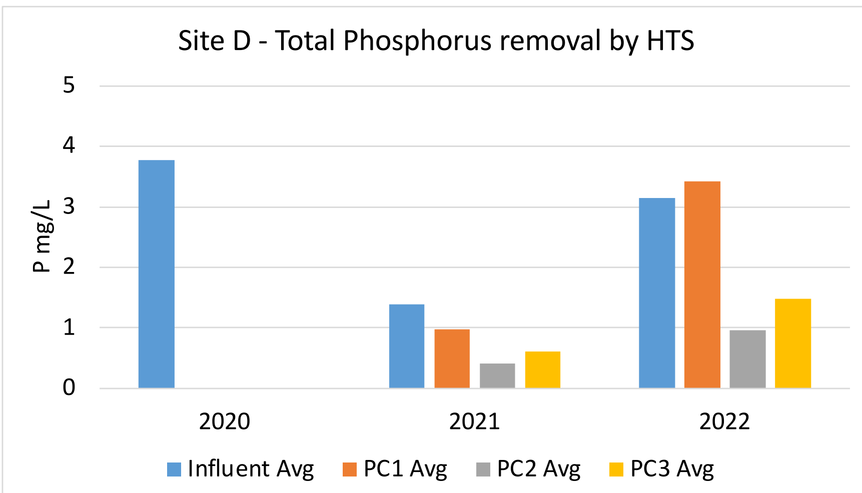

Phycocyanin Site D 2020-2022
20
15
10
5
0
-5
10-Mar-20
18-Jun-20
26-Sep-20
4-Jan-21
14-Apr-21
23-Jul-21
31-Oct-21
8-Feb-22
19-May-22
27-Aug-22
5-Dec-22
WEST Influent
WEST POND

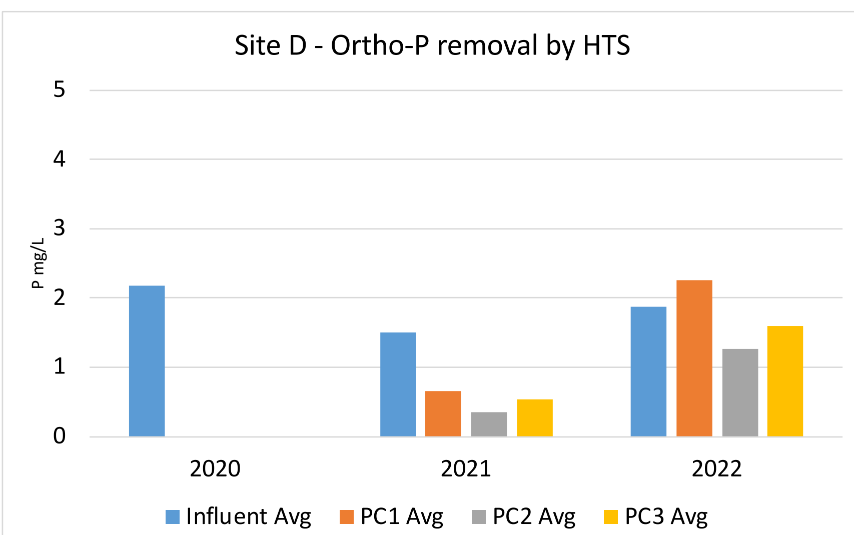
Average west pond water quality over years sampled



