Optimizing the Benthic Chambers Part Design

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BOM	Bill of Materials
DO	Dissolved Oxygen
Eutrophication	Natural process as a result when the ecosystem becomes enriched with nutrients.
GPH	Gallons Per Hour
GTMNERR	Guana Tolomato Matanzas National Estuarine Research Reserve
In-Situ	In the original place.
Intertidal Region	Where the water meets the land between high and low tides.
Subtidal Region	Portion of the land that remains submerged except during particularly low tides.

Abstract

A benthic chambers design was optimized to improve the performance, functionality, and cost required for the materials and manufacturing of the concept. A benthic chamber is a device utilized in an in-situ environment to isolate the water column and gather information necessary for further analysis. The current design is utilized to measure sediment denitrification with the presence of oysters in the Guana Tolomato Matanzas National Estuarine Research Reserve (GTMNERR), in both subtidal and intertidal regions. The initial design included a 12-inch diameter black PVC midsection, fastened lid and sampling base, connected with four metal latches. From testing of this design, it was determined that aspects of the design needed to be improved, including the midsection material, midsection thickness, latch style, and pump orientation. Therefore, in the final design, a clear 12-inch PVC midsection was extended along the entire height of the benthic chambers, only latching a lid and sampling base, if necessary. Both prototypes were tested to observe the temperature, dissolved oxygen, leaking, mixing performance, and sediment distribution. The performed tests displayed that both tests had minimal leaking, and had relatively similar results of the sampled DO, with no significant drops in the DO overtime. However, both designs yielded an overall lower DO percentage, of 9.33% for the initial prototype and 1.16% for the final prototype. The temperature of the initial benthic chambers was observed to increase over time by 5.70%, while the final prototype observed 2.67%. The mixing performance and sediment distribution for both designs also performed as expected. The initial prototype required a greater time to fully distribute the water column, at 25.2 seconds, while the final prototype required 15.3 seconds at a voltage of 1.6 volts. However, it was observed that the final prototype disturbed sediment at a lower applied voltage than the initial prototype, which was likely a result of the placement of the pump in each design. Overall, the design and testing of the benthic chambers developed a further understanding of the design aspects required to create an effective design, and future plans include thorough testing to evaluate the performance of the benthic chambers design, as well as the additional features to further improve the design functionality, including battery voltage adjusters and a battery support structure.

Introduction

The benthic chambers design was optimized in the subject research project to improve the performance, lower the cost of materials and assembly, and enhance the functionality of the device. Benthic chambers are utilized in in-situ studies to closely observe the biochemical processes that occur within a sediment community [1]. The primary objective of a benthic chamber is to simulate the natural environment around an organism while maintaining the water column and gathering data necessary for analysis. Therefore, this concept requires various design adjustments depending on the tide, environment, organism of research, or processes recorded for further analysis.

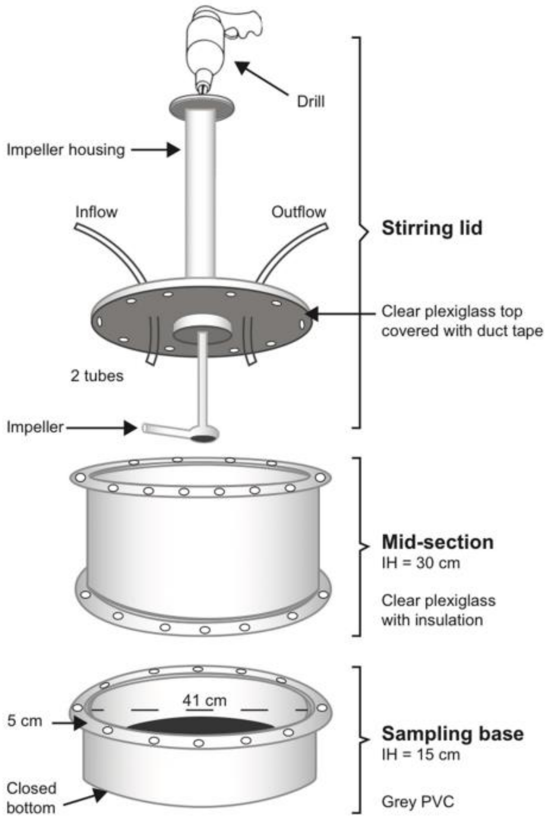

Figure 1. The benthic chambers design [1] includes an impeller powered by a hand drill mounted into a lid with inflow and outflow tubes, as well as a midsection and sampling base.

A common design for benthic chambers can be seen in Figure 1 [1], where a stirring lid is utilized to routinely distribute the water column in the chambers. A midsection is commonly constructed with a clear plexiglass or PVC material, and a sampling base is commonly constructed with PVC material.

Processes examined in the subject research project are sediment denitrification, which is the conversion of organic and dissolved inorganic [2] forms of nitrogen to forms of nitrogen gas (1) [4]. To measure the amount of nitrogen gas generated, the oxygen gas in the water is measured over a period of time. The denitrifying microbes utilize the oxygen in the water to function and process the organic and inorganic matter, and therefore this measurement can provide helpful information of denitrification rates.

$$2NO_3 + 12H_2 \rightarrow N_2 + 6H_2O \qquad (1)$$

The Guana Tolomato Matanzas National Estuarine Research Reserve (GTMNERR) was the focus of the benthic chamber's optimization, where denitrification rates are studied along the nine mile stretch of marshes, estuary, and is used to identify potential concerns to provide management recommendations for the wildlife.

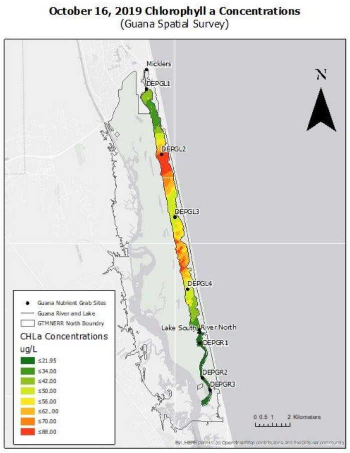

Figure 2. The chlorophyl concentration at various locations in GTMNERR displayed higher-than-expected quantities, which can provide information of the excess nutrients throughout the ecosystem.

