Project Title:
FINAL REPORT: Phosphorus Reduction System

FDEP Project: INV23

Final Report

Executive Summary

This Phosphorus Reduction System (PRS) funded under the Florida Department of Environmental Protection's (FDEP) Innovative Technology Grant was awarded to the Lakewood Ranch Stewardship District (LRSD) to demonstrate the reduction in total phosphorus (TP) concentrations in Manatee County's non-Advanced Wastewater Treatment (AWT) reclaimed water. This reclaimed wastewater is beneficially reused for irrigation of lawns and landscapes throughout the LRSD. Specifically, the target average effluent TP concentration was 1.0 mg/L or below (AWT TP standard). Over the 4 month operation period, an activated carbon-based adsorption media, HydRestor®, was employed to reduce TP concentrations of the influent water prior to storage and distribution for irrigation.

The PRS consisted of four 500-gallon vessels containing adsorption media. The vessels were plumbed to accept a cumulative flow of 43,000 gallons per day of influent water. The 4-month operation period included 3 phases with a media change-out after 2 months. The first Phase of work includes groundwater treatment from June 26, 2023, through July 25, 2023. Phase 2 includes data collected from treatment of reclaimed water once the supply of groundwater ceased and occurred from July 26 through August 18. The final Phase 3 occurred after a media changeout in all 4 vessels, and treated reclaimed water from September 19 through November 10. Field samples were collected and analyzed for the influent as well as effluent TP concentrations for each vessel. TN concentrations were also analyzed to monitor any effects to TN concentrations.

Due to periodic issues with the water quality and pressure of the Manatee County reclaimed water, the PRS experienced the periodic and at times prolonged input of groundwater as an alternative irrigation source water during the initial 2-month phase. This issue was resolved in coordination with Manatee County to assure that influent water for the third phase consisted exclusively of reclaimed wastewater.

Results from the initial phase demonstrated that the PRS could reduce the already low influent TP concentrations associated with groundwater by nearly 70% in the first few days of use, and an average of 17% and 28% over the first week for System 1 and System 2 respectively. This performance tailored off after the first week, and much of the removal efficiency was derived during this period of high adsorption. With low influent concentrations observed in this phase, a lead/lag configuration of carbon vessels showed to be important as with shorter contact times, the carbon quickly achieved its adsorption capacity and the second polishing vessel provided additional removal efficiency. Analyses of the reclaimed wastewater during the third phase indicated an average 63% reduction of TP concentrations (and up to 99% removal over the first week of media usage between Sept. 12 through Sept. 19, where the adsorption capacity is highest). While not the target nutrient, TN from the reclaimed wastewater was reduced by an average of nearly 20%.

Therefore, the PRS demonstrated the success of this innovative nutrient reduction and recovery technology capable of reducing and maintaining TP concentrations below the AWT standards for residence times of 60-minutes or more for an approximate duration of 2 months. Since the technology relies on adsorption, no biological process needs to be maintained and operation can be customized based upon average influent and target effluent TP concentrations. Furthermore, the adsorption kinetics are such that shorter vessel residence times can be leveraged to maximize performance and water production. This study showed that residence times of 30 minutes were

adequate to remove TP, and if necessary, a secondary or tertiary vessel in lead-lag configuration (in series) can be added to extend bed life and increase removal efficiency. The use of modular vessels allows for flexibility for this sorbent to be used at a wide range of water utilities that may not have the greenfield space to build large biological treatment or activated carbon basins. Rather, installing a modular configuration of vessels can be more economically and practically feasible. Specifically, the PRS technology demonstrated a residence time of 60 minutes was able to reduce average influent and effluent TP concentrations from 1.9 mg/L to less than 1.0 mg/L, respectively, thereby meeting phosphorus criteria for AWT standards set forth in Florida Statutes § 403.086.

1.0 Project Overview

PROJECT LOCATION: The project site is located within the Lakewood Ranch Stewardship District (LRSD) which extends into portions of Manatee County and Sarasota County, Florida. The site is located on White Eagle Boulevard between State Road 64 and Post Road (coordinates: 27°28'38.88"N; 82°24'53.19"W). The entirety of the project was done within a protected housing enclosure that includes several pump stations which provide irrigation to the community.

PROJECT BACKGROUND: The LRSD contains approximately 50 square miles of residential areas and related commercial and recreational services. Associated landscaped and recreational areas are irrigated with non-potable water sources, including reclaimed wastewater from the City of Sarasota (COS), the City of Bradenton (COB), and Manatee County and surrounding groundwater. While the reclaimed wastewater provided by COS and COB meet or exceed Advanced Wastewater Treatment (AWT) standards including for effluent phosphorus concentrations, the reclaimed water provided by Manatee County does not. Therefore, the objective is to meet or exceed the AWT standard for phosphorus concentrations for Manatee County's reclaimed wastewater prior to distribution for irrigation within the Lakewood Ranch Community.

During this work, a pilot Phosphorus Reduction System tested an innovative water treatment media (HydRestor®) designed to adsorb phosphorous and reduce Total Phosphorus (TP) concentrations. Specifically, HydRestor® is an engineered activated carbon adsorbent designed to be used in vessels typical to other activated carbon applications for water treatment. It is patented by C12 Environmental Services (C12) and has undergone testing and development for the past two years in southwest Florida. HydRestor® is manufactured using a pelletizing technique to extrude activated carbon combined with active binders, into 4mm diameter pellets to produce an adsorption media. By meeting or exceeding AWT standards for Manatee County's reclaimed water, the anticipated benefits from this project will allow the LRSD to beneficially use and distribute reclaimed water throughout its jurisdiction and underlying watershed with reduced phosphorus concentrations and environmental loadings throughout the community.

PROJECT DESCRIPTION: The Phosphorus Reduction System included the use of a mobile trailer, site preparation, and deployment of the Phosphorus Reduction System including 4, 512-gallon vessels filled with the HydRestor® media. The Phosphorus Reduction System was operational for approximately 4 months, with a media change out scheduled and conducted after 2-months. During the operational phases, the influent and effluent nutrient parameters were sampled and analyzed in accordance with the approved Quality Assurance Project Plan. Upon completion, the media was removed from the vessels, the vessels and mobile trailer were then removed, and the site was restored to its original conditions. This report was prepared to detail the results of the project.

Pursuant to the FDEP Agreement No. INV23 executed on 03/15/23, the total amount of funding awarded is $290,000 with an expiration date of 04/01/2024.

2.0 Financial Summary

The project was completed within the awarded budget and with no additional sources of revenue being provided. The project budget is shown below in **Table 1**. A change order was issued in late October to recategorize funds in Task 3 as shown below. The change order is included in the Appendix. With respect to budget, actual costs for laboratory fees and operation associated with Task 3 exceeded the lump sum budget. This was due to increased laboratory fees and longer-than-planned equipment rental. Since this and all tasks were contractually based upon a lump sum amount, the resulting budget exceedance of $14,928 was completely absorbed by C12.

Table 1. Budget breakdown by task.

Task	Budget Category	Budget Amount	Actual Amount
1 – Quality Assurance Project Plan	Contractual Services	$10,000	
	Total for Task:	**$10,000**	
2 – Planning and Design	Contractual Services	$55,000	
	Total for Task	**$55,000**	
3 – Install and Startup	Contractual Services	$60,000	
	Misc./Other Expenses	$40,000	
	Total for Task	**$100,000**	
4 – Operations	Contractual Services	$30,000	
	Misc./Other Expenses	$45,000	$59,928
	Total for Task	**$75,000**	
5 – Demobilization	Contractual Services	$20,000	
	Total for Task	**$20,000**	
6 – Final Reporting	Contractual Services	$30,000	
	Total for Task	**$30,000**	
	Total Budget	**$290,000**	**$304,928**

3.0 Project Schedule

Initial adjustments to the project startup, expected to begin in early June 2023, were necessary due to delays with manufacturing. This resulted in an approximate 1-month delay to 06/26/23 of the schedule. A subsequent delay occurred during the planned media changeout due to unforeseen difficulties with extraction of the media from the vessels and Hurricane Idalia in August 2022. The project timeline adjustments as previously proposed and approved are provided in **Table 2** below.

Table 2. Summary of Project Timeline

Task/ Deliverable No.	Task or Deliverable Title	Task Start Date	Original Task End Date	New Task End Date	Status
1	Quality Assurance Project Plan				
1a	Draft Quality Assurance Project Plan	07/01/21	11/15/22		COMPLETE
1b	Final Quality Assurance Project Plan	07/01/21	04/15/23		COMPLETE
2	Design and Permitting	07/01/21	09/30/23		COMPLETE
3	Site Preparation and System Start-up	07/01/21	09/30/23		COMPLETE
4	Operation and Monitoring	07/01/21	09/30/23	11/10/23	COMPLETE
5	Demobilization and Site Restoration	07/01/21	09/30/23	11/30/23	COMPLETE
6	Final Report	07/01/21		12/30/23	COMPLETE
6a	Draft Final Report	07/01/21	09/30/23	11/30/23	COMPLETE
6b	Final Report	07/01/21	11/30/23	12/30/23	COMPLETE

4.0 Summary of Activities Completed

Over the four (4) month operational period, the Phosphorus Reduction System was operated as shown in **Figure 1,** with minor fluctuations in average flow. As originally specified, 32 sampling events were completed, including 8 required field blank samples. Each vessel was loaded with the same Hydrestor® media as received from the manufacturer from consecutive lot numbers. Similar media loading was done after the Phase 2 media changeout and again, the same Hydrestor® media from consecutive lot numbers were loaded.