Hybrid Treatment Swale results 2021-2022

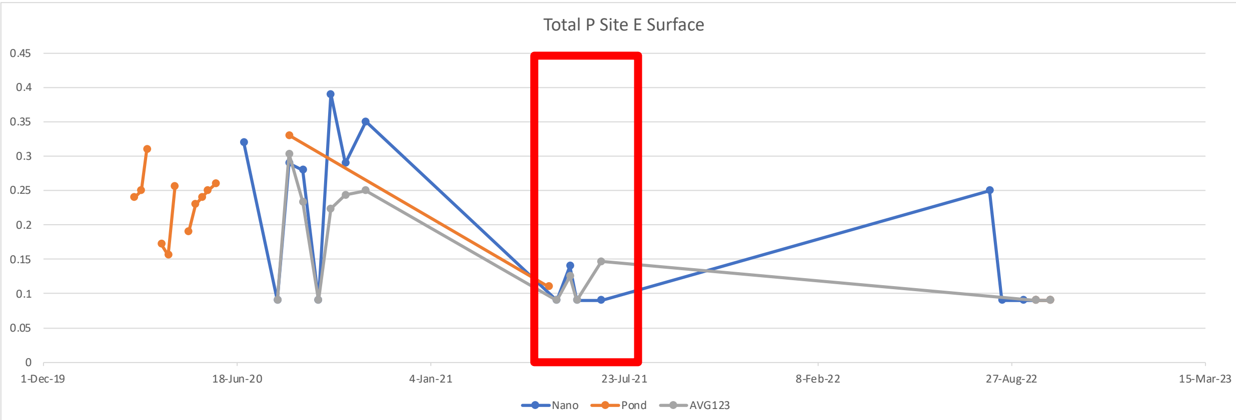


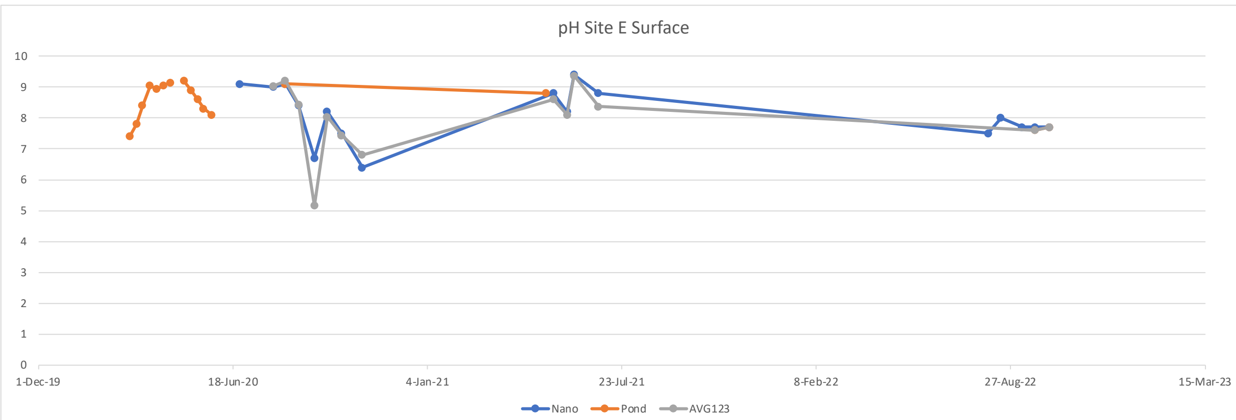


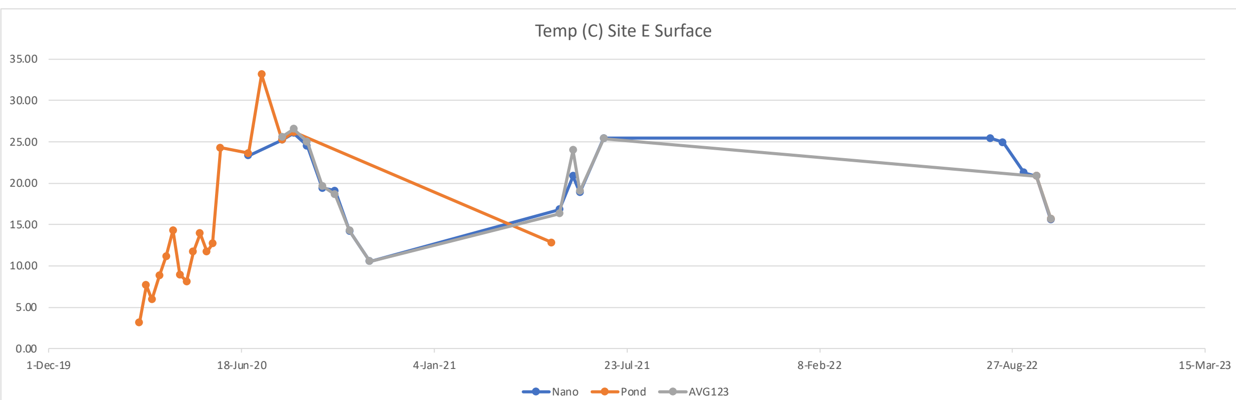


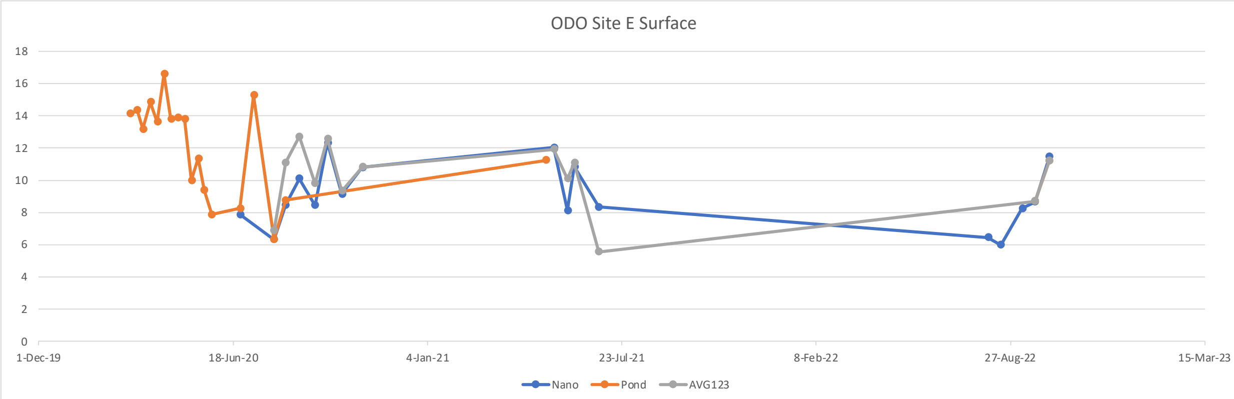
Appendix E – Site E Selected Results

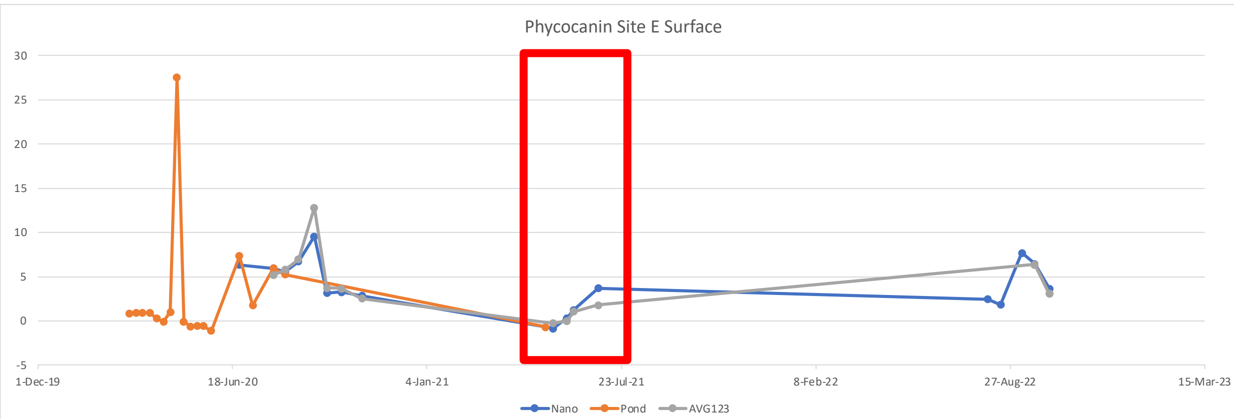
Average Data from Pond Surface – red box indicates period with hyacinth covering

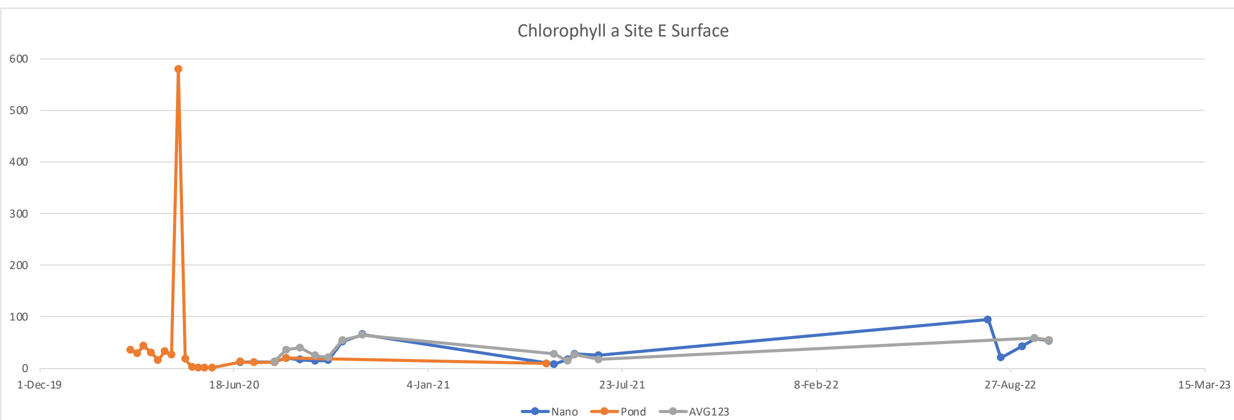


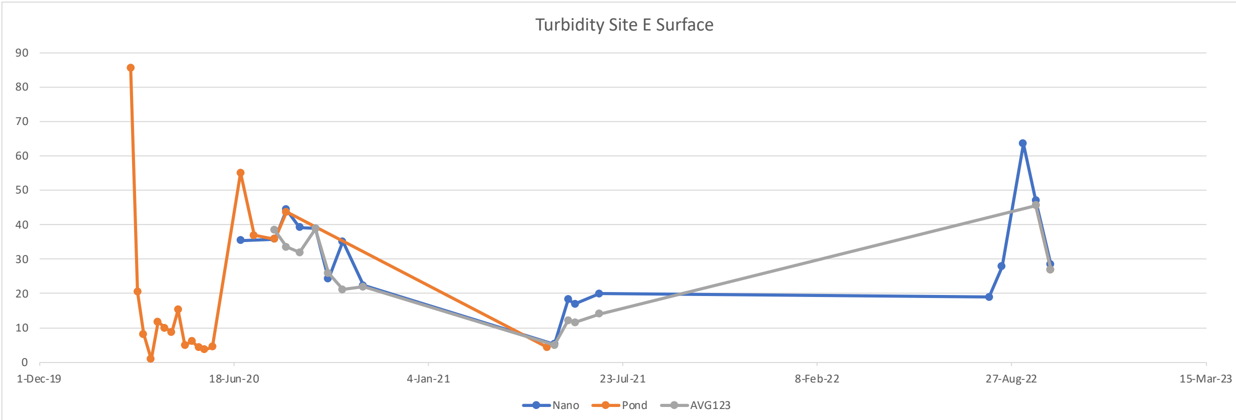


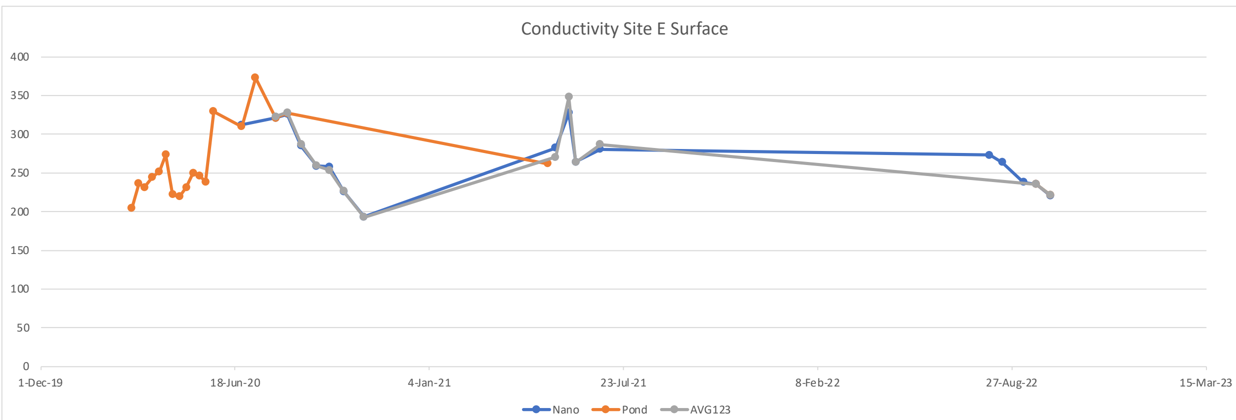



ODO Site E Surface
18
16
14
12
10
8
6
4
2
0
1-Dec-19
18-Jun-20
4-Jan-21
23-Jul-21
8-Feb-22
27-Aug-22
15-Mar-23
Nano
Pond
AVG123

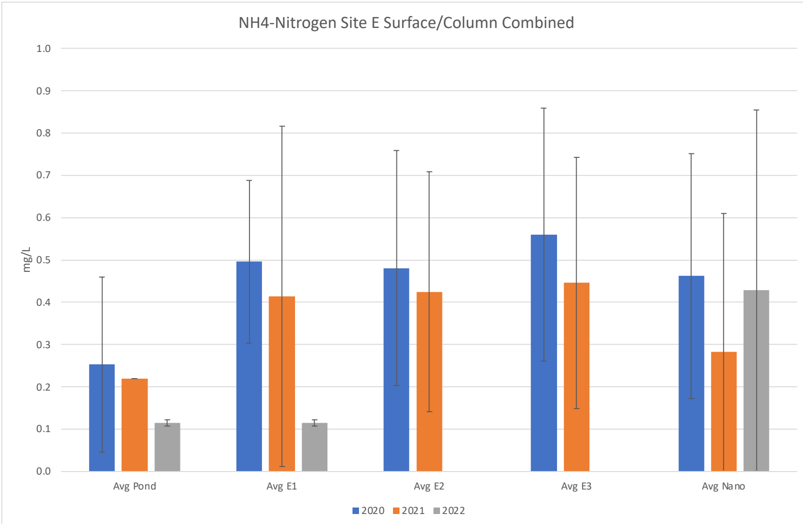

Phycocanin Site E Surface
30
25
20
15
10
5
0
-5
1-Dec-19
18-Jun-20
4-Jan-21
23-Jul-21
8-Feb-22
27-Aug-22
15-Mar-23
Nano
Pond
AVG123

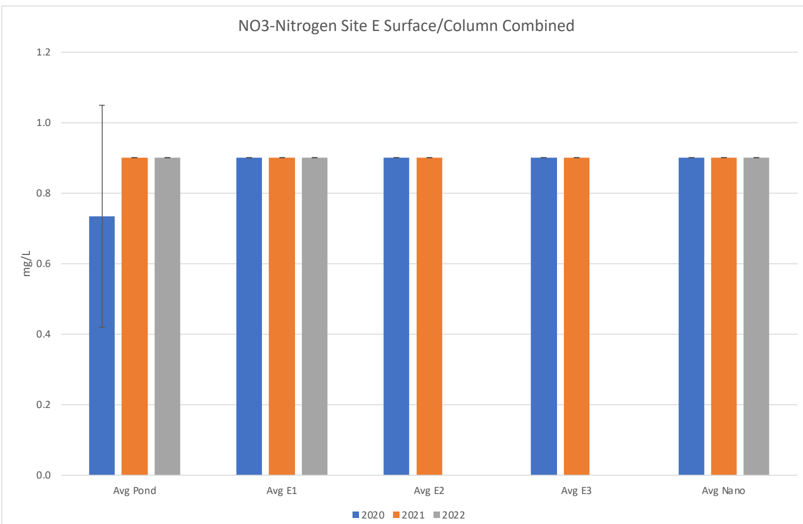

Chlorophyll a Site E Surface
600
500
400
300
200
100
0
1-Dec-19
18-Jun-20
4-Jan-21
23-Jul-21
8-Feb-22
27-Aug-22
15-Mar-23
Nano
Pond
AVG123