From previously accomplished research projects performed in the GTMNERR, a higher-than-expected concentration of chlorophyl has been identified, shown in Figure 2 [3]. High chlorophyl can indicate an excess of nitrogen and other nutrients, which can contribute to eutrophication. Eutrophication, which is an excess of nutrients in an ecosystem [3], can decrease the number of grazers and overwhelm the ecosystem and decrease water quality. Therefore, the intended us of the benthic chamber is to quantify sediment denitrification trends as a result of oyster clusters in the lower intertidal region or subtidal regions, or sediment denitrification without any organism to contribute to the process.

The benthic chambers design project had a few objectives during the optimization process: to improve the performance, to lower the overall price, and to enhance the functionality of the device.

The benthic chambers design was intended to be utilized in subtidal and intertidal zones to measure the denitrification process of organisms and communities. The intertidal zone is the portion land that is submerged between the high and low tides, whereas the subtidal zone is a portion of land that is always submerged, except during especially low tides. In previous iterations of the benthic chambers design, the ability to perform experimental measurements in either zone proved to be difficult. A “tray” or an attachment to the bottom of the chambers was required to maintain the water in the chambers during the low tides in an intertidal zone, as well as to maintain the watertight seal in a subtidal zone. However, an added tray and midsection, as well as a stirring created many issues with leaking. Therefore, a watertight tray and lid was researched in the optimization to improve the performance of the benthic chamber. As previously mentioned, the benthic chambers are used to record high precision measurements are utilized for further analysis, requiring that the seal in the benthic chambers be sufficient to prevent leaking of liquid or gas. Additionally, the sampling process requires continuous monitoring of the system, with periods of time required for mixing the water column to ensure the benthic boundary layer is evenly distributed. Therefore, the method to mix the system's water column was optimized to become more effective.

The cost of the benthic chamber design was minimized to ensure that multiple systems could be manufactured. From components and materials purchased, to manufacturing processes, a lower budget was utilized to limit overall costs.

The last objective was to improve the functionality of the benthic chamber. Various aspects of the benthic chamber added additional difficulty for users while gathering data. Features ranging from the design of the stirring lid to the addition of handles were considered to improve ease of use.

To meet each objective, a complete redesign of the benthic chamber was performed. An initial prototype was designed with prior designs in mind: a midsection with a lid fastened on top, a sampling base with a fastened bottom, and metal latches to attach the midsection to the sampling base. A 12-inch black PVC with wall thickness of 0.687-inches was selected as the most structural sound and affordable material for the midsection and sampling base, a 0.25-inch clear polycarbonate lid was selected to be fastened to the midsection, and a 0.25-inch white polyethylene slab was selected to be fastened to the bottom of the sample base. In the testing of the initial design, multiple issues were identified. The wall thickness of 0.687-inches increased the weight of the design significantly to approximately 18.69 pounds with the chamber empty. Given that the design had no handles, this weight contributed to field-related difficulties with using the benthic chamber. Additionally, the sampling base and midsection had been sized such that removing any bubbles in the chamber prior to testing was challenging. The latches that had been added were also difficult to use, given that they were sharp and required a larger force to close. Lastly, the sampling base and midsection both had an added lip to improve the sealing abilities of the benthic chambers. This specific design addition required more time in the machining of both the midsection and sampling base and added complications when mating the two parts in the field. Therefore, the feedback provided from the initial design testing provided helpful information for the redesign of the benthic chambers, and various adjustments were made in the final design of the component.

The final design of the benthic chambers prioritized the usability and performance of the benthic chambers, while still aiming to minimize the overall cost. First, the prior concept of a midsection and sampling base was altered to minimize potential leaking points in the design. In the initial prototype, the midsection included a fastened lid, which was latched to the sampling base, which also had a fastened bottom. In the final design, the midsection was 12-inch diameter, 17-inch-long part, where a lid is attached to the top of the midsection, and a sampling base was changed to a PVC pipe cap which can be tightened to the bottom of the midsection. Therefore, the lid could be easily removed to remove any bubbles or access the test section during data collection. The lid was also adjusted to include the pump mount, sampling ports, and inflow and outflow ports. This simplified the overall design and ensured that the lid can be removed to access the pump, sampling ports, or oxygen sensor port. The next adjustment made was to remove any unnecessary fastener holes in the design. With a 0.5-inch-thick lid and a 0.406-inch-thick midsection, threads were added to allow for any hardware to support the tensile strength but prevent any leaks and corrosion. Also, metal latches added difficulties, so rubber latches were researched and yielded promising results for the required compressive strength and usability. For functionality, handles were added to the midsection to allow for the design to be easily transported if necessary. Lastly, the midsection material was changed to be clear PVC, which had comparable price ranges, and resulted in a more accurate photosynthesis rate of the sediment [2]. A beveled edge was added at the bottom of the midsection, which allowed for the chamber to be easily inserted into the sediment during testing. A battery adjuster was added to allow the pump to function at varying flow speeds, so that the preferred flow rate could be customized depending on the testing performed. The final prototype was machined and tested to observe the performance and functionality of the design.