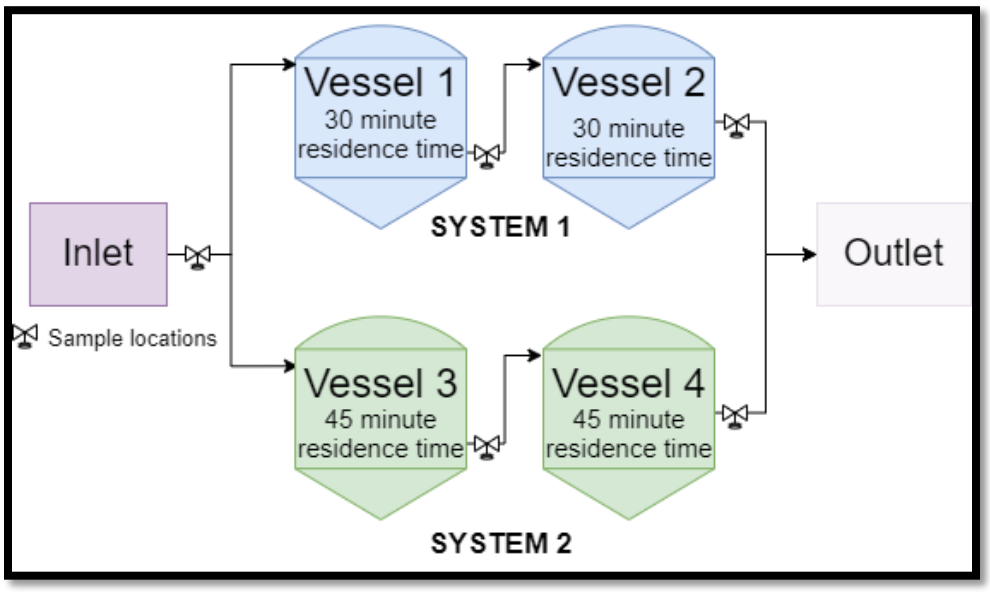

Figure 1. Flow schematic of Phosphorus Reduction System Treatment Trains.

4.1 – Phase 1 Data Summary

Lab reports subsequently received for samples collected during the initial 2 months of operation, indicated lower than expected influent nutrient concentrations. Upon investigation, it was determined that issues with the pressure and quantity of reclaimed water from Manatee County had resulted in the temporary source water being switched to groundwater. Therefore, the Phosphorus Reduction System had similarly been receiving groundwater. Once this was realized, the Lakewood Ranch Stewardship District, Braden River Utilities, and Manatee County Utilities met on 08/15/23 and to develop short-term and long-term plans of action to assure that the Phosphorus Reduction System received reclaimed water exclusively and that the Lakewood Ranch community were receiving reclaimed water as a primary irrigation source, respectively. Data collected and analyzed during this period did indicate that the HydRestor® media was effective in reducing influent water with low total phosphorus concentrations, through the addition of multiple vessels in series. The intent of HydRestor® media is to be used for non-AWT compliant reclaimed wastewater.

Table 3 and Table 4 provide a summary of the average influent and effluent concentrations for each vessel and their respective average residence times and removal efficiencies for the Phase 1 operation period (06/26/23 – 07/25/23).

Overall, in this phase, as expected, the HydRestor® media has the highest removal efficiency towards the first few days of testing, however, performance quickly declined and the media seemed to have little, to no effect on effluent concentrations. This may be indicative of low TP concentrations in the influent. Both the influent and effluent concentrations are near the PQL for TP of 0.032 mg/L and therefore changes in concentration may be from instrument variability. HydRestor® media is intended to reduce influent TP concentrations from above 1.0 mg/L to below AWT standards, rather than the average 0.083 mg/L experienced in Phase 1. In some instances, through Vessel 1, the concentration increased significantly and cannot be explained at this time.

Table 3. Phase 1 Operation Period Flow Average Results

Vessel	Average Residence Time (Mins)	Volume of Water Treated (Gallons)
1	30	597,250
1 + 2	60	597,250
3	45	424,972
3 + 4	90	424,972

Table 4. Phase 1 Operation Period TP Average Results

Vessel	Average TP Influent Concentration (mg/L)	Standard Deviation TP Influent Concentration (mg/L)	Average TP Effluent Concentration (mg/L)	Standard Deviation TP Effluent Concentration (mg/L)	Average Removal Efficiency (%)
1	0.0829	0.0402	0.1257	0.1228	-52%
1 + 2	0.0829	0.0402	0.0720	0.0491	13%
3	0.0776	0.0414	0.0700	0.0473	10%
3 + 4	0.0776	0.0414	0.0654	0.0432	16%

Note: Vessels 3 and 4 began operation two days after Vessels 1 and 2 thus have different average influent concentrations.

The results are also presented graphically in Figure 2 through Figure 5.

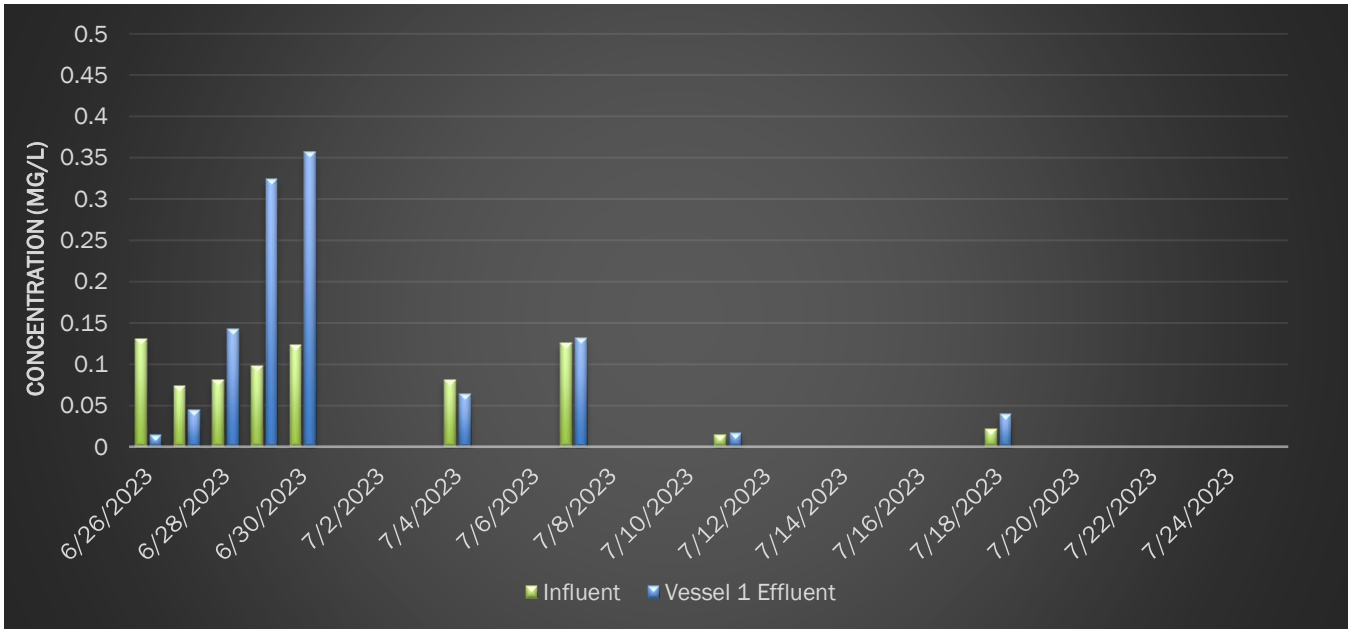

Figure 2. Total Phosphorus Concentrations for Vessel 1 (06/26/23 – 07/25/23)

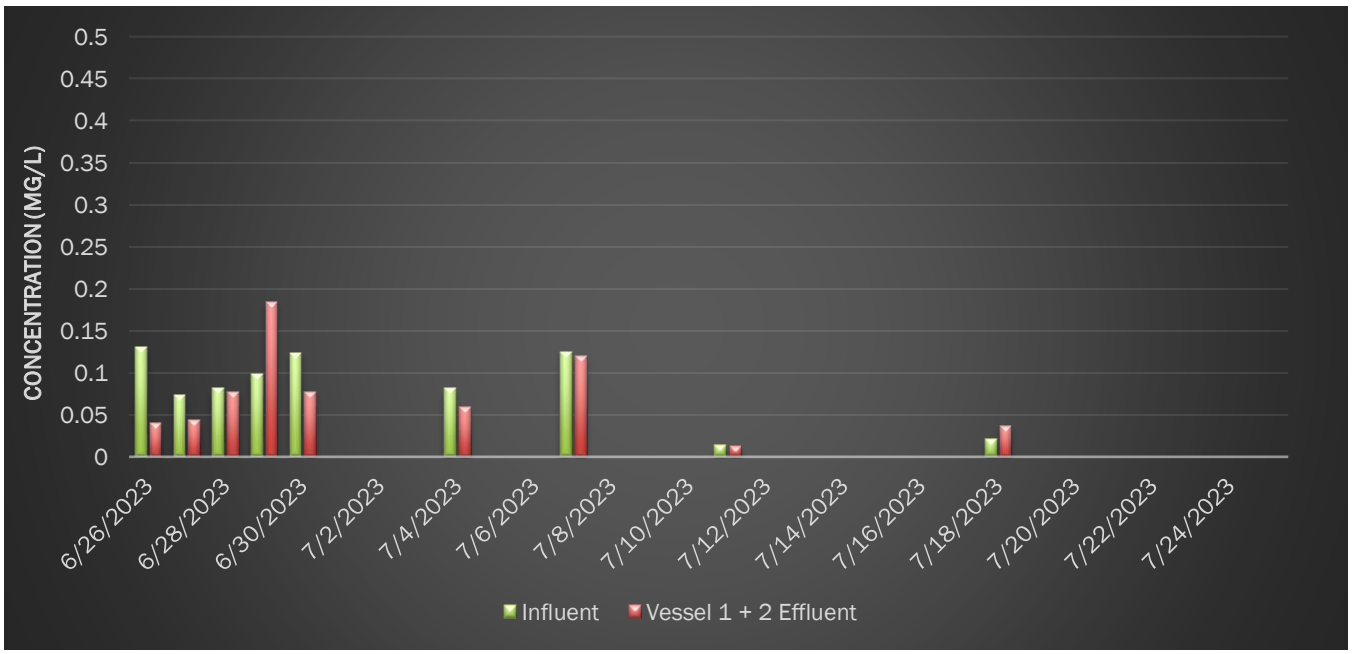

Figure 3. Total Phosphorus Concentrations for Vessels 1 + 2 (06/26/23 – 07/25/238/18/23)