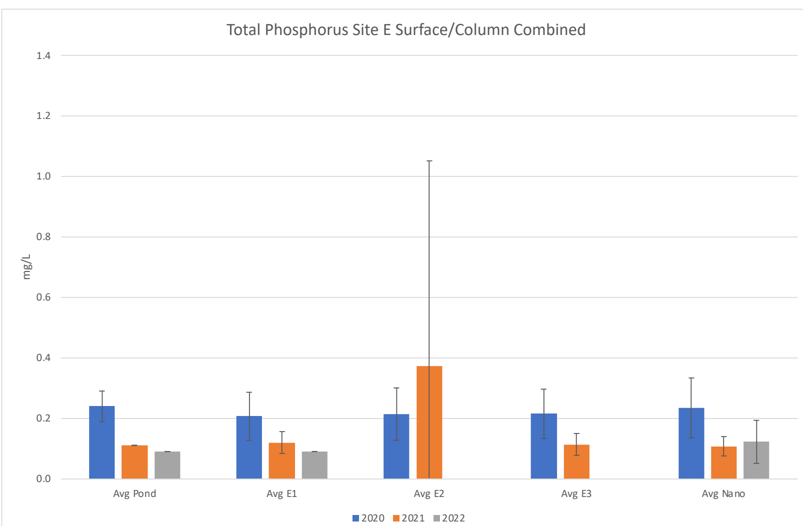

Turbidity Site E Surface
90
80
70
60
50
40
30
20
10
0
1-Dec-19
18-Jun-20
4-Jan-21
23-Jul-21
8-Feb-22
27-Aug-22
15-Mar-23
Nano
Pond
AVG123

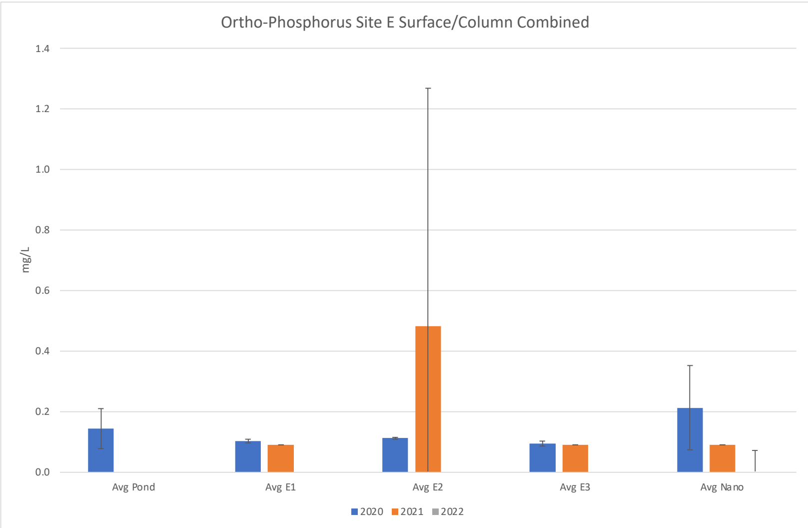

Conductivity Site E Surface
400
350
300
250
200
150
100
50
0
1-Dec-19
18-Jun-20
4-Jan-21
23-Jul-21
8-Feb-22
27-Aug-22
15-Mar-23
Nano
Pond
AVG123

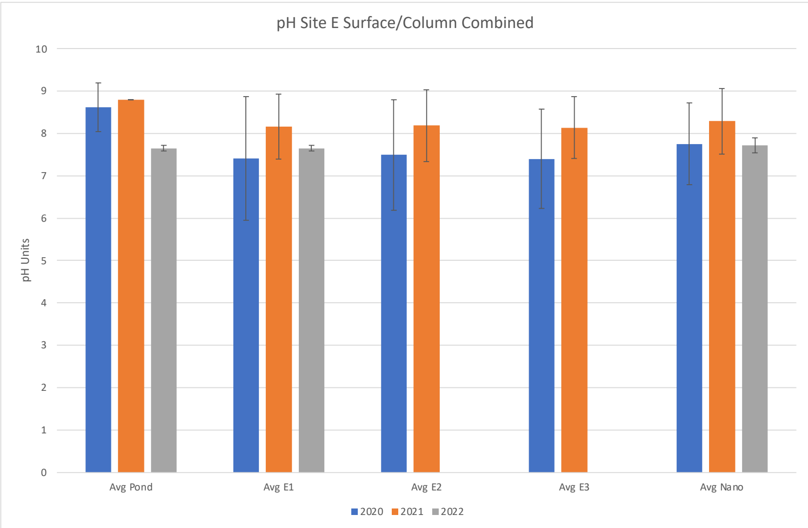
Averages over seasons for all sample sites, combining surface and column data 2020-2022

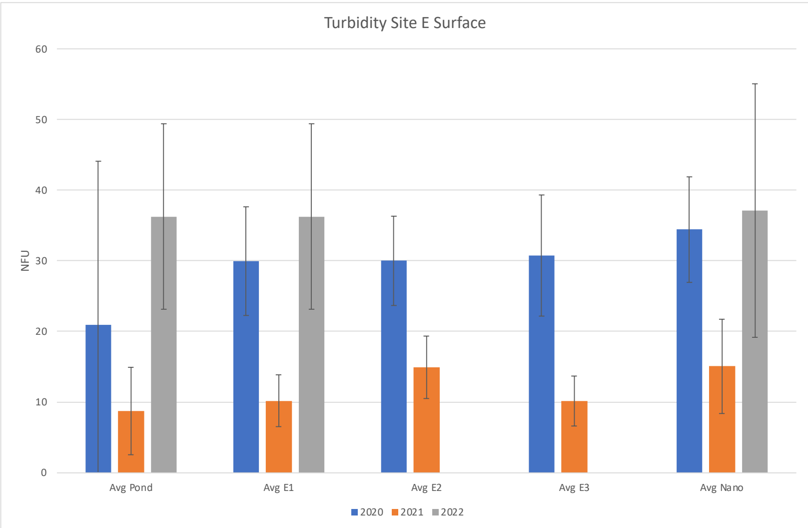


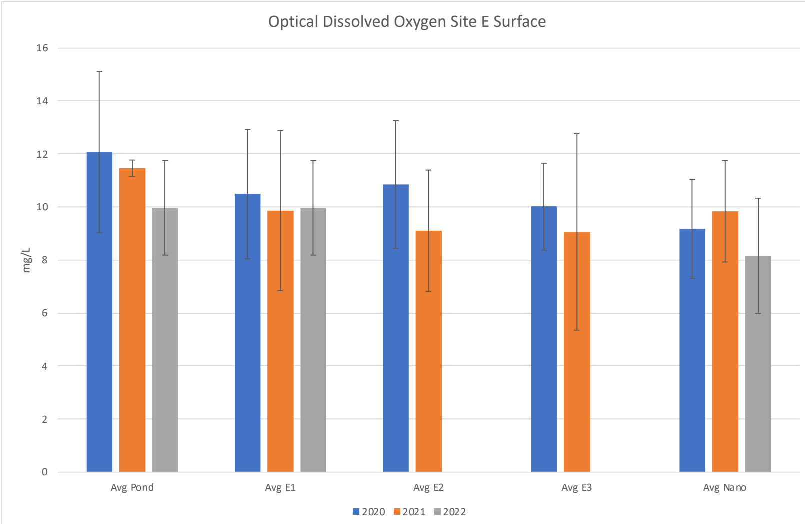


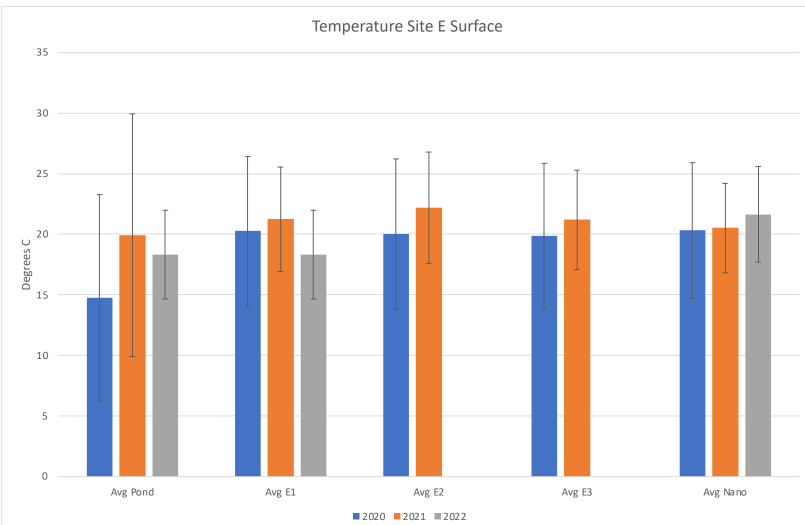


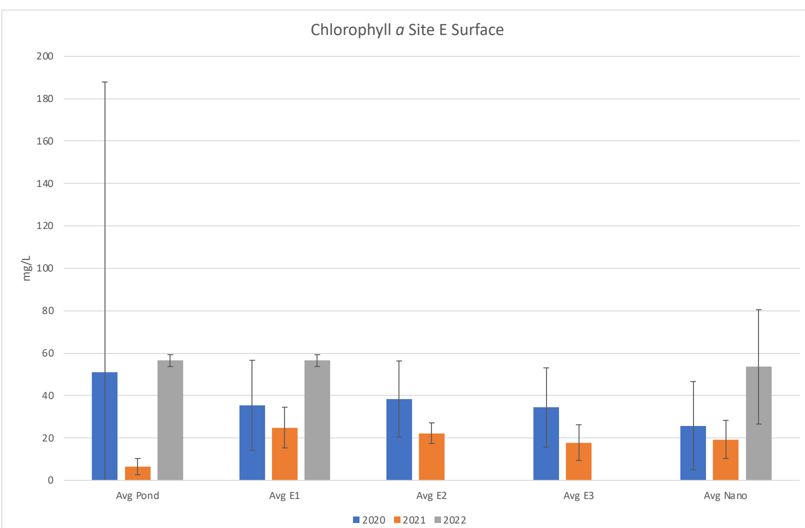

Ortho-Phosphorus Site E Surface/Column Combined
mg/L
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Avg Pond
Avg E1
Avg E2
Avg E3
Avg Nano
2020 2021 2022