Various tests were performed on the initial and final prototypes of the benthic chambers to evaluate the performance of each. Tests including the temperature, dissolved oxygen (DO), and pump distribution provided helpful information concerning the capabilities of each design, as well as potential improvements and further research. First, a test was performed in-situ measuring the dissolved oxygen and temperature over the course of an hour with data sampled every 15-minutes was performed. The DO data was relatively inconclusive, with no clear decrease in the DO percentage over the hour observed. However, this test was performed by withdrawing a large sample of water to measure the DO and temperature content, so this addition of the water from the surrounding environment could’ve skewed the results. The overall surrounding water DO was larger than the chamber DO content, by 9.33% for the initial prototype and 1.16% for the final prototype. The temperature, however, yielded clear trends. In the initial design, an increase of 5.70% was observed, while the final prototype only yielded an increase of 2.67%. A test was also performed with red dye inserted into the benthic chambers to observe the sealing abilities of the chambers. Both tests displayed that the designs maintained the water in the benthic chamber and prevented leakage in the attach points and in the sediment. An additional test was performed to observe the relationship of the voltage applied to the pump to the time required to fully distribute the water, and the content of the sediment exchanged with the water in the process. This test measured the initial and final chambers at 15 different voltage levels and displayed that at a low applied voltage of 1.6 volts, the initial design required 25.81 seconds to full distribute the water column, while the final prototype required 15.52 seconds. As the applied voltage increased, the time required to distribute the water column decreased by 60.6%, while the final prototype decreased by 54.8%. However, it was observed with a set visual scale that the final prototype disturbed the sediment at a lower voltage than the initial prototype, which can be a result of the inclination of the pump towards the sediment, while the initial prototype had the pump oriented horizontally along the water column. In both tests, it was observed that the functionality of the final prototype was significantly better than the initial prototype, as well as prior designs. The lighter weight, rubber latches, and handles contributed to the user experience. The cost also improved, with a decrease of 64.0% from past designs priced at $1,200.00 for an entire device.

Overall, the benthic chamber optimizations process was effective, with clear improvements in the performance, function, and cost. More research will be performed to evaluate various aspects of the performance. In the testing completed during the redesign, only subtidal regions were simulated, so more regions will be studied to identify any issues in the design. Additional features, including a battery adjuster and support will be researched to contribute to the functionality of the concept.

Benthic Chamber Past Designs

In initial designs of the benthic chamber, clear acrylic cores, 40 cm high and with a diameter of 13.3 cm were utilized, as shown in Figure 3. However, this design had a poor seal, and denitrification measurements were difficult to accurately record. Also, a magnetic stirrer with a rotating motor, labeled in Figure 1 was used to distribute the water column. While a magnetic stirrer can be used to distribute the benthic distribution in the water column, the stirrer required manual input and was difficult to assemble and use in the field.

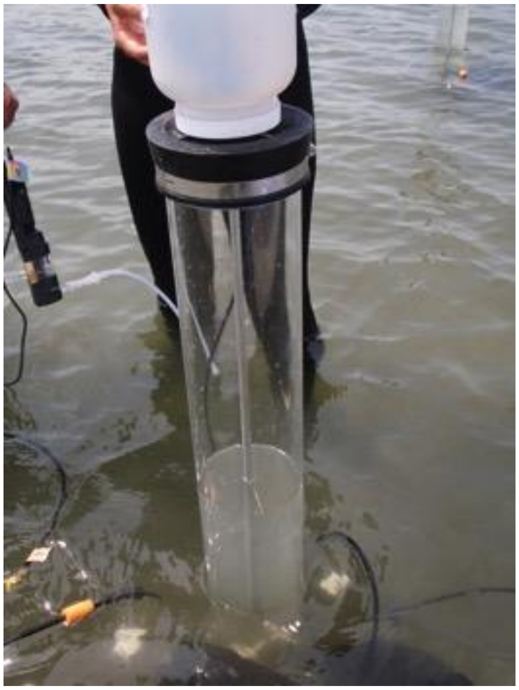

Figure 3. Clear acrylic cores were powered with a hand drill in a bottle and had a diameter of 13.3 cm.

In another iteration, a 16-inch diameter, gauge 80 PVC pipe was used to allow for testing with oyster cores in more strenuous environments, shown in Figure 4. This design had multiple midsections to allow for adjusted height, as well as additional capabilities for sediment denitrification analysis. However, this design had many issues in the cost and ease of use. The weight of the chamber was relatively higher than previous designs due to the increased wall thickness and was difficult to carry due to a larger midsection diameter. Additionally, the metal latches were difficult to use due to the high compressive strength of the springs used, and the amount of latches placed throughout the device. Due to the increased weight and high compression metal latches, this design was difficult to test with in the field. Next, the cost for materials and manufacturing amounted to over twelve hundred dollars per benthic system, which was costly given the relatively simple design.

Figure 4. The 12-inch diameter PVC benthic chamber can be observed, with two-midsections and a sampling base.

Benthic Chamber Redesign Process

Various objectives were established in designing an effective benthic chamber concept. From prior iterations, it was observed that performance of the chamber declined due to a poor seal between the environment in the test section and the surrounding water. Given that the ability to measure the gas accurately is critical to the research topic of denitrification, this factor was emphasized in the benthic chamber redesign process. Additionally, the ability of light to reach the sediment, as well as any community researched in the chamber was required. Next, the functionality of the design was considered. Features such as the latch material, handles, and overall weight were factored in to ensure that the design was ergonomic. Lastly, the cost for part and manufacturing was prioritized, given that multiple benthic chambers were required for field studies.

In addition to design factors, parameters required for the benthic chamber design were set. A diameter of 12 inches for the test section was required to properly isolate the environment around an organism. The design was intended to be utilized in the sub-tidal and intertidal zones, requiring that an effective method of connection be used between midsection and the sampling base, if needed.

Initial Prototype Design

With all established design parameters, a concept was drafted which included a midsection and sampling base machined from schedule 80 PVC, an attached lid made of clear polycarbonate, and a bottom to the sampling base of white polyethylene. Also, a pump was selected instead of a stirrer due to the ability to effectively distribute water and requiring less user involvement. The midsection and sampling base were designed to be attached with stainless steel latches, as shown below in Figure 5. Fasteners were selected to securely hold the midsection to the lid, and the sampling base to the bottom. Holes in the polycarbonate lid were added for the fasteners, pump wiring, and oxygen sensor.