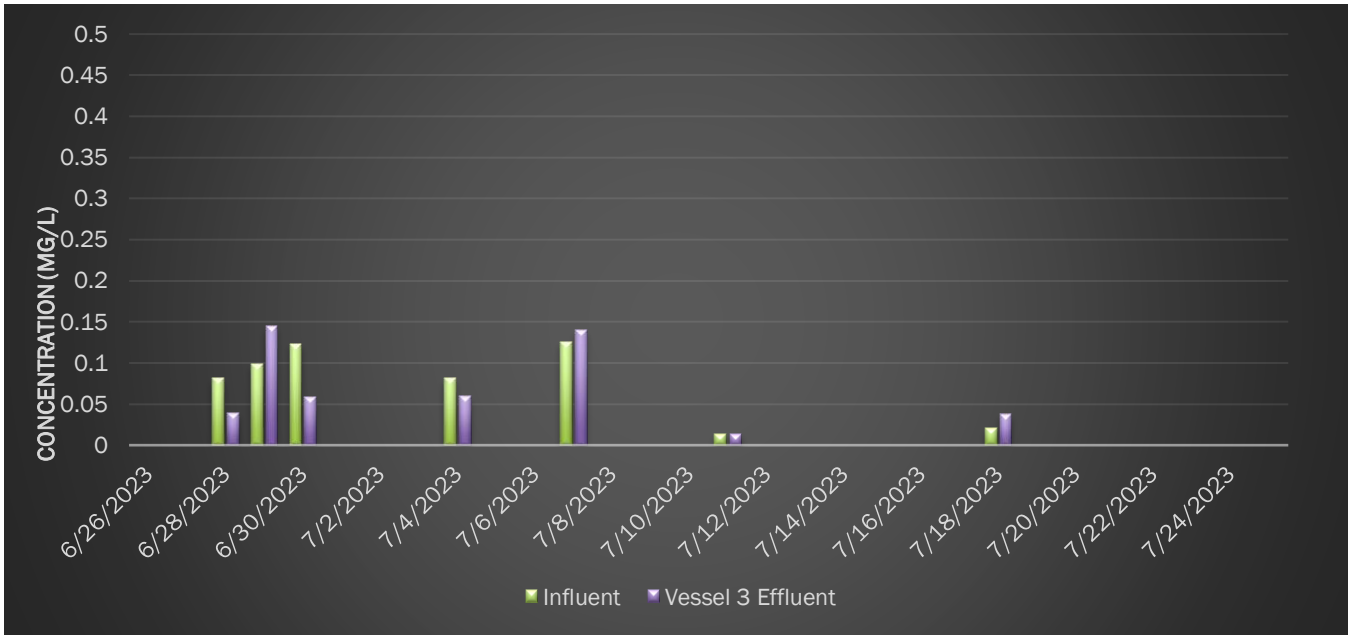

Figure 4. Total Phosphorus Concentrations for Vessel 3 (06/28/23 – 07/25/23)

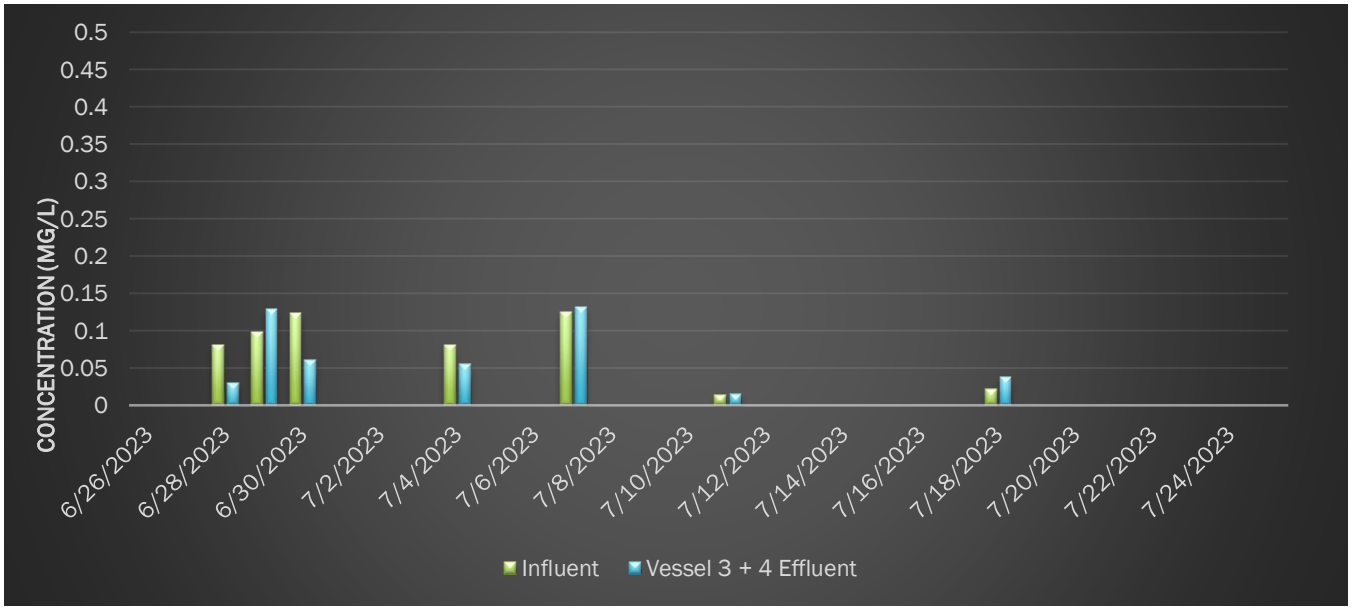

Figure 5. Total Phosphorus Concentrations for Vessels 3 + 4 (06/28/23 – 07/25/23)

4.2 – Phase 2 Data Summary

Reclaimed water was reinitiated to LWRSD on or near 7/26/23 which is the starting point of Phase 2. In this second phase (Phase 2) of the trial test, this influent water with was treated with HydRestor® media that was in place and used during Phase 1. The confirmation that reclaimed wastewater was reinstated as the source water to the Phosphorus Reduction System coincided with the scheduled media change out on 09/04/2023 (approximate halfway point of operation). Upon the completion of the media change out, the system was brought back online with reclaimed water. The HydRestor® media demonstrated removal efficiencies between 21% and 77% for Phase 2.

Table 5 and Table 6 provides a summary of the average influent and effluent concentrations for each vessel and their respective average residence times and removal efficiencies for the Phase 2 operation period (07/26/23 – 08/18/23).

Table 5. Phase 2 Operation Period Flow Average Results

Vessel	Average Residence Time (Mins)	Volume of Water Treated (Gallons)
1	30	419,927
1 + 2	60	419,927
3	45	367,861
3 + 4	90	367,861

Table 6. Phase 2 Operation Period TP Average Results

Vessel	Average TP Influent Concentration (mg/L)	Standard Deviation TP Influent Concentration (mg/L)	Average TP Effluent Concentration (mg/L)	Standard Deviation TP Effluent Concentration (mg/L)	Average Removal Efficiency (%)
1	1.242	0.593	0.771	0.402	38%
1 + 2	1.242	0.593	0.615	0.457	51%
3	1.242	0.593	0.986	0.503	21%
3 + 4	1.242	0.593	0.288	0.207	77%

The results are also presented graphically in **Figure 6** through **Figure 9**.