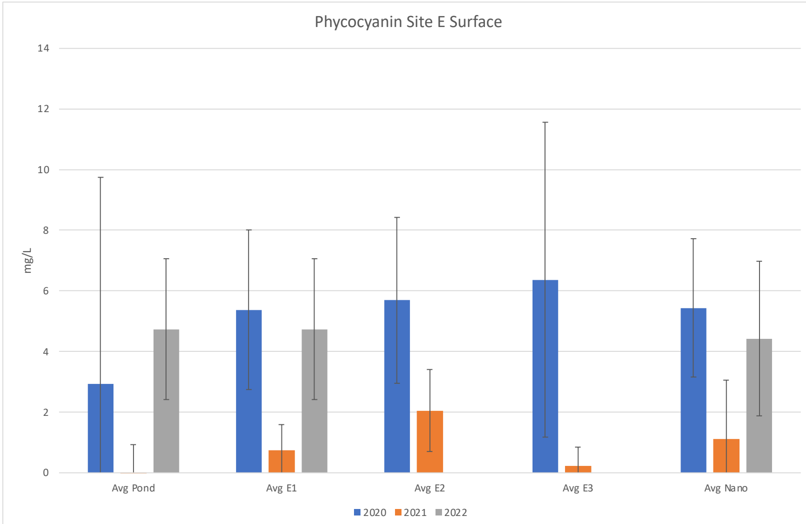

pH Site E Surface/Column Combined
pH Units
10
9
8
7
6
5
4
3
2
1
0
Avg Pond
Avg E1
Avg E2
Avg E3
Avg Nano
2020 2021 2022


Turbidity Site E Surface
NFU
60
50
40
30
20
10
0
Avg Pond
Avg E1
Avg E2
Avg E3
Avg Nano
2020 2021 2022

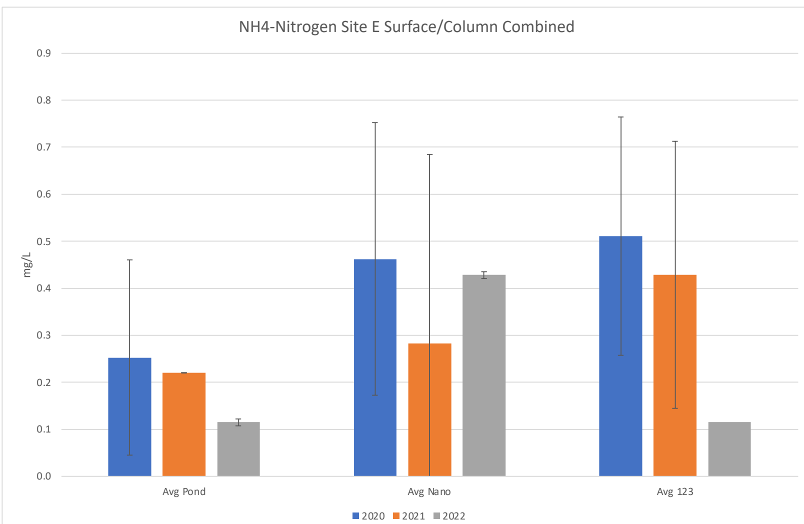

Optical Dissolved Oxygen Site E Surface
16
14
12
10
8
6
4
2
0
mg/L
Avg Pond
Avg E1
Avg E2
Avg E3
Avg Nano
2020
2021
2022

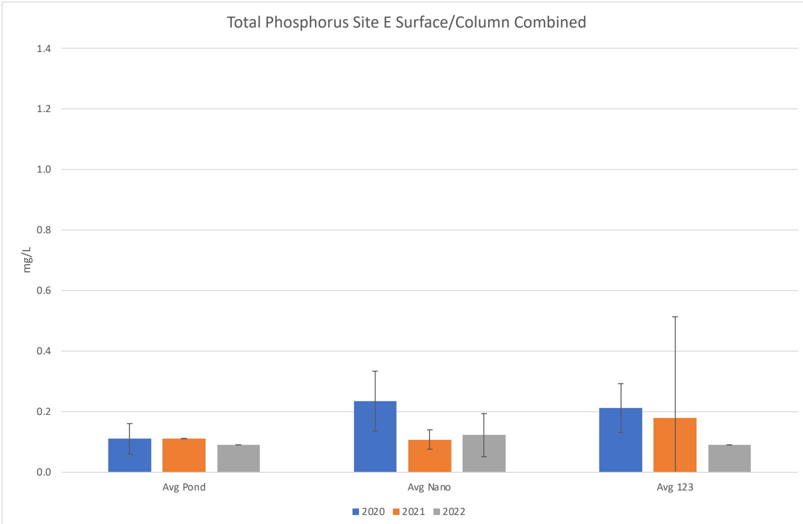

Temperature Site E Surface
35
30
25
20
15
10
5
0
Degrees C
Avg Pond
Avg E1
Avg E2
Avg E3
Avg Nano
2020
2021
2022

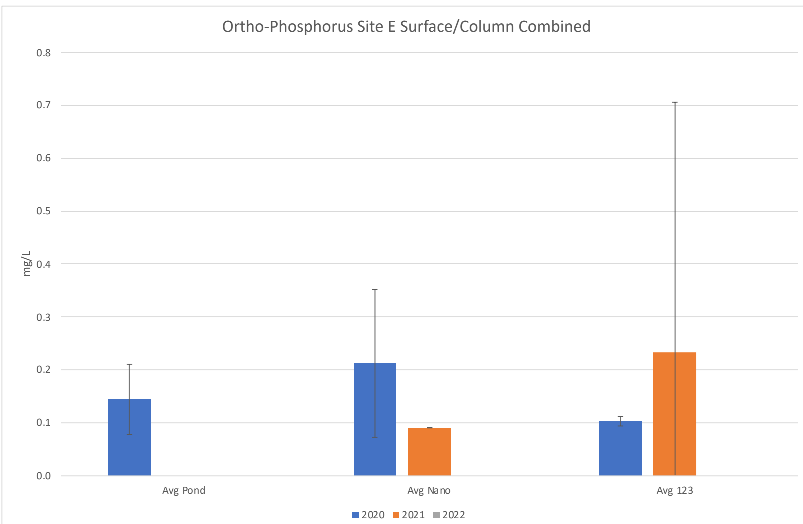

Chlorophyll *a* Site E Surface
200
180
160
140
120
100
80
60
40
20
0
mg/L
Avg Pond
Avg E1
Avg E2
Avg E3
Avg Nano
2020
2021
2022

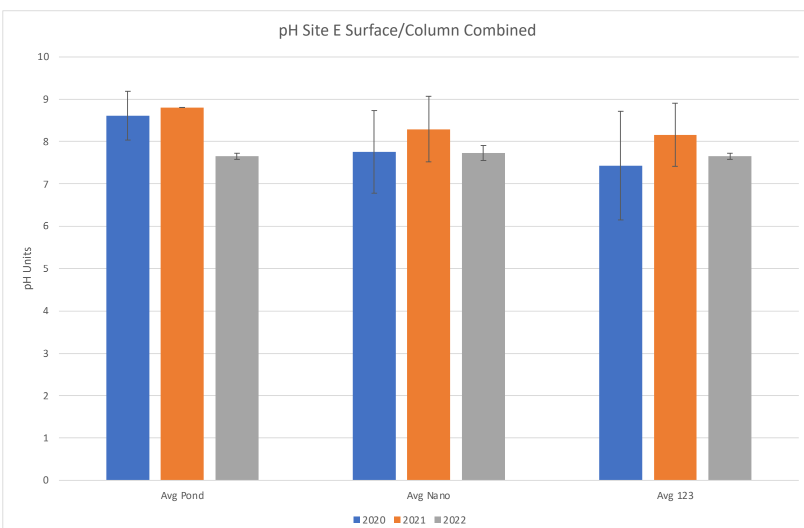


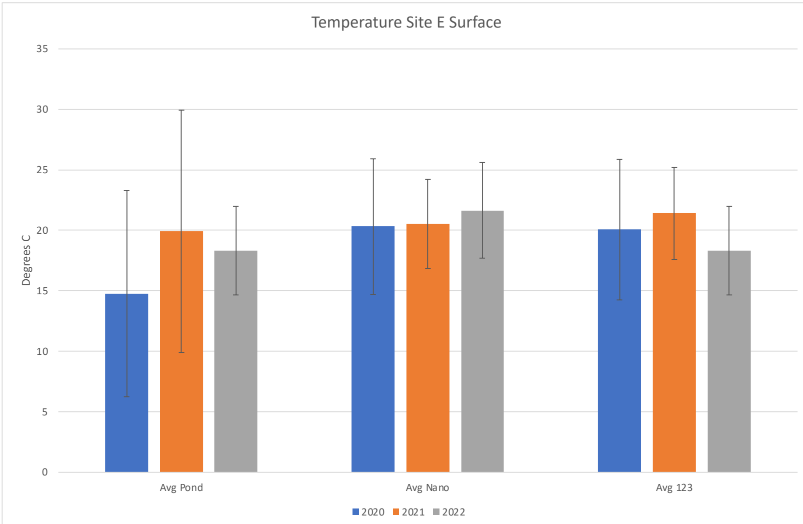
Averages over seasons for combined E1, E2 and E3; combining surface and column data