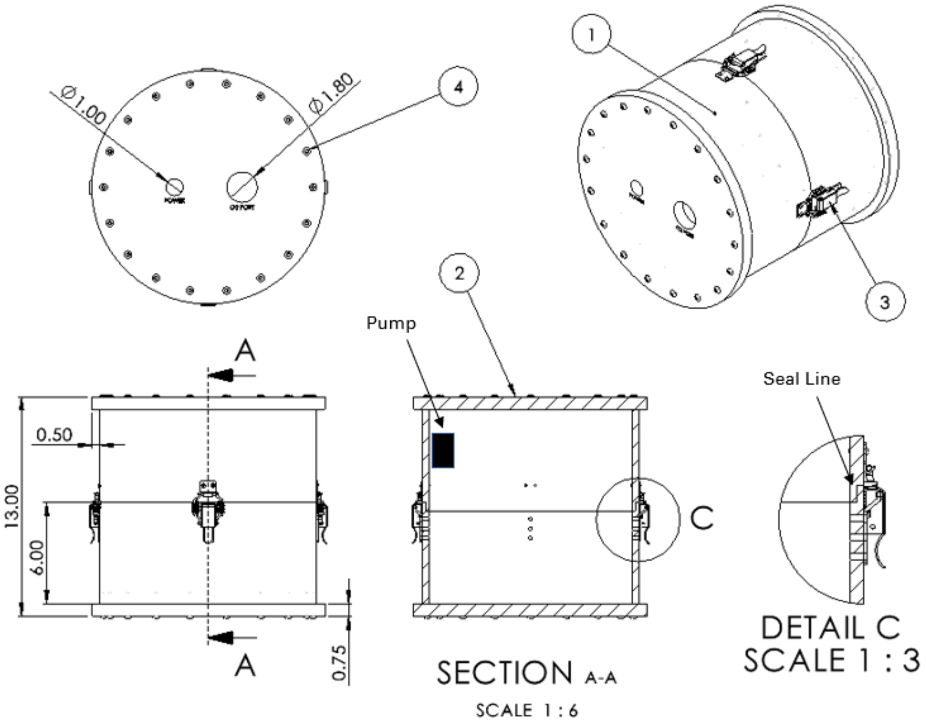

Figure 5. The initial design was created with PVC, polyethylene, and polycarbonate. A pump was designed to be mounted to the midsection, and an oxygen and pump electric port was added.

A seal line was added between the midsection and sampling base to ensure that no exchange of gases occurred in the test section. Schedule 80 PVC was selected due to the ability to carry stresses in the chamber design and a polycarbonate lid was selected to allow sunlight to reach the benthic chamber contents. It was noted that after consideration, it was decided that 8 fasteners were sufficient to attach the lid to the midsection and the bottom to the sampling base. With the initial design established, the prototype was manufactured with a 12-inch PVC tube, a 0.25-inch polycarbonate slab, 0.25-inch white polyethylene base, and fastened with ¼-28 bolts. Additional functional equipment including a 1100 gallon per hour (GPH) bilge pump and stainless-steel spring latches. These parts, shown in Table I, totaled to a price of $429.98.

Table 1: Initial Prototype Parts List

Description	Qty.	Cost
12-Inch PVC Pipe	1	200.00
White Polyethylene Slab, 0.25-Inch Thick	1	40.09
Clear Polycarbonate Plexiglass Slab, 0.25-Inch Thick	1	32.50
Stainless Steel Spring Latches	4	60.00
12-Volt Battery	1	52.89
Submersible Water Pump	1	44.50
Total		429.98

With the ordered parts, the initial prototype was shown in Figure 6 and 7. The metal latches are shown, along with the pump attached to the wall of the midsection, used to distribute the water column in a circular motion around the chamber.

Figure 6. The initial prototype was manufactured and tested to determine the effectiveness of the design. The benthic chamber can be seen in an operational configuration, with latches aligned to secure the midsection and the sampling base.

Figure 7. The top view of the benthic chambers in an unlatched configuration was shown. A custom 3D printed mount was created to attach the bilge pump to the midsection. The white polyethylene plate was also shown in the sampling base, and the polycarbonate lid on the midsection.

After testing was performed on the first prototype, various issues were identified with the design. Firstly, a sampling base that extended to the mid-point of the incubator was unnecessary. A shorter sampling base was preferred to support the sediment and if required, organism. Also, due to a midsection wall thickness 0.687 inches, the design was too heavy, with a weight of around 18.69 lb. empty. While this increased thickness offered strength, it was over-conservative considering the applied loads. Additionally, to enhance test accuracy, a clear midsection was preferred given that the material allows light to enter the midsection as well as the lid. In the initial testing performed, it was also determined that an attached bottom to the sampling base was often unnecessary in subtidal zones. A design that allowed for a bottomless benthic chamber, as well as an added bottom was suggested. The seal in the initial design appeared to be effective, but required a significant amount of machining time, and would be less feasible with a lower wall thickness. Metallic latches were also an issue; the latches were difficult to use in murky water, caused corrosion regardless of the stainless-steel material used, and were potentially hazardous if a user bumped into the chamber while testing. Lastly, the benthic chamber design was difficult to carry. At a 12-inch diameter around over 70 lbs., additional features were necessary to comfortably transport the component in the field. These points of feedback were considered, and a final prototype was designed.

Final Prototype Design

From the previously tested prototype, changes were considered for the redesign and manufacturing process of the benthic chamber. The overall weight of the benthic chamber, hardware, and midsection hardware were qualities adjusted for the final prototype. The following section detailed the design and manufacturing process to create the final prototype of the benthic chamber.

Initially, a sampling base was added to the benthic chambers design to allow for effective in-situ testing [1] that would provide the flexibility to then relocate a research sample while still enclosed. A traditional sampling base latched to the midsection, as shown in Figure 1, was assumed to be the most effective method to include the potential to further research a study beyond the field. However, a sampling base limited the flexibility of applications in which the benthic chambers could be tested. Additionally, having fastened joints in the sampling base, midsection introduced added potential for leaking during use. Therefore, the concept of a midsection and sampling base was adjusted to include a lid, midsection, and a removeable sampling base.

Benthic chambers often use a transparent midsection to ensure the sediment photosynthesis rate inside the test section is similar to the surrounding environment [4]. Therefore, to improve the final prototype, a clear PVC midsection was utilized. A material with thickness of 0.406-inches was selected for the midsection to ensure that the design could support structural loads during testing, as well as ensure the weight was lowered. Clear polycarbonate was researched due to its durability to structural loads and cutting forces, as compared to acrylic, or other materials. However, clear PVC was selected due to its affordability and increased ability to manage structural loads.