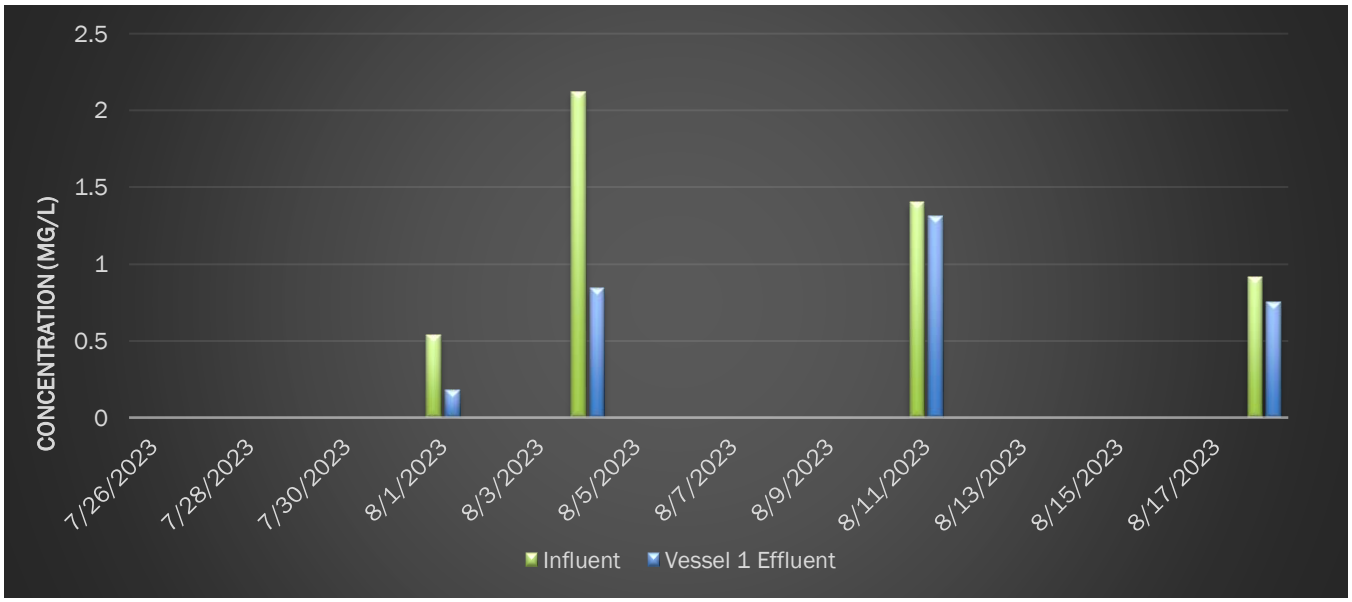

Figure 6. Total Phosphorus Concentrations for Vessel 1 (07/26/23 – 08/18/23)

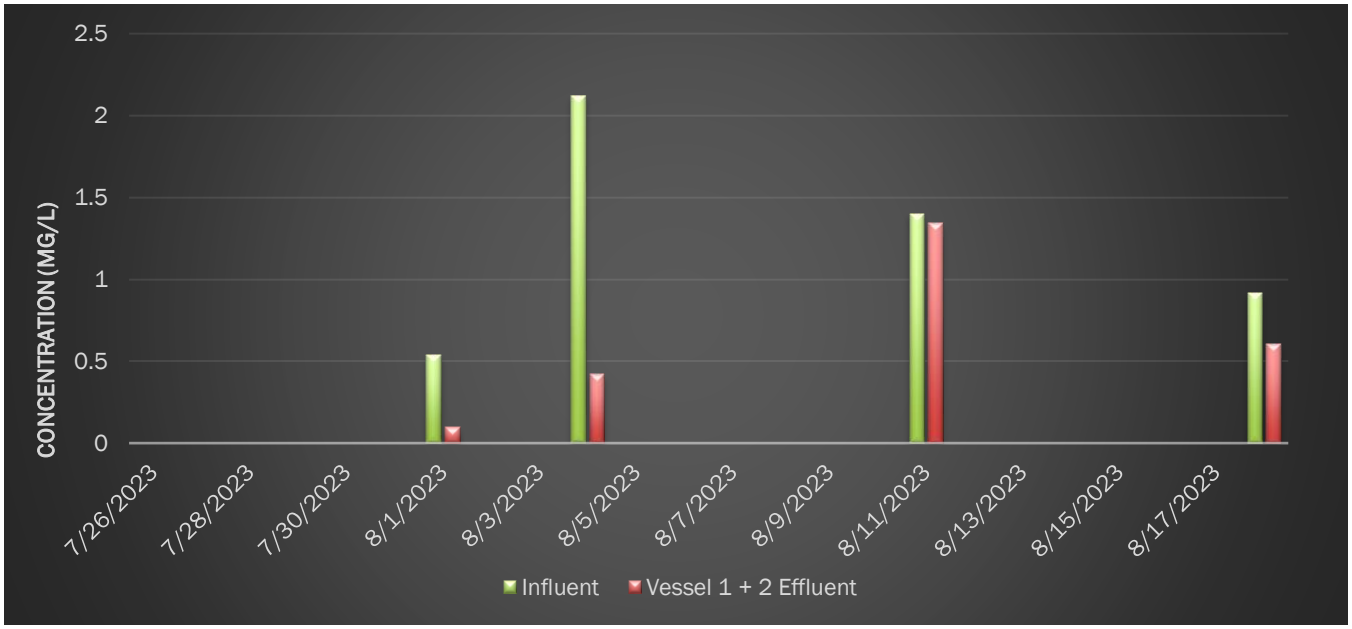

Figure 7. Total Phosphorus Concentrations for Vessels 1 + 2 (07/26/23 – 08/18/23)

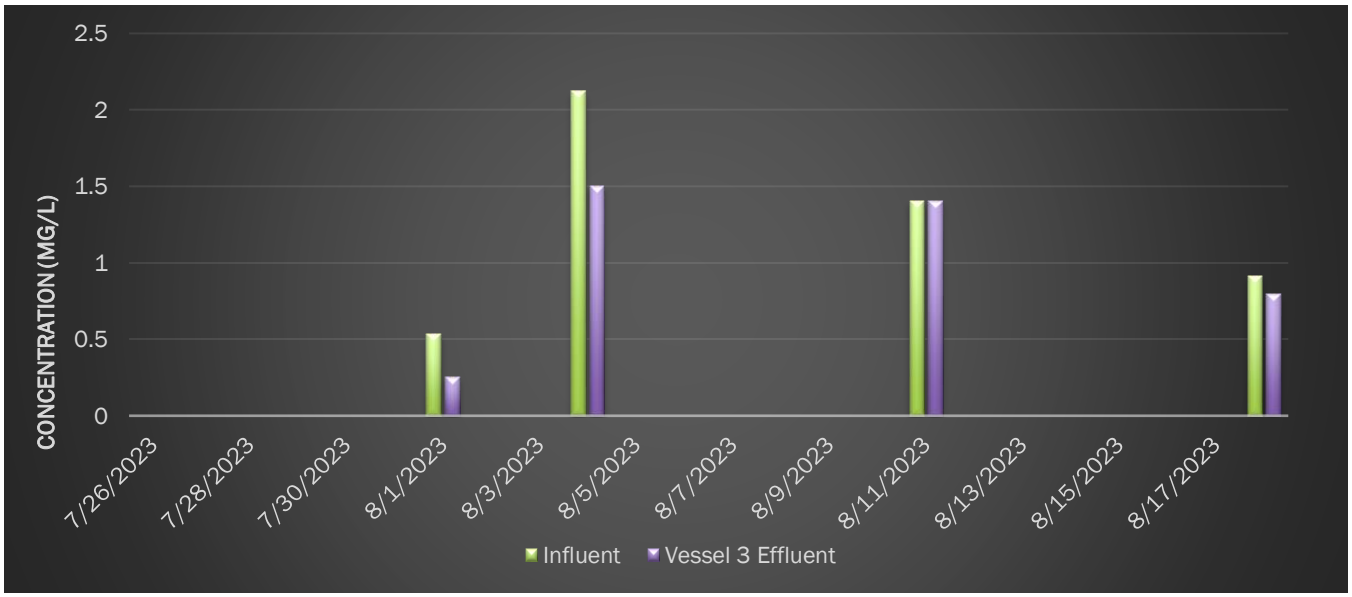

Figure 8. Total Phosphorus Concentrations for Vessel 3 (07/26/23 – 08/18/23)

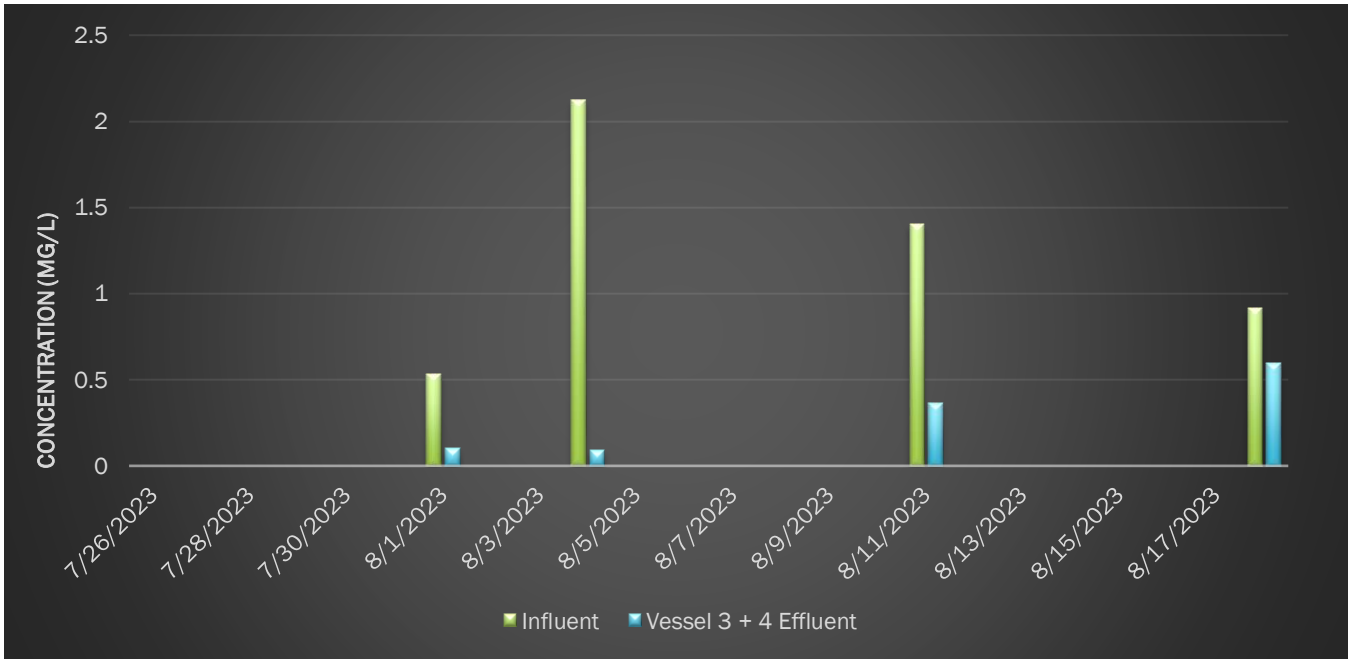

Figure 9. Total Phosphorus Concentrations for Vessels 3 + 4 (07/26/23 – 08/18/23)