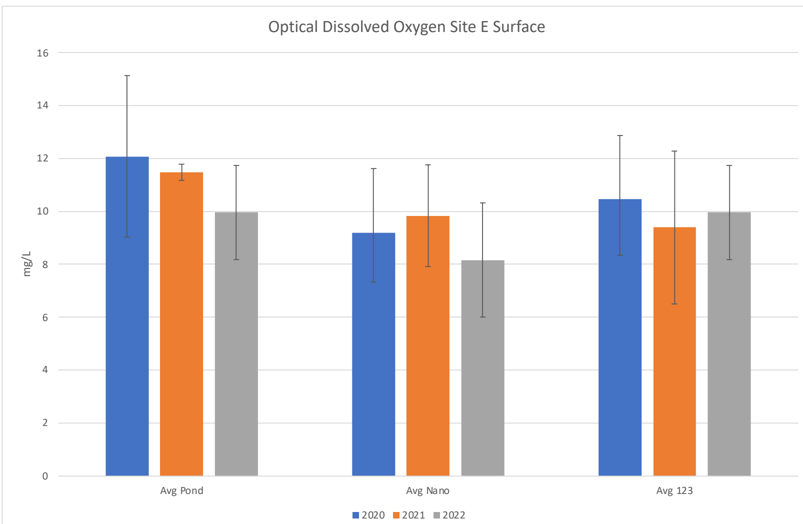


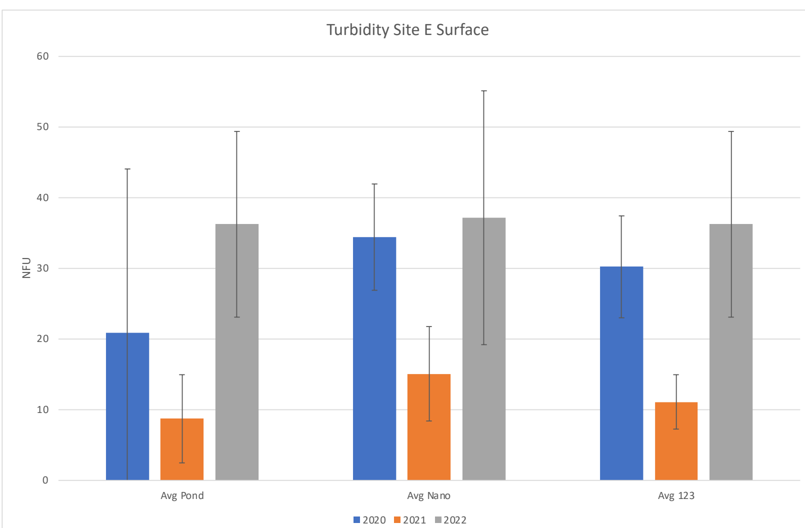

Total Phosphorus Site E Surface/Column Combined
mg/L
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Avg Pond
Avg Nano
Avg 123
2020
2021
2022

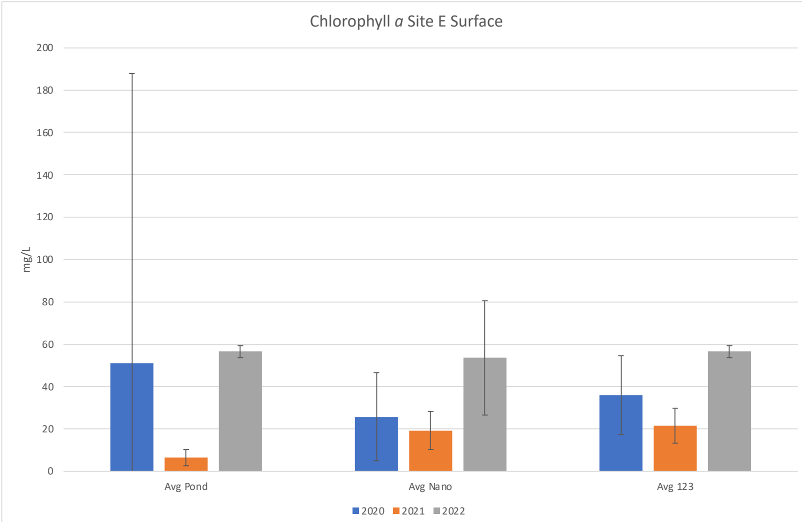

Ortho-Phosphorus Site E Surface/Column Combined
mg/L
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Avg Pond
Avg Nano
Avg 123
2020
2021
2022

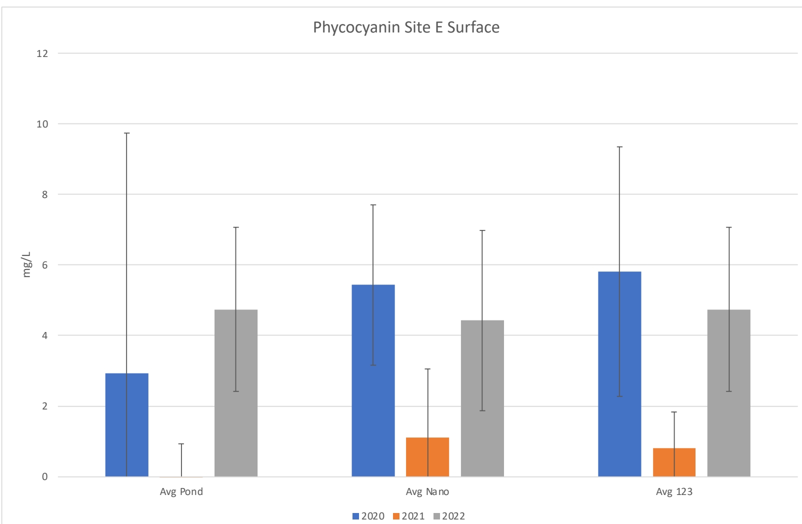

pH Site E Surface/Column Combined
pH Units
10
9
8
7
6
5
4
3
2
1
0
Avg Pond
Avg Nano
Avg 123
2020
2021
2022


Temperature Site E Surface
Degrees C
35
30
25
20
15
10
5
0
Avg Pond
Avg Nano
Avg 123
2020
2021
2022

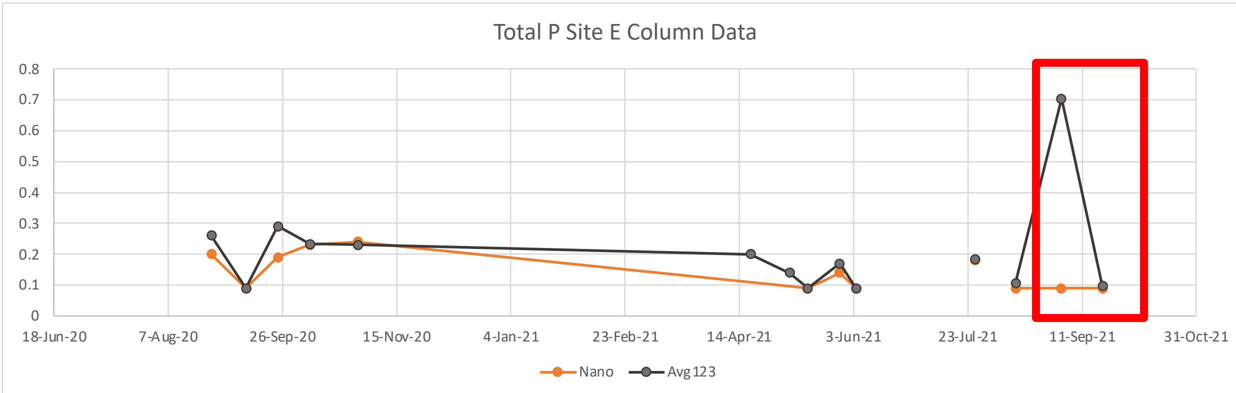

Optical Dissolved Oxygen Site E Surface
mg/L
16
14
12
10
8
6
4
2
0
Avg Pond
Avg Nano
Avg 123
2020
2021
2022

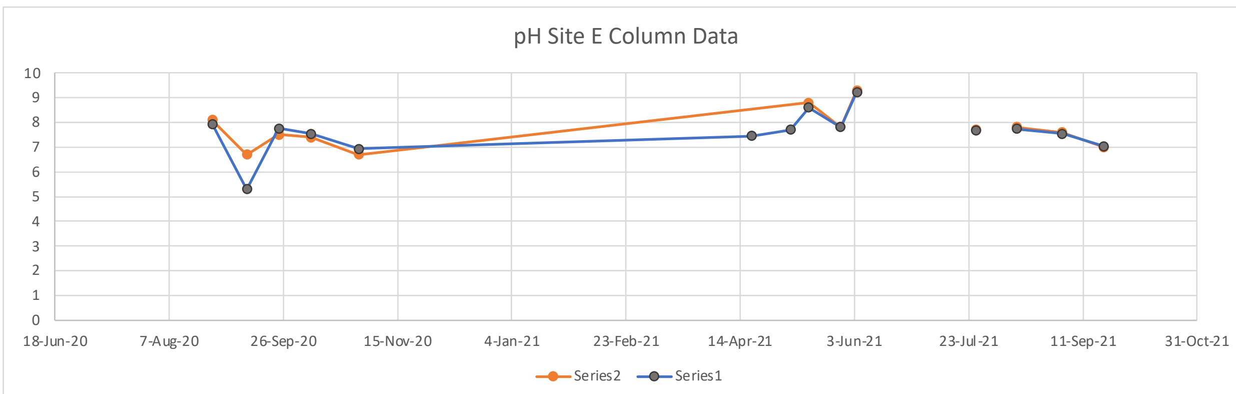

Turbidity Site E Surface
NFU
60
50
40
30
20
10
0
Avg Pond
Avg Nano
Avg 123
2020
2021
2022