Instead of machining two sections of PVC to mate within a tight tolerance for the midsection and sampling base, which was used in the initial prototype in Figure 6, a lid was designed with a machined step-down at a tight tolerance to fit within the midsection. The lid cross-section was shown below in Figure 8.

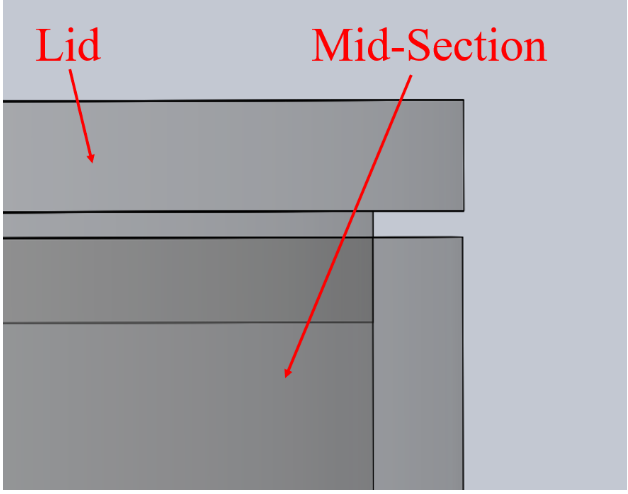

Figure 8. The lid and midsection assembly were shown in Solidworks.

To improve the seal between the lid and the midsection, a gasket was researched to be added to the prototype. To verify the size of the gasket, information concerning O-ring diameters, often used in Piston applications, was referenced [5]. For an effective seal, an O-ring with an inner diameter (ID_{o-ring}) less than the groove width (w_{groove}) divided by the stretched circumference percentage (x) (2) was selected [5].

$$ID_{o-ring} = \frac{w_{groove}}{x+1} \qquad (2)$$

Additionally, an O-ring with hardness related to the applied pressure was selected [6]. With a Buna Nitrile rubber O-ring at an initial diameter of 10-inches, and a stretched diameter of 11.938 inches, a stretched percentage of 19.38% was calculated. With a groove width of 0.20 inches, it was determined that the O-ring inner diameter must be less than 0.17 inches. Therefore, a 12-inch O-ring of inner diameter of 1/8-inches was selected to properly seal the benthic chamber. The cross-sectional view of the lid and midsection was shown below in Figure 9.

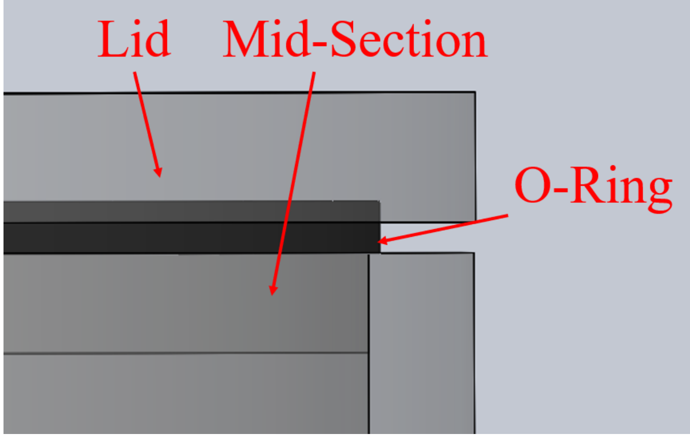

Figure 9. The lid, midsection, and O-ring assembly were shown in Solidworks.

The next adjusted feature in the final prototype design was the pump mount location and design. To simplify the overall benthic chambers design, it was determined that the majority of the hardware should be placed on the lid. With a thicker cross-section, the lid was designed to properly manage structural loads more effectively and the port required for the electrical cables in the pump can be directed through a sealed location in the lid, ensuring that minimal leaking will occur given that the height difference that creates force will be less on the top of the sealed chamber. Therefore, to equally distribute the water column in the chambers, a pump mount was designed to be inclined towards the bottom of the chamber. Initially, an inclination angle of 45° was selected, but to prevent excessive sediment distribution, a lower angle of 30° was selected. The pump mount within the benthic chamber at an inclination of 45° Figure 10, and at 30° in Figure 11.

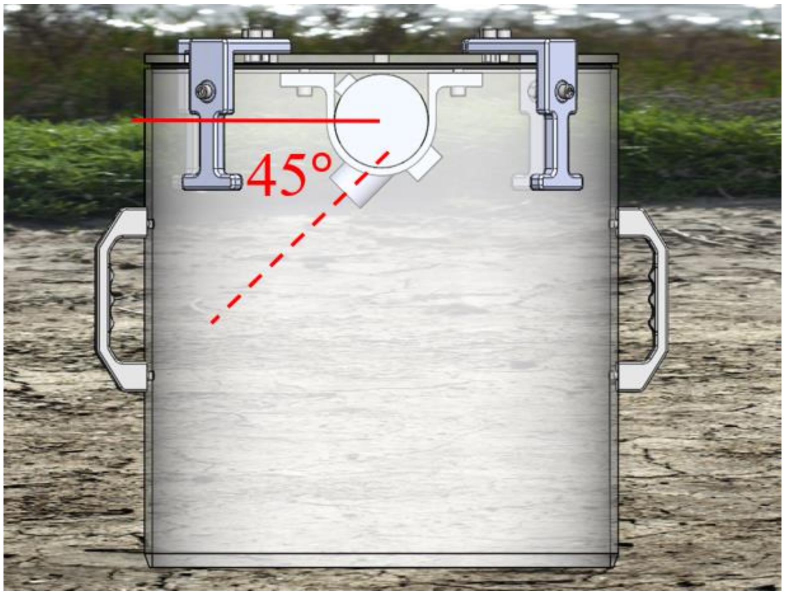

Figure 10. The pump mount, as well as the pump, was shown in a Solidworks CAD design.