4.3 – Phase 3 Data Summary

Table 7 and Table 8 provide a summary of the average influent and effluent concentrations for each vessel and their respective average residence times and removal efficiencies for the Phase 3 operation period (09/12/23 – 11/10/23).

Throughout Phase 3, the HydRestor® media demonstrated reduction of influent TP between 27% 63% dependent on residence time. Once the adsorption capacity is reached, in some instances, such as on 10/13 and 10/17, there may be leaching of phosphorus back into the effluent water. This was observed to a larger extent in the vessels with lower residences times since they neared their adsorption capacity more quickly.

Table 7. Phase 3 Operation Period Flow Average Results

Vessel	Average Residence Time (Mins)	Volume of Water Treated (Gallons)
1	30	1,138,616
1 + 2	60	1,138,616
3	45	768,661
3 + 4	90	768,661

Table 8. Phase 3 Operation Period TP Average Results

Vessel	Average TP Influent Concentration (mg/L)	Standard Deviation TP Influent Concentration (mg/L)	Average TP Effluent Concentration (mg/L)	Standard Deviation TP Effluent Concentration (mg/L)	Average Removal Efficiency (%)
1	1.860	0.766	1.365	0.526	27%

1 + 2	1.860	0.766	0.965	0.521	48%
3	1.860	0.766	1.016	0.693	45%
3 + 4	1.860	0.766	0.688	0.476	63%

The results are also presented graphically in **Figure 10** through **Figure 13**.

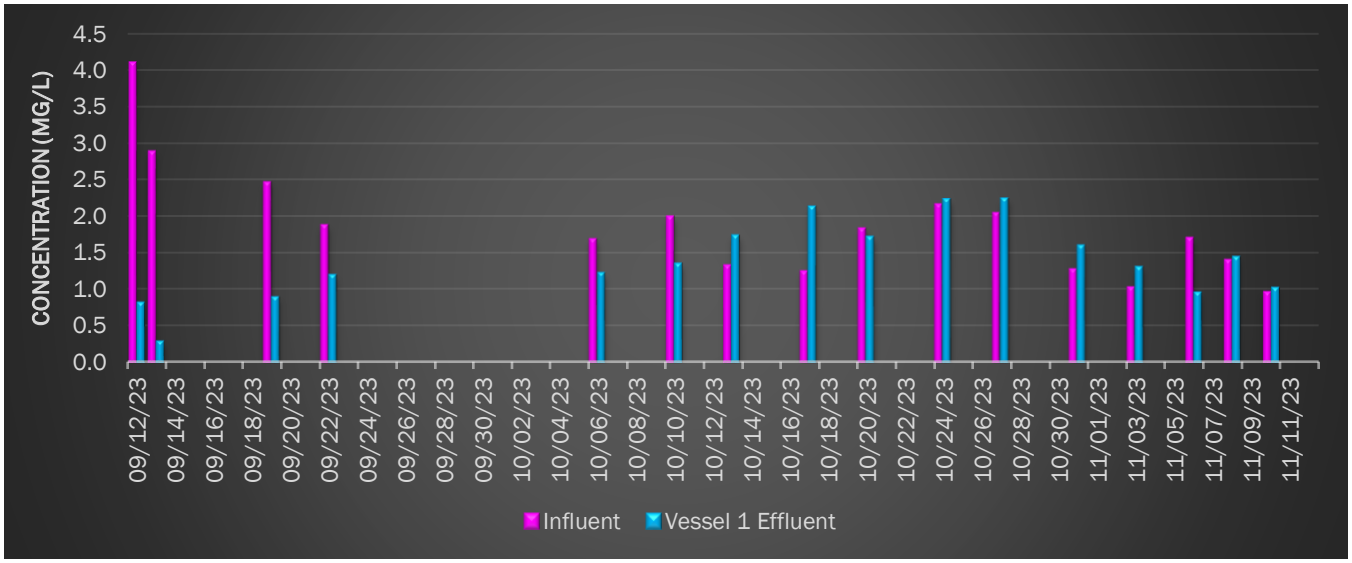

Figure 10. Total Phosphorus Concentrations for Vessel 1 (09/12/23 – 11/10/23)

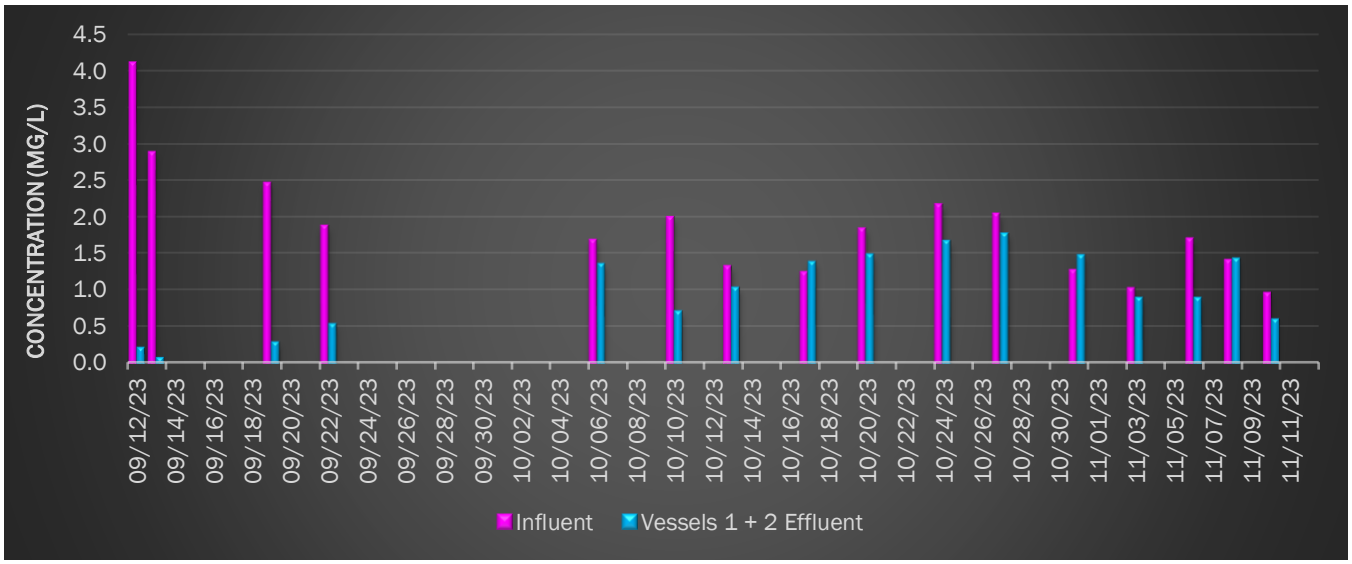

Figure 11. Total Phosphorus Concentrations for Vessels 1 + 2 (09/12/23 – 11/10/23)

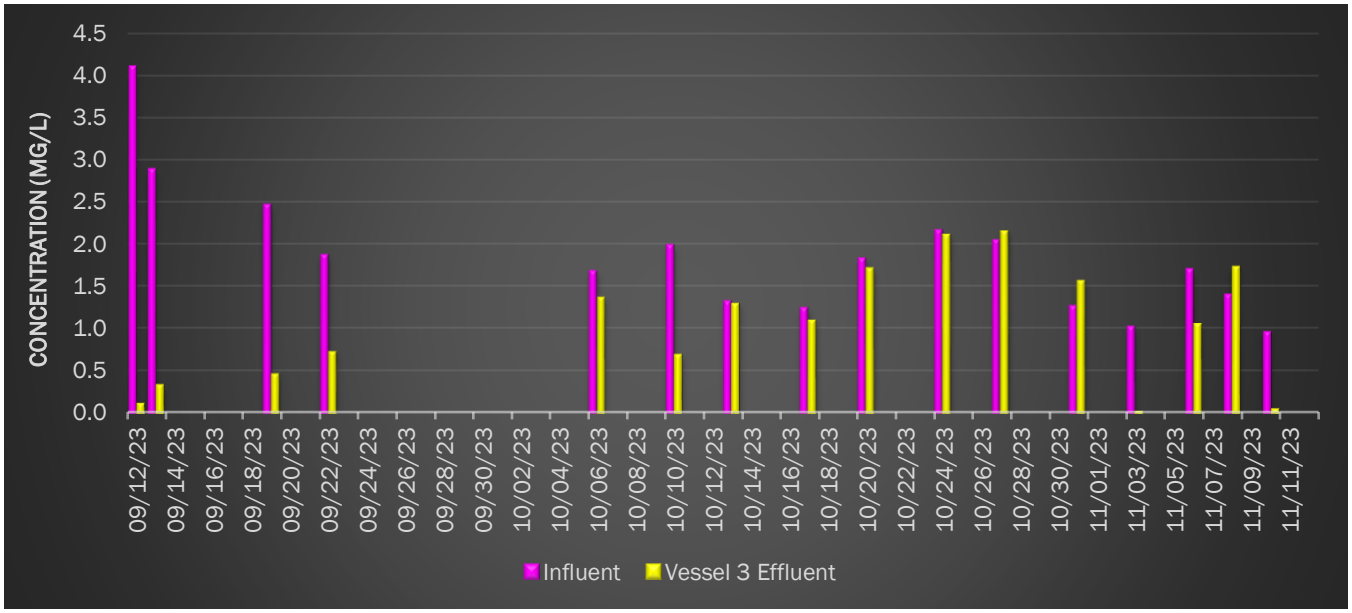

Figure 12. Total Phosphorus Concentrations for Vessel 3 (09/12/23 – 11/10/23)