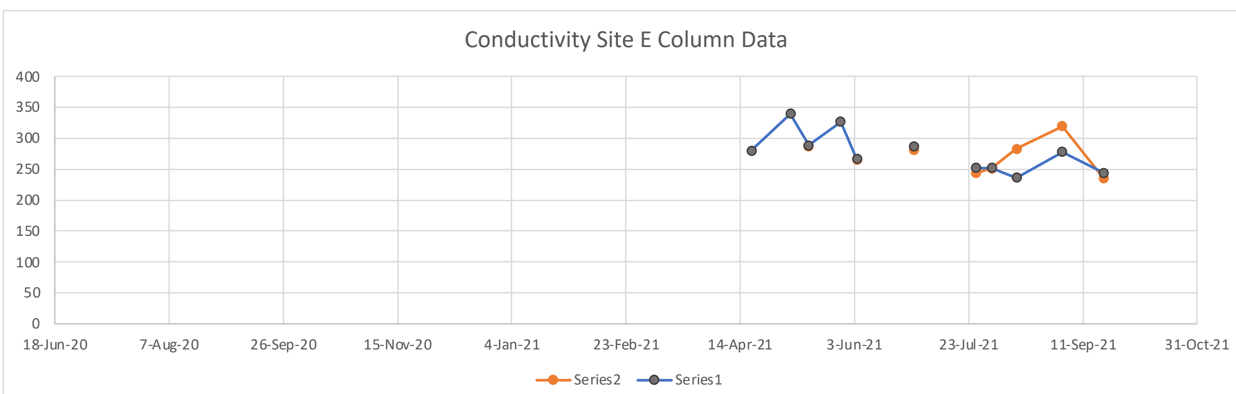

Chlorophyll a Site E Surface
200
180
160
140
120
100
80
60
40
20
0
mg/L
Avg Pond
Avg Nano
Avg 123
2020
2021
2022

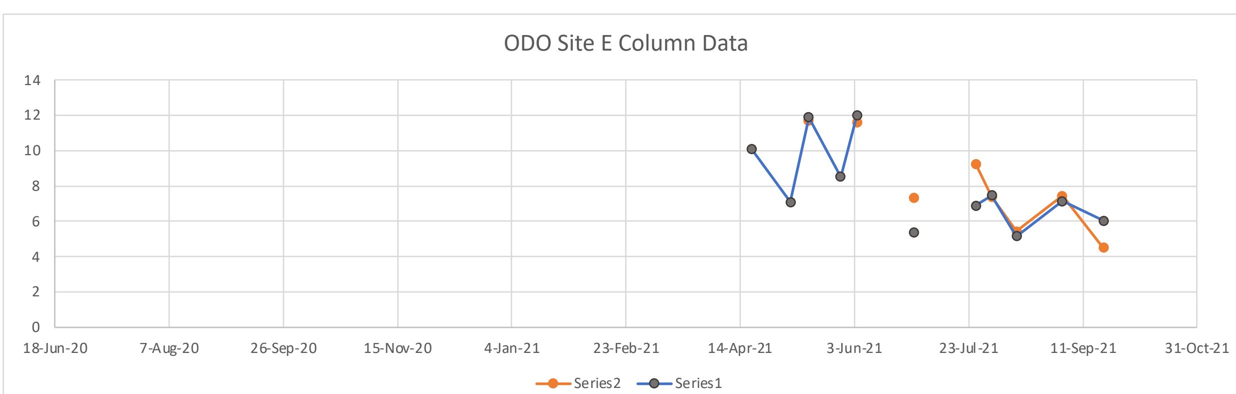

Phycocyanin Site E Surface
12
10
8
6
4
2
0
mg/L
Avg Pond
Avg Nano
Avg 123
2020
2021
2022

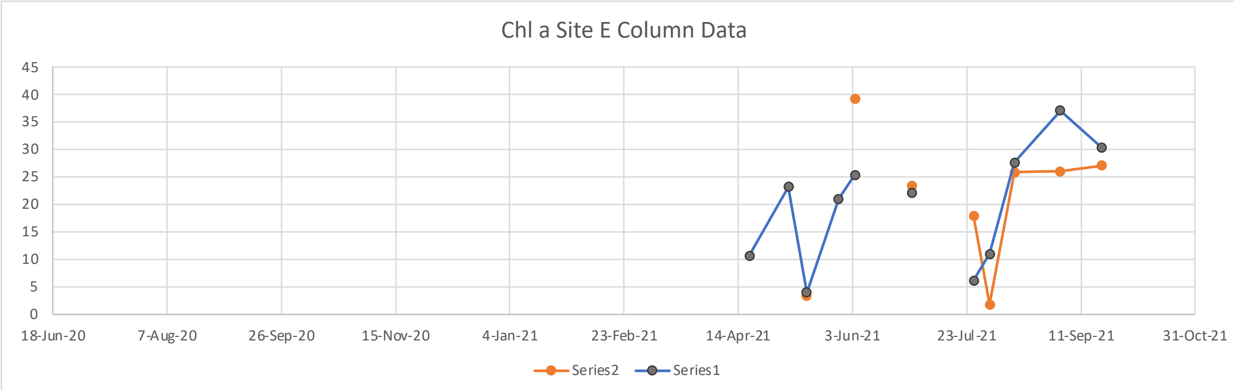
2020-2021 column data for Site E (no column pond data), red box is period of complete coverage by hyacinths