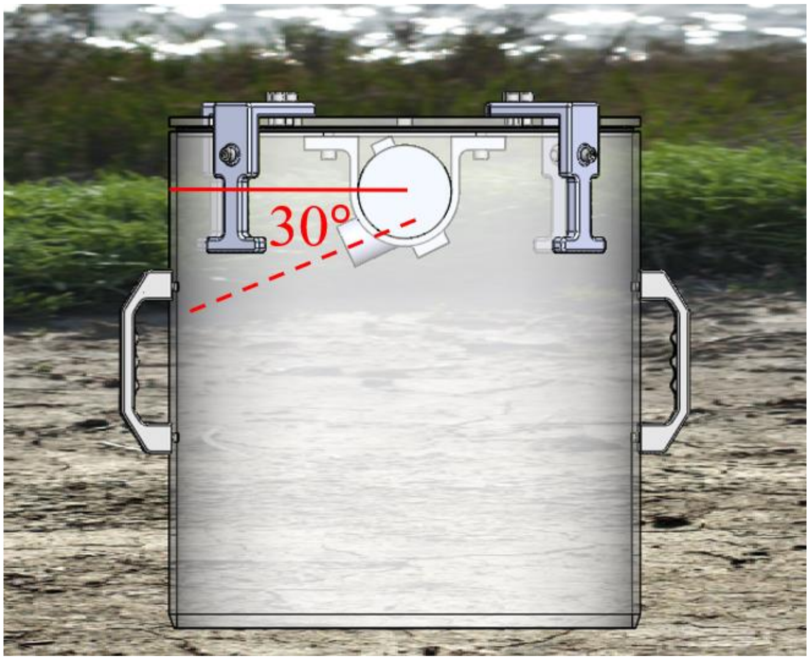

Figure 11. The pump mount, as well as the pump, was shown in a Solidworks CAD design.

In the first prototype of the benthic chambers, it was identified that at a higher weight, the design was difficult to carry in the field. Therefore, handles were added in the final prototype to allow users to carry the test sample in the field, or to place the design in the sediment for testing. Black plastic handles were added with quarter inch fasteners to ensure that the weight of the benthic chamber with water and sediment could be supported.

In the initial prototype, it was found that removing the midsection from the sampling base after developing a vacuum seal within the benthic chamber was difficult. Therefore, a lip was added to the lid, to allow for the lid to be removed easily.

The last adjusted feature in the benthic chamber design was the method of fastened hardware. In the first prototype, fasteners and nuts were used in through-holes in the design to add the pump and latches, which added more locations for potential leaks. Additionally, the combination of fastener and nuts added more corrosive materials interfacing with salt water. Therefore, to improve the design, tapped holes were added to the design for any hardware fastener locations, and nuts were removed from the design. To ensure the tapped threads would sustain applied loads, a half inch lid and 0.406-inch-thick PVC midsection were used to ensure that a sufficient number of threads were added. Generally, 3 threads of engagement are required for tapped holes [8]. Therefore, in the final prototype, 4-5 threads were added to ensure that any structural loads would be adequately supported.

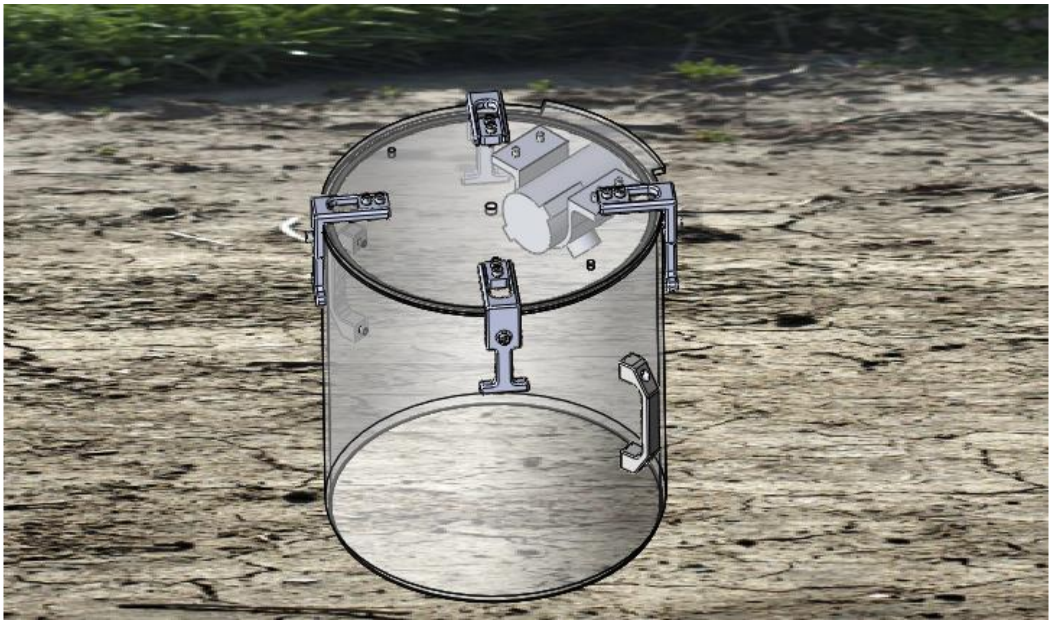

Figure 12. The benthic chambers design shown in Solidworks CAD displays the beveled edge at the bottom of the design to allow for the midsection to easily be buried in the sediment for testing.

Figure 13. The benthic chambers design shown in Solidworks CAD displays the added rubber pipe cap to allow for intertidal region testing, as well as for the samples to be transported to the lab environment.

With provided feedback of the initial prototype, the complete Solidworks CAD model of the final prototype for the benthic chambers was established, shown in Figure 12 and Figure 13. Figure 12 displays the benthic chamber in a configuration without the added sampling tray, which could be used primarily subtidal regions for in-situ testing. Figure 13 displays the added sampling tray, which was a rubber PVC cap to allow for in-situ testing in intertidal regions, or for portable lab testing.

After the theoretical design was reviewed, the final prototype was machined and assembled. The CAD drawing was used to provide dimensions for the manufacturing process. The first portion of the design was the midsection, which had a length of 17-inches, and added threaded holes for the latches and handles. The handles used threaded fastener holes to the callout ¼-20 UNC 0.25, and the latches to 10-24 UNC 0.25. This depth ensured that the correct number of threads were engaged with any added fasteners. These features are shown below in Figure 14.