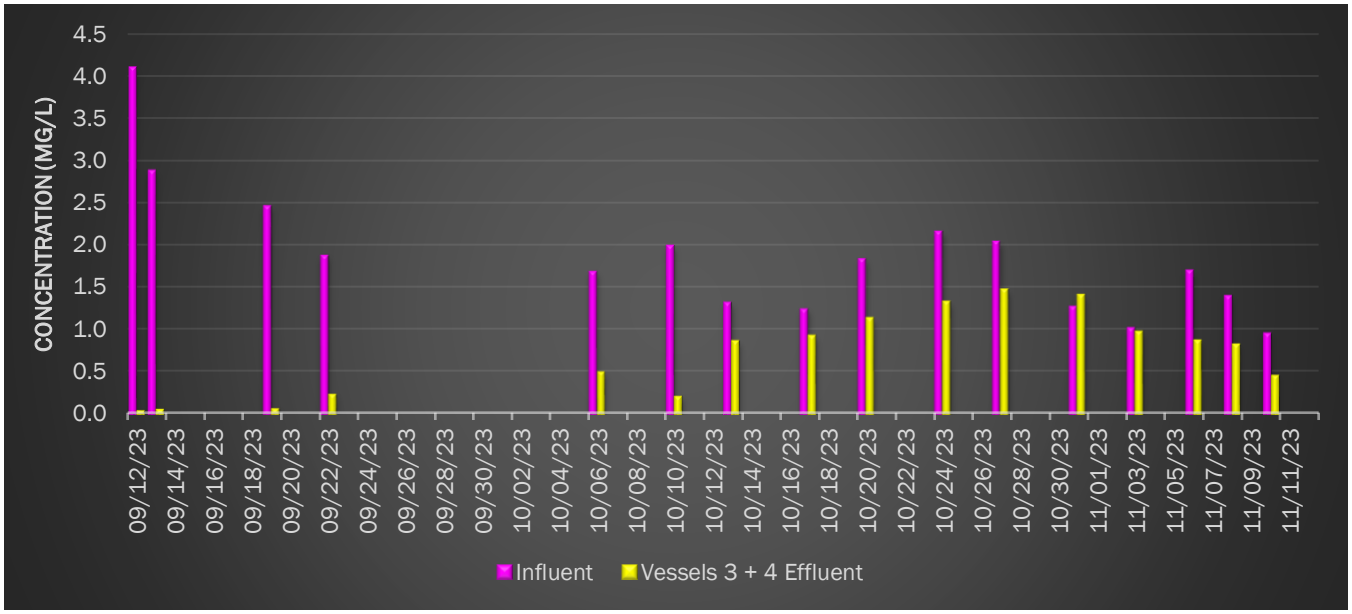

Figure 13. Total Phosphorus Concentrations for Vessels 3 + 4 (09/12/23 – 11/10/23)

Although not targeted for reduction by the HydRestor® media, effluent samples were also analyzed for nitrogen related parameters with the intent of documenting that such was not being adversely impacted (increased). **Table 9** provides a summary of the average influent and effluent TN concentrations for each vessel as well as their associated average residence times and average removal efficiencies over the entire operational period (06/26/23 – 11/10/23).

Table 9. Phase 3 Operation Period TN Average Results

Vessel	Average Residence Time (Mins)	Average TN Influent Concentration (mg/L)	Standard Deviation TN Influent Concentration (mg/L)	Average TN Effluent Concentration (mg/L)	Standard Deviation TN Effluent Concentration (mg/L)	Average Removal Efficiency (%)
1	30	7.168	2.689	6.000	1.250	16%
1 + 2	60	7.168	2.689	5.868	1.250	18%
3	45	7.168	2.689	5.873	1.250	18%
3 + 4	90	7.168	2.689	5.623	1.250	22%

As indicated in **Table 9**, TN concentrations were consistently reduced on average between 16% to 22% by the Phosphorus Reduction System. These reductions generally increased with increased residence times. In addition, when the influent TN concentrations exceeded 10 mg/L, the Phosphorus Reduction System consistently reduced these concentrations by approximately 50%, with the majority of removal in the TKN speciation of nitrogen (organic and ammonia).

5.0 Photo Documentation of Project Work

Figure 14. Aerial image of Vessels being installed (Task 3 – Start up).

Figure 15. Image of control panel (Task 3 – Start up).

Figure 16. Inlet (vertical) and outlet (horizontal) pipes (Task 3 – Start up).

Figure 17. Media removal via vacuum truck (Task 4 – Operations).

Figure 18. Site restored with plumbing capped (Task 5 – Demobilization).

Figure 19. Fencing reinstalled surrounding site (Task 5 – Demobilization).

6.0 Data Analysis and Discussion of Benefits

6.1 Data Analysis

Equation 1 and Equation 2 were utilized to compute the total phosphorus removal (in milligrams) and the adsorption capacity of the media for each vessel (and their associated residence times). Table 10 and 11 summarizes the results for Phase 1 (06/26/23 – 07/25/23) and Phase 2 (07/26/23 – 08/26/23) which included low influent total phosphorus concentrations and some mixed reclaimed wastewater as the supply was changed. Table 12 summarizes the results for Phase 3 (09/12/23 – 11/10/23) which included the higher influent total phosphorus concentrations associated with the exclusive evaluation of reclaimed water. Each vessel was filled with 2200 lbs each of Hydrestor® media. This equates to 997.9 kg. The cumulative addition of two vessels in series results in 1,995.8 kg. These masses are used to calculate the adsorption capacity at described in Equations 1 and 2 below.

Equation 1: Cumulative Total Constituent Removal (milligrams) =

$$Average\ Influent\ Concentration\ \left(\frac{mg}{L}\right) * Total\ Volume\ (L) * Average\ Percent\ Removal(\%)$$

Equation 2: Adsorption Capacity (mg/g) =

$$\frac{Cumulative\ Total\ Constituent\ Removed\ (mg)}{Mass\ of\ Media\ Bed\ (g)}$$

Table 10. Tabulation of Phosphorus Removal Data for Phase 1

Vessel	Average Residence Time (Mins)	Average TP Influent Conc. (mg/L)	Average Removal Efficiency (%)	Volume of Water Treated (Gallons)	Volume of Water Treated (Liters)	TP Removed (mg)	Mass of media bed (kg)	Adsorption Capacity (mg/g)
1	30	0.0829	-52%	597,250	2,260,837	-97,460	997.9	-0.098
1 + 2	60	0.0829	13%	597,250	2,260,837	24,365	1,995.8	0.012
3	45	0.0776	10%	424,972	1,608,694	12,483	997.9	0.013
3 + 4	90	0.0776	16%	424,972	1,608,694	19,974	1,995.8	0.0100

Table 11. Tabulation of Phosphorus Removal Data for Phase 2

Vessel	Average Residence Time (Mins)	Average TP Influent Conc. (mg/L)	Average Removal Efficiency (%)	Volume of Water Treated (Gallons)	Volume of Water Treated (Liters)	TP Removed (mg)	Mass of media bed (kg)	Adsorption Capacity (mg/g)
1	30	1.242	38%	419,927	1,589,426	750,145	997.9	0.752
1 + 2	60	1.242	51%	419,927	1,589,424	1,006,773	1,995.8	0.504
3	45	1.242	21%	367,861	1,392,505	363,193	997.9	0.364
3 + 4	90	1.242	77%	367,861	1,392,505	1,331,708	1,995.8	0.667

Table 12. Tabulation of Phosphorus Removal Data for Phase 3

Vessel	Average Residence Time (Mins)	Average TP Influent Conc. (mg/L)	Average Removal Efficiency (%)	Volume of Water Treated (Gallons)	Volume of Water Treated (Liters)	TP Removed (mg)	Mass of media bed (kg)	Adsorption Capacity (mg/g)
1	30	1.860	27%	1,138,616	4,326,741	2,172,889	997.9	2.18
1 + 2	60	1.860	48%	1,138,616	4,326,741	3,862,914	1,995.8	1.94
3	45	1.860	45%	768,661	2,920,912	2,444,803	997.9	2.45
3 + 4	90	1.860	63%	768,661	2,920,912	3,422,725	1,995.8	1.71

Tables 10 and 11 indicate an approximate 200 times greater adsorption capacity for the higher total phosphorus influent concentrations (Phase 3) than for the lower total phosphorus influent concentrations (Phase 1). In addition, TP concentration reductions during Phase 3 operation are proportional to residence time durations as indicated in Table 12. In addition, for Phase 3 the average effluent TP concentrations from Vessel 1, Vessel 3, Vessels 1 + 2, and Vessels 3 + 4 were 1.365 mg/L, 1.016 mg/L, 0.965 mg/L, and 0.688 mg/L, respectively. Therefore, for the duration of Phase 2 and 3 operation the TP standard of an average of 1.0 mg/L or less was attained for residence times of 60- and 90-minutes.