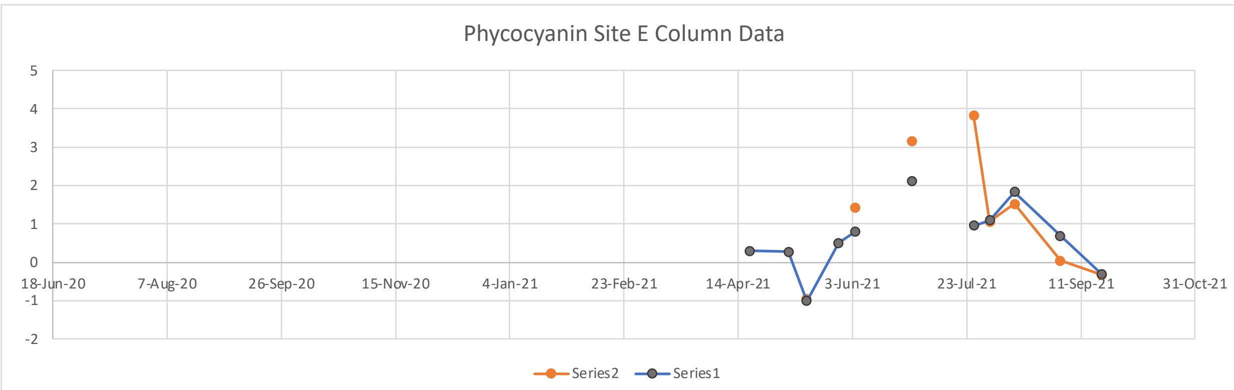


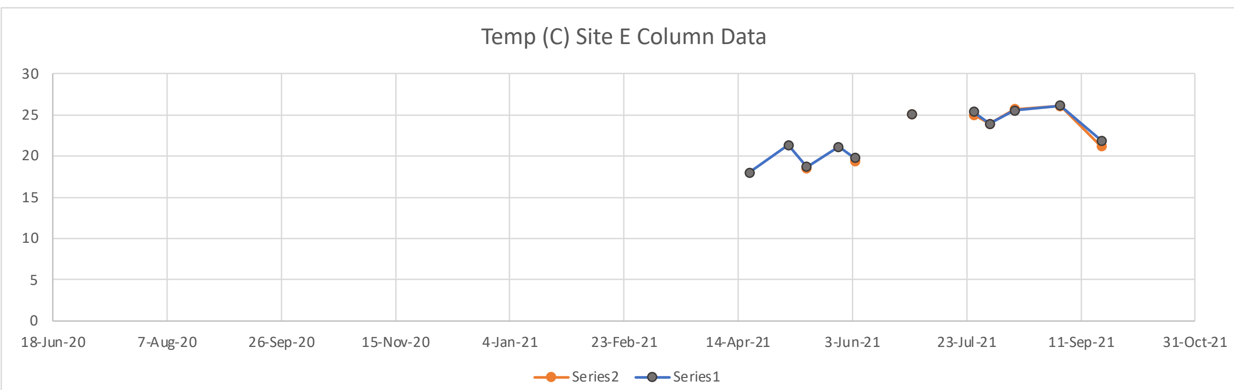


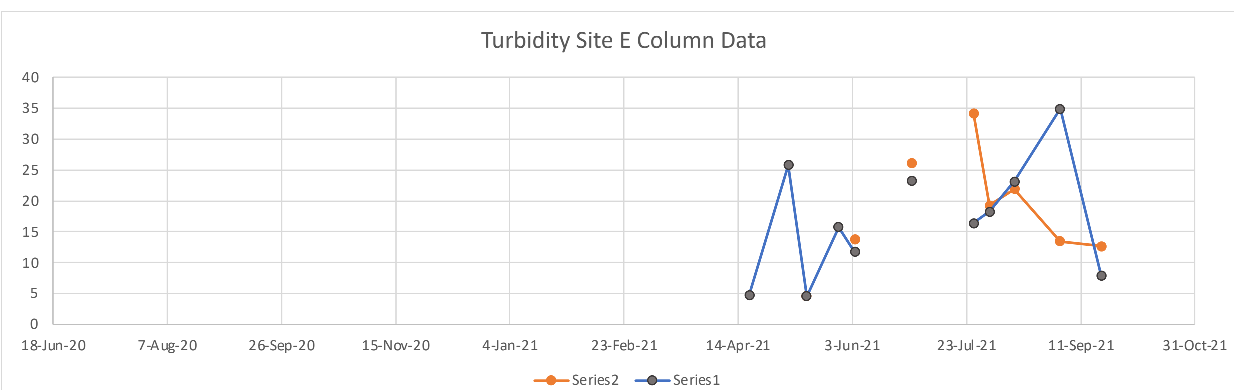




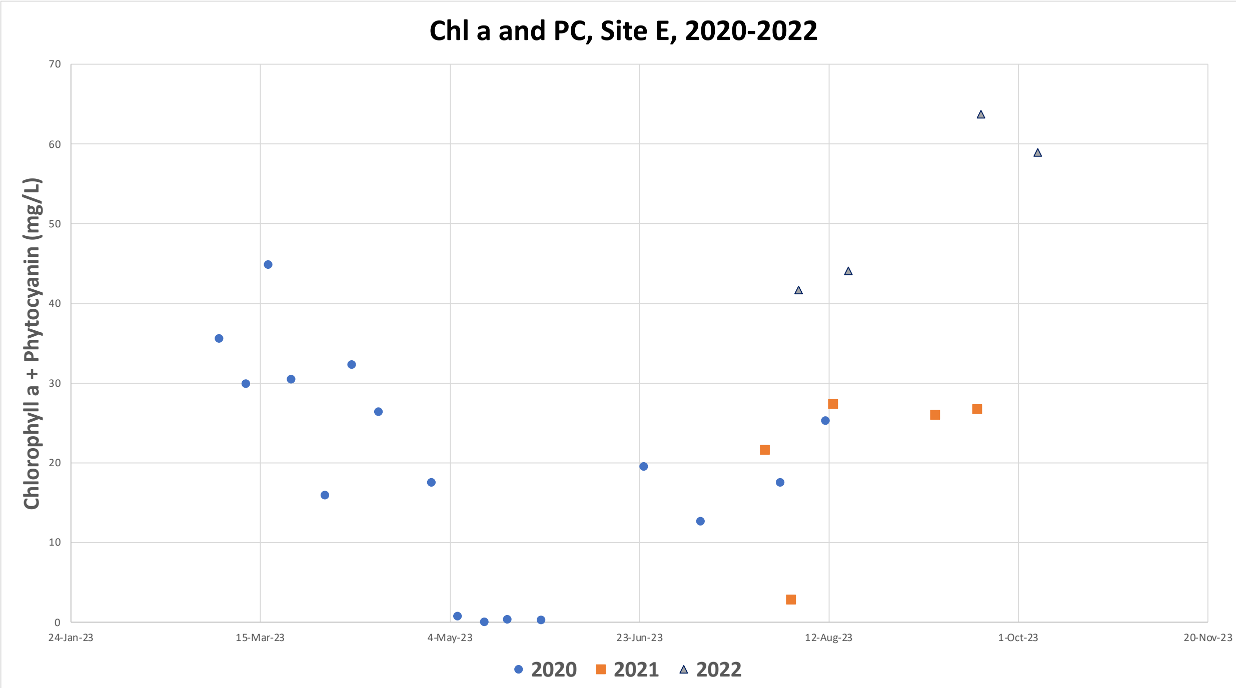

Chl a Site E Column Data
45
40
35
30
25
20
15
10
5
0
18-Jun-20
7-Aug-20
26-Sep-20
15-Nov-20
4-Jan-21
23-Feb-21
14-Apr-21
3-Jun-21
23-Jul-21
11-Sep-21
31-Oct-21
Series2
Series1

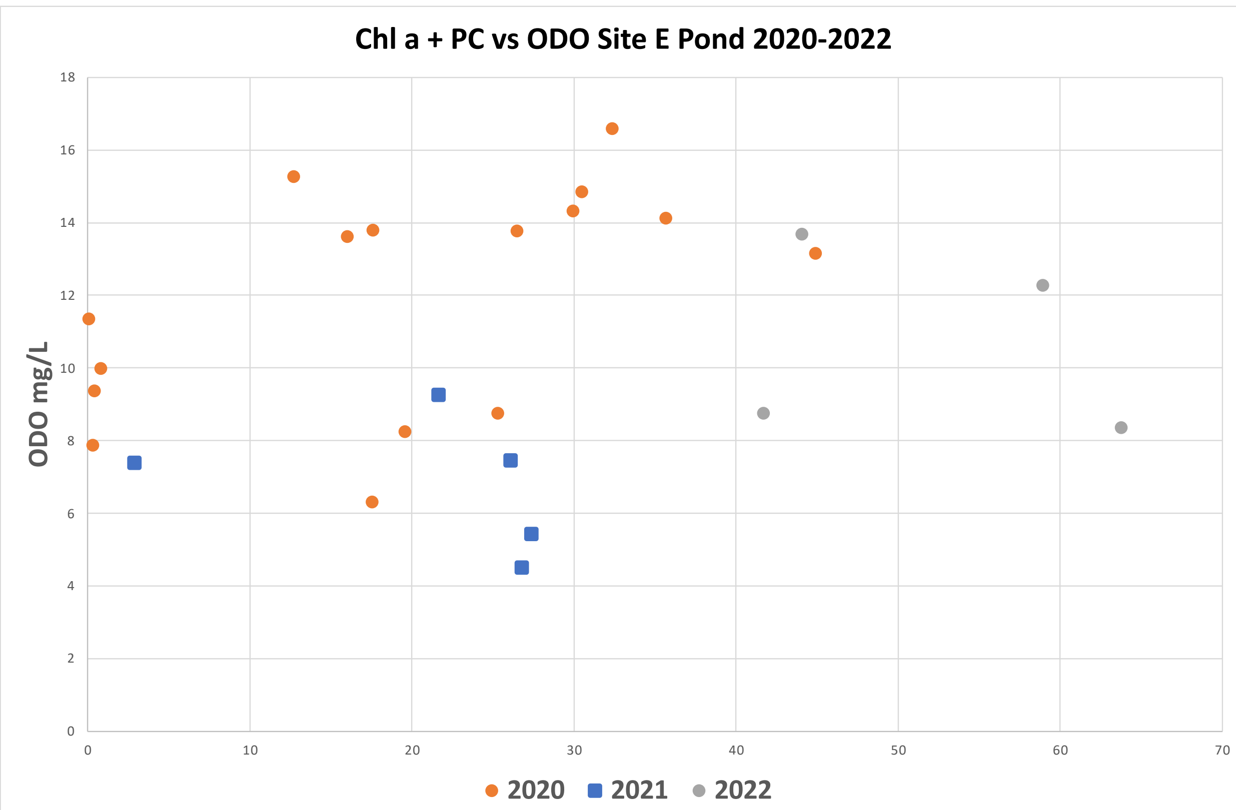

Phycocyanin Site E Column Data
5
4
3
2
1
0
-1
-2
18-Jun-20
7-Aug-20
26-Sep-20
15-Nov-20
4-Jan-21
23-Feb-21
14-Apr-21
3-Jun-21
23-Jul-21
11-Sep-21
31-Oct-21
Series2
Series1

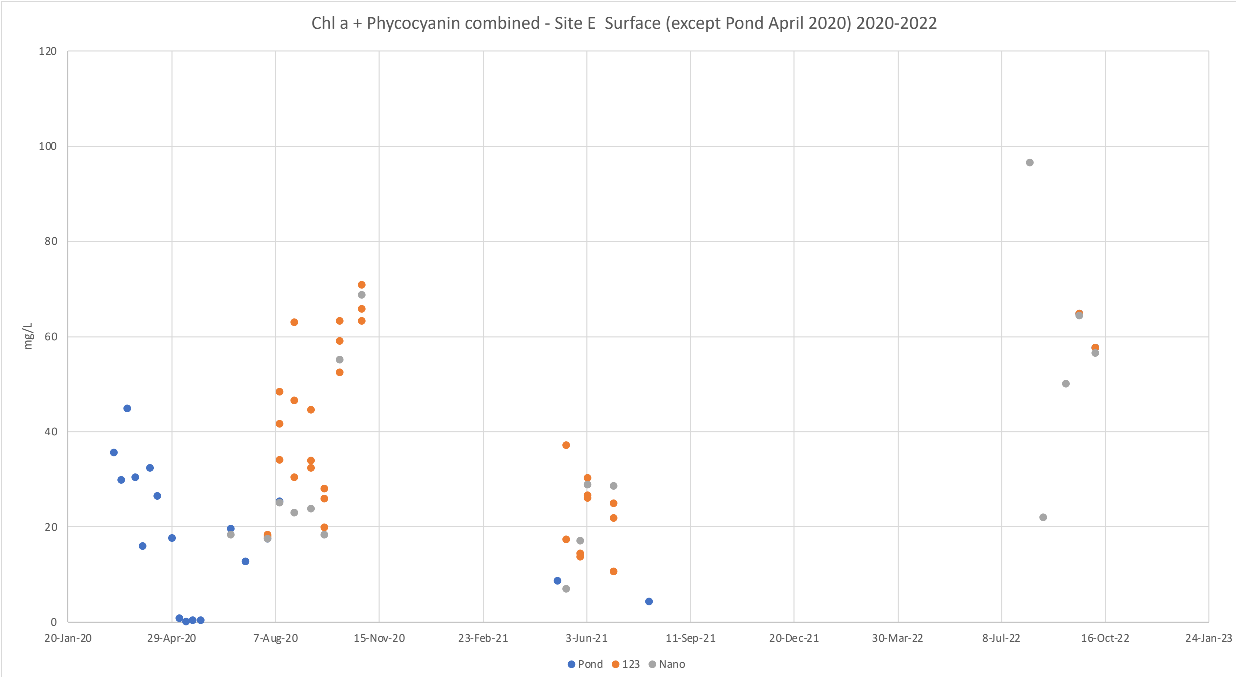

Temp (C) Site E Column Data
30
25
20
15
10
5
0
18-Jun-20
7-Aug-20
26-Sep-20
15-Nov-20
4-Jan-21
23-Feb-21
14-Apr-21
3-Jun-21
23-Jul-21
11-Sep-21
31-Oct-21
Series2
Series1