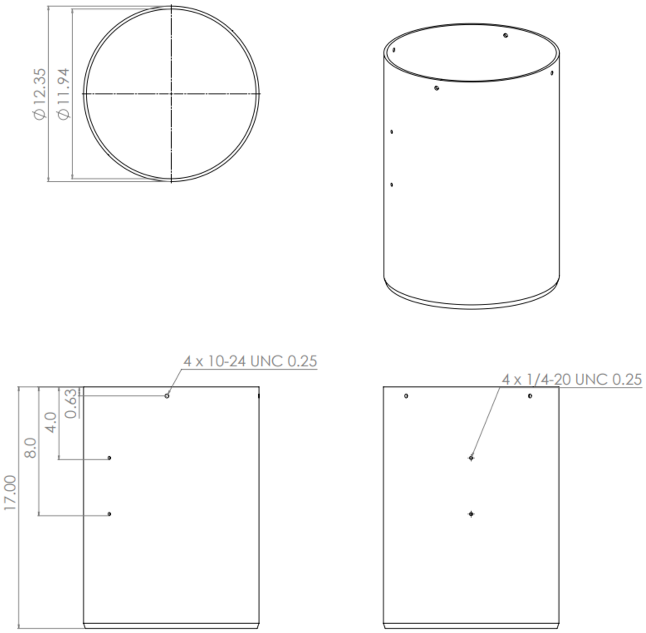

Figure 14. The clear PVC midsection drawing had relatively simple features, including fastener holes and a beveled edge.

The lid drawing, shown in Figure 15, included a machined handle, a lip for the seal between the lid and midsection, fastener holes for the latches, an oxygen sensor port, and sampling ports.

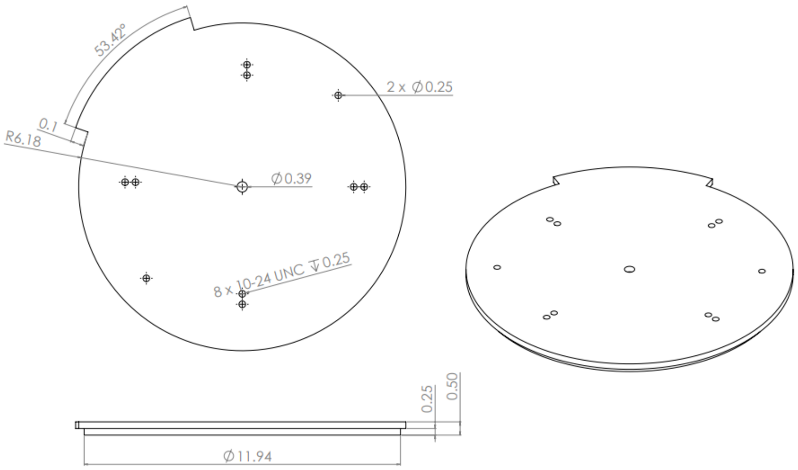

Figure 15. The lid drawing was created with features included an added edge to improve the seal, as well as added threaded holes and port holes for testing.

With the final prototype design, a bill of materials (BOM) was created, and all materials totaled to $432.23 in Table 2. The increase in overall price was a result of the clear PVC pipe, which was selected to improve the photosynthesis rate of the sample during testing.

Table 2: Final prototype bill of materials.

Description	Qty.	Cost
12-Inch Clear PVC Pipe	1	212.19
Rubber PVC Cap	1	28.99
Clear Polycarbonate Plexiglass Slab, 0.5-Inch Thick	1	20.00
Plastic Handles	2	13.70
Rubber Latches	4	59.96
12-Volt Battery	1	52.89
Submersible Water Pump	1	44.50
Total		432.23

In the manufacturing process, the major processes included the following: cutting the midsection and lid, leveling the surface of the midsection, adding latches, handles, and pump mount hardware, and assembly. The clear PVC, which was used to fabricate the midsection, arrived in a 10-foot length piece, and had to be cut down to 17-inch sections with a table saw. This process was used to minimize surface roughness, as well as this machine having a large enough work section for the 12-inch pipe diameter. The 10-foot section of clear PVC was shown in Figure 16.

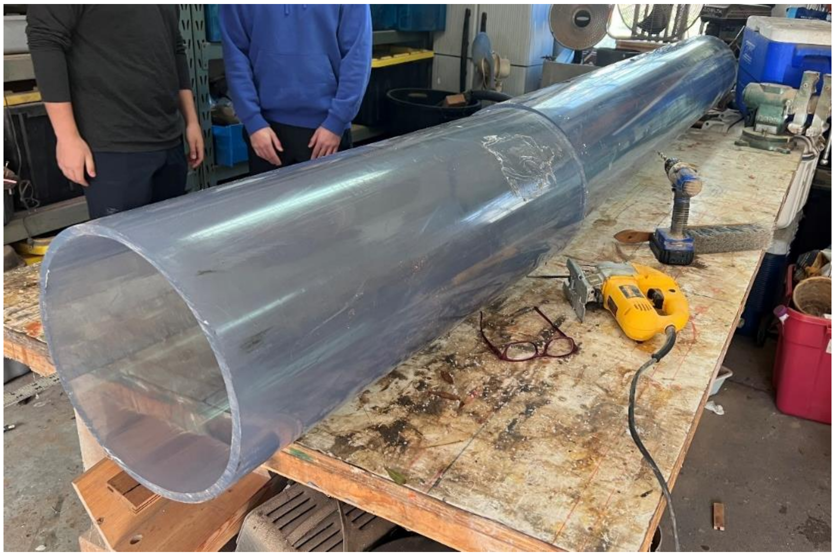

Figure 16. The clear PVC arrived in a 10-foot section, and had to be cut down to have size, which was performed by a hand-held reciprocating saw.

The lid, fabricated from polycarbonate, was cut with a Grizzly bandsaw to approximate dimensions specified. This included the circular exterior, as well as the lip contour. A band saw was selected due to the ability to machine the lid easily and given that the seal between the lid and the midsection was the only design feature that required a higher tolerance. Therefore, the band saw was used with a greater tolerance, shown in Figure 17.