Adsorption capacity as shown here is a function of both residence time and cumulative hydraulic/phosphorus loading. This test shows that as expected for a fixed bed adsorption system, a longer residence time of 45 minutes (Vessel 3) provided higher TP removal than a residence time of 30 minutes (Vessel 1). The lead/lag configuration with additive residence times shows that a secondary polishing vessel can provide additional removal efficiency and extend bed life of the treatment train. As shown in the figures above for Phase 3 and the lower adsorption capacities calculated for the two vessel systems, it can be concluded that the two-vessel lead/lag systems have not reached their adsorption capacity yet. As calculated here, the adsorption capacity is a function of phosphorus loading, since the media in the two vessel systems (samples for Vessel 1+2, and Vessels 3+4) had not reached their adsorption capacity, the reported adsorption capacity is lower than the single vessels because of the differences in mass of media bed. Adsorption capacity was found to be highest for longer residence times vessels and to be near 2.5 mg/L, which is an expected value. Although not targeted for reduction, TN concentrations during Phase 3 operation were on average reduced in proportion to residence time durations as summarized below in Table 13.

Table 13 – TN effluent concentrations and removal efficiencies for Phase 3 Operation

Vessel	Average Residence Time (Mins)	Average TN Influent Concentration (mg/L)	Average Removal Efficiency (%)	Volume of Water Treated (Gallons)	Volume of Water Treated (Liters)	Nitrogen Removed (mg)	Adsorption Capacity (mg/g)
1	30	7.168	16%	1,138,616	4,326,741	4,962,253	4.97
1 + 2	60	7.168	18%	1,138,616	4,326,741	5,582,534	2.98
3	45	7.168	18%	768,661	2,920,912	3,768,678	3.78
3 + 4	90	7.168	22%	768,661	2,920,912	4,606,161	2.31

The average influent TN concentration for the Phase 3 operation period was 7.168 mg/L and in instances where large amounts of TN were reduced, the majority of the reduction was associated with the removal of TKN species of nitrogen (organic nitrogen and ammonia).

6.2 Additional Analytes

Secondary parameters analyzed during this study are shown below. These parameters are reported throughout the entirety of the project including each Phase. The gap between 08/18/23 and 09/12/23 represents the duration of down time for the media changeout. Other gaps in data represent omitted data that did not meet QAQC standards.

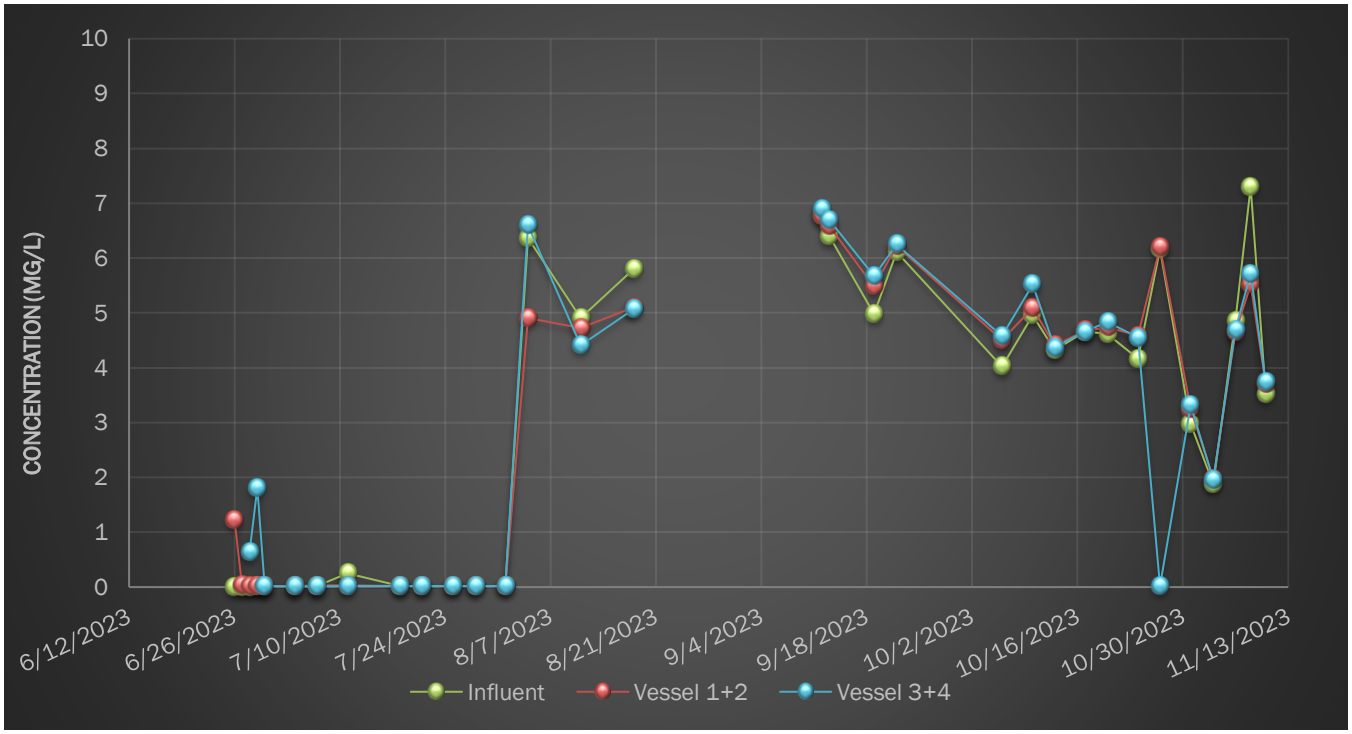

Figure 20. Nitrate + Nitrite analysis across the entirety of the project.

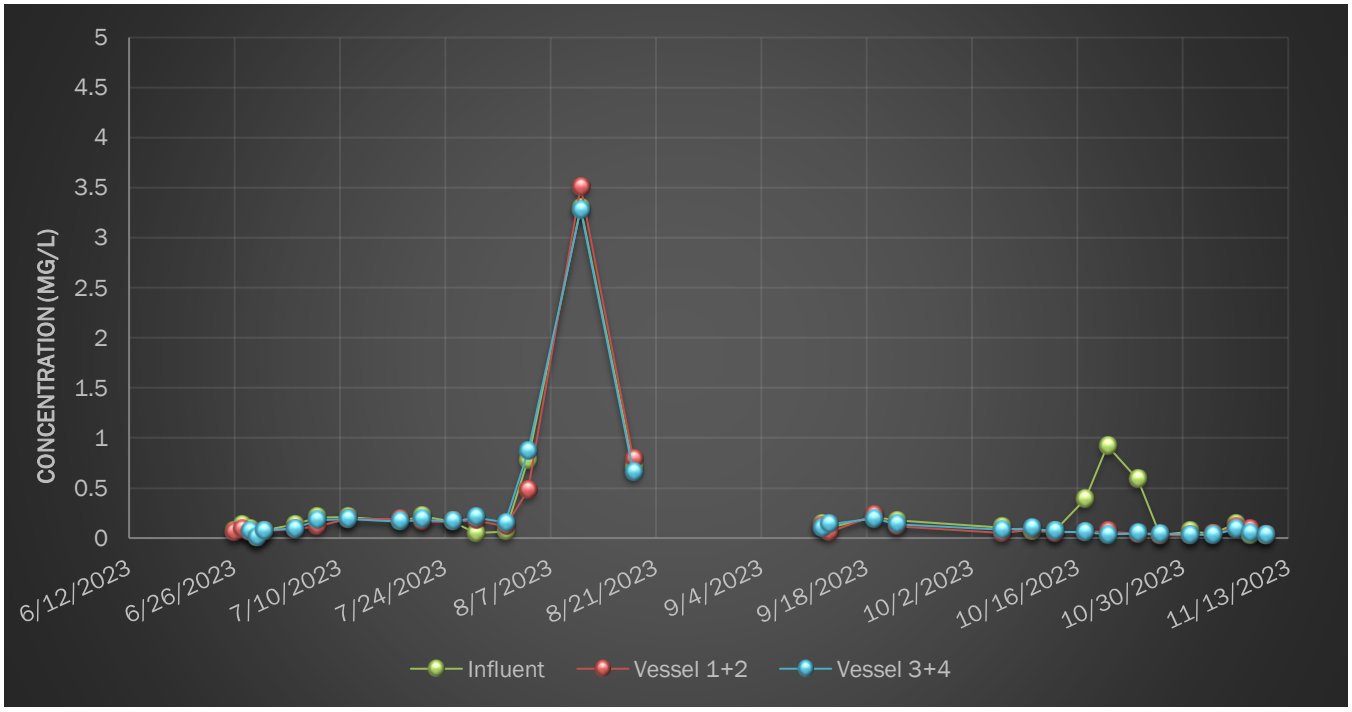

Figure 21. Ammonia analysis across the entirety of the project.