Turbidity Site E Column Data
40
35
30
25
20
15
10
5
0
18-Jun-20
7-Aug-20
26-Sep-20
15-Nov-20
4-Jan-21
23-Feb-21
14-Apr-21
3-Jun-21
23-Jul-21
11-Sep-21
31-Oct-21
Series2
Series1

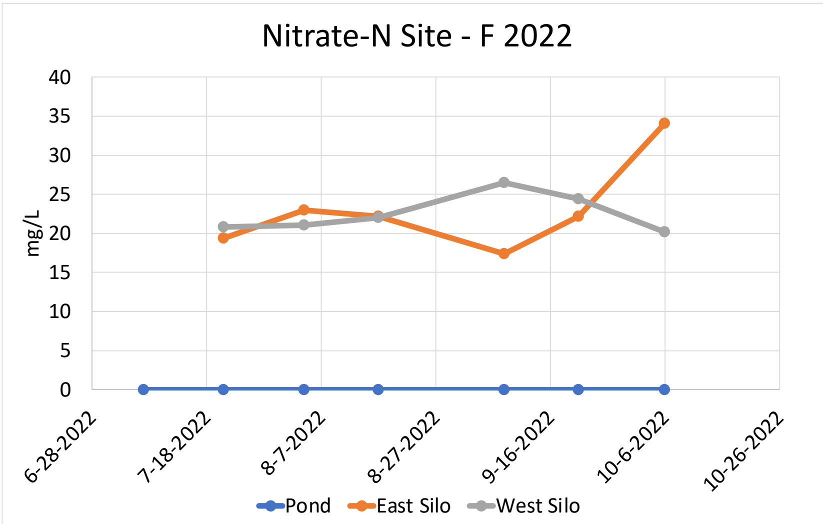
Interesting combination plots, Site E, all surface data over the three years:

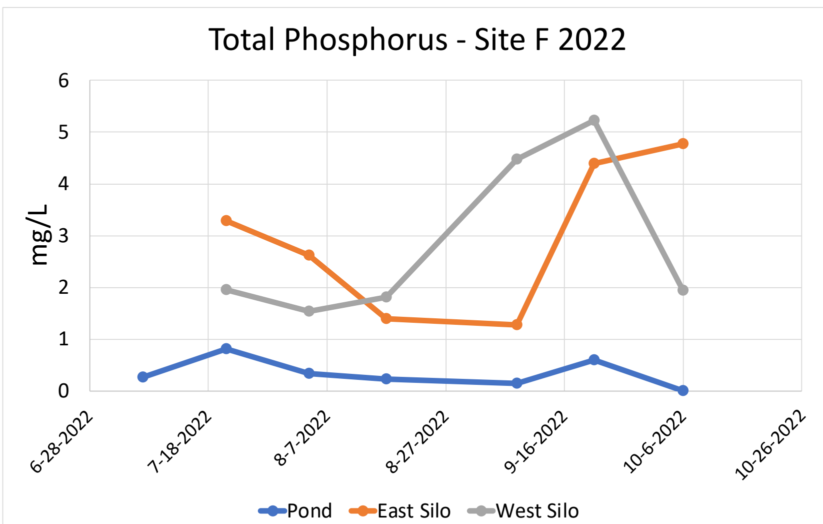


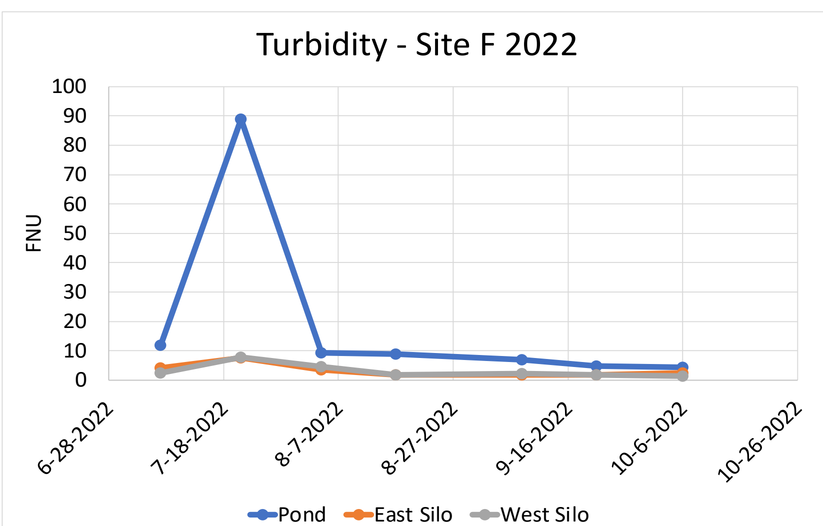


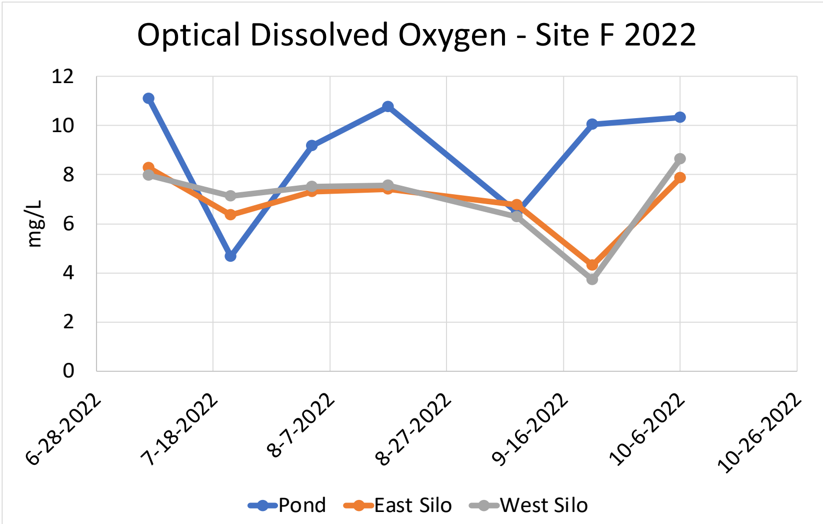

Chl a + Phycocyanin combined - Site E Surface (except Pond April 2020) 2020-2022
mg/L
120
100
80
60
40
20
0
20-Jan-20
29-Apr-20
7-Aug-20
15-Nov-20
23-Feb-21
3-Jun-21
11-Sep-21
20-Dec-21
30-Mar-22
8-Jul-22
16-Oct-22
24-Jan-23
Pond
123
Nano

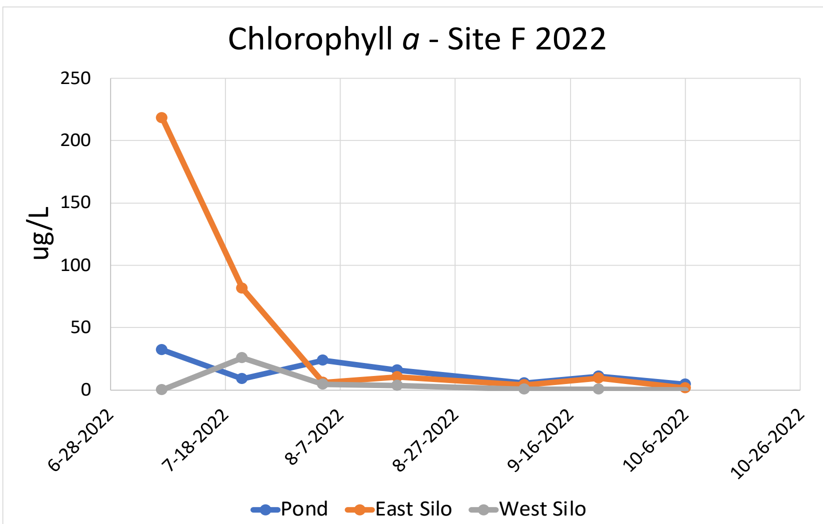
Appendix F – Site F Selected Results

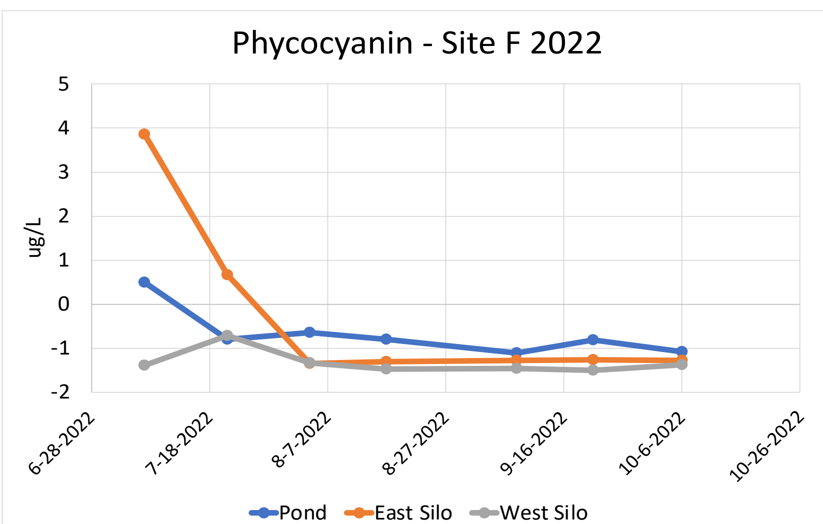







Optical Dissolved Oxygen - Site F 2022
mg/L
12
10
8
6
4
2
0
6-28-2022
7-18-2022
8-7-2022
8-27-2022
9-16-2022
10-6-2022
10-26-2022
Pond
East Silo
West Silo


Chlorophyll *a* - Site F 2022
ug/L
250
200
150
100
50
0
6-28-2022
7-18-2022
8-7-2022
8-27-2022
9-16-2022
10-6-2022
10-26-2022
Pond
East Silo
West Silo


Phycocyanin - Site F 2022
ug/L
5
4
3
2
1
0
-1
-2
6-28-2022
7-18-2022
8-7-2022
8-27-2022
9-16-2022
10-6-2022
10-26-2022
Pond
East Silo
West Silo