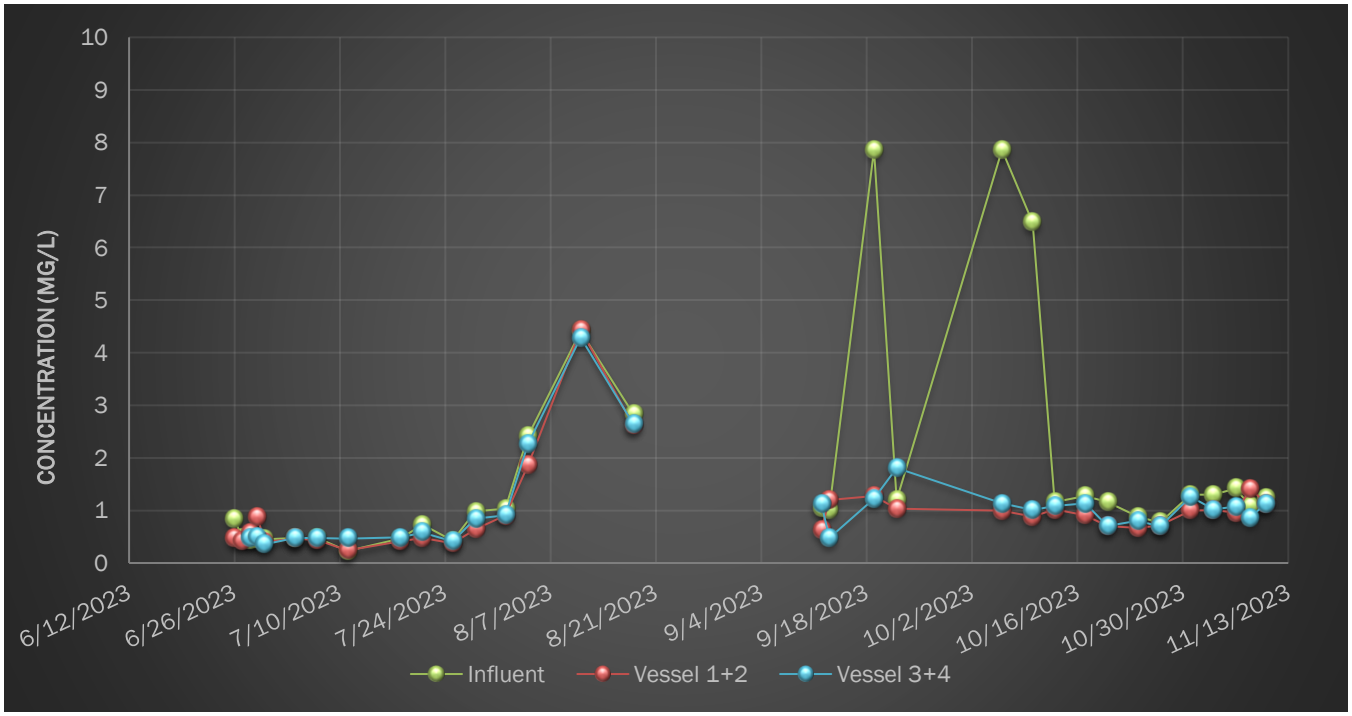

Figure 22. Total Kjeldahl Nitrogen analysis across the entirety of the project.

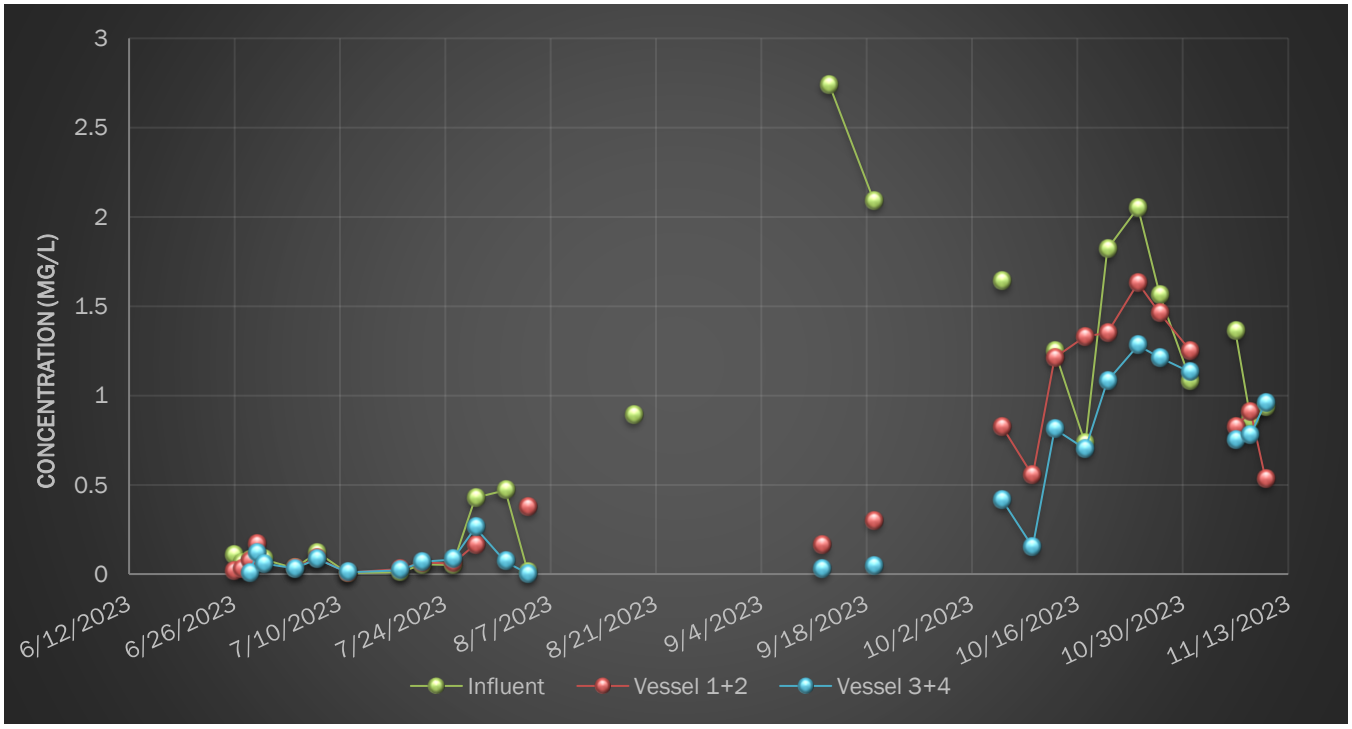

Figure 23. Ortho Phosphorous analysis across the entirety of the project.

6.3 Benefits

Under Phase 3 operation, the Phosphorus Reduction System was able to demonstrate reductions of influent TP concentrations in reclaimed wastewater to meet or exceed the Advanced Wastewater Treatment (AWT) standard of 1 mg/L or less. The adsorption capacity in units of milligrams of TP per gram of media was also determined as indicated in Tables 6 through 8. Over the Phase 3 period of evaluation, the average reclaimed wastewater influent TP concentration was 1.86 mg/L. The HydRestor® media with residence times of 60-minutes or more was able to reduce average effluent TP concentration to 1.0 mg/L or less thereby meeting AWT standards.

As shown in Phase 3 of this project, and based on target sales pricing for HydRestor® media, it is estimated that the unit media cost is approximately $366/pound of TP removed (calculated as the media cost divided by the amount of total phosphorus removed). This will vary as a function of residence time and the influent TP concentration which influences the media adsorption capacity.

Long term scalability including economic and engineering analysis was also conducted. Cost for a full-scale 1 MGD system rated at a residence time of 60-minutes using a similar vessel configuration and scalable vessel design was considered. Influent TP concentrations, media adsorption, and phosphorus removal were assumed to equal those of this pilot system. Upgrading this pilot system to a full-scale system can be facilitated by utilizing 6 vessels in series, each holding 30,000 lbs of media. For an all-inclusive system operating at 60-minute residence time, capital costs for a new installment are estimated at $650,000, inclusive of vessel materials, equipment, installations, control panel, and pump station. Annual operational costs include power consumption, and routine media change-outs. For the 1 MGD system operating with a 60-minute residence time, these are estimated to be at $1,100,000. This translates to an annual unit cost of $393 per pound of TP removed. The largest contributor to the cost being replenishment of adsorption media. As each water

utility will be operated at different Total Phosphorus concentrations and have different background concentrations of other nutrients and minerals, this value may vary.

This system can be called up for small and/or rural wastewater facilities. The effectiveness can be translated to a full-scale system where influent and target effluent concentrations (presumably AWT standard) is specified to determine the residence time and media volume required. The modularity of vessels may suit small and/or rural facilities where typical biological processes prove costly or difficult to operate.

This pilot study successfully demonstrated the novel and innovative use of an engineered activated carbon pellet by achieving effluent TP concentrations at or below AWT standards (average annual of 1.0 mg/L) for residence times of 60-minutes or more. It was also demonstrated that the Phosphorus Reduction System would not adversely increase Total Nitrogen (TN) effluent concentration of the reclaimed water. In fact, an 18 to 22% reduction in TN was observed. Economic and engineering analysis of a customizable and scalable treatment train showed competitive costs structures with long term annual operating costs below $400/ pound of total phosphorus removed based on water quality parameters demonstrated in this pilot study.