Figure 17. The Grizzly band saw was used to cut a defined shape of the lid.

After the lid was machined with the band saw, the added ledge to create the seal with the midsection, shown in Figure 8 was created with a cutting router. To cut the ledge into the lid for the step-down between the midsection and the lid, the router bit was raised by a quarter inch, and the router was adjusted to cut a quarter inch into the lid diameter. After the lid was machined, the midsection and lid were assembled to ensure that the tolerance between each machined part was maintained, shown in Figure 18.

Figure 18. After the midsection was cut from the PVC material, and the lid from the polycarbonate material, these pieces were assembled together to determine the quality of the fit for the overall assembly.

After the lid and midsection were cut and assembled, 80 grit sandpaper was placed on a flat surface to level the midsection face that interfaced with the lid. This was achieved to level any imperfections that resulted from machining processes, to ensure that an effective seal can be created with the lid and the midsection. After leveling the midsection with 80-grit, 120-grit sandpaper was used to further refine the midsection piece, and smooth out any deformities left from the leveling process. The lid was also sanded lightly with 120-grit sandpaper to minimize any deformities. This process was shown below in Figure 19.

Figure 19. The 80-grit sandpaper was fastened to a flat surface, and the midsection was passed over to create a flat and even surface.

With the lid and midsection machined and sanded, the latches, handles, and pump mount were added. The latches required 10-24 fasteners, and the pump mount and the handles required ¼-20 fasteners. Therefore, taps were used to add threads to the midsection and lid, along with the required drill sizes of #27 and #7 [9]. The locations of all added hardware attach points were followed per drawing in Figures 14 and 15. After the final prototype was assembled, the holes required for the ports and oxygen sensor were added.

Prototype Testing Methods

The initial and final prototype, shown in Figure 20, were tested to evaluate the performance of the benthic chamber designs. Both designs were tested for the ability to gather data, the accuracy of the data measured, and the functionality of each design. To meet the set objectives, the initial and final prototype designs were set with sediment samples for one hour, with data gathered at 15-minute intervals. The testing was performed in a subtidal region, where the entire chamber was fully submerged. The dissolved oxygen (DO) and temperature was measured from the performed tests, given that this information could provide information concerning the accuracy of the tests. Additionally, tests to evaluate the efficiency of the pump were performed, where the sediment disturbance and the time to fully distribute the water column distribution as well as the sediment distribution was recorded.

To gather DO and temperature data in the field, the initial and final prototypes were fully submerged, and any bubbles that gathered inside were dispersed to minimize errors during the experiment. Then, both designs were inserted into the sediment and a seal was attempted. It was noted that in a subtidal environment, to ensure accurate tests, a sampling base is not added. Therefore, the white polyethylene sheet in the initial prototype was removed for the test.

Figure 20. The initial prototype (right) and the final prototype (left) were tested in Gilchrist Springs, Florida on a sunny day.

To ensure that both designs could operate with the same pump voltage, the final prototype was tested first for an hour, and the initial prototype was tested for another hour. Both pumps were powered at 1.93 volts throughout the entire experiment to properly distribute the water, while also preventing sediment distribution. A YSI ProODO dissolved oxygen meter device was used to gather temperature and DO data in units of percentage. The benthic chamber had an inflow and outflow line: one to gather samples, and the other to either allow ambient surrounding water into the chamber, or to seal the chamber from the surrounding water. When collecting samples, the inflow line was opened, and after gathering data, the inflow line was closed. After the benthic chamber had been settled in the water, a syringe was used to purge water from the lines connecting the outflow port to the syringe. When samples were gathered with the syringe, the samples were transported to a cup, where the YIS ProODO device would be used to take 10 measurements of the DO data and the temperature data. Samples were taken over an hour at approximately 15-minute intervals. Both the initial and final prototype testing setup is shown below in Figure 21.

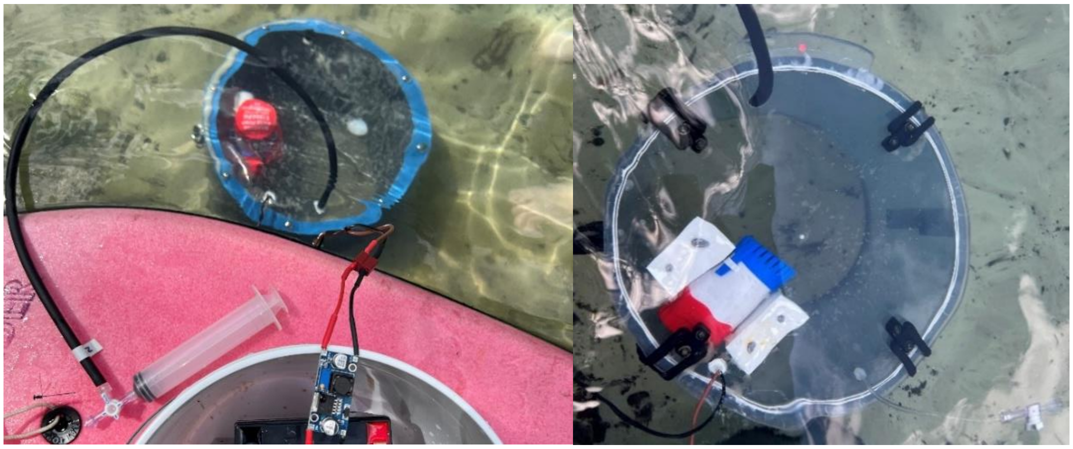

Figure 21. The initial prototype (left) and the final prototype (right) testing setup.

Next, a test was performed to observe the seal abilities of both benthic chambers. In the in-situ environment, a syringe filled with dyed water was added to the benthic chambers, and a time was set to record the time required for the chambers to fully distribute the dyed water. Then, both chambers were observed for any leaking through the sediment or the component. The benthic chambers after both tests are shown below in Figure 22.

Figure 22. The initial prototype (left) and the final prototype (right) dye test.

Lastly, a test was performed to correlate the amount of voltage applied to the pump to the time required to mix the water column, as well as the amount of sediment that is dispersed. This data can present an observation of the location of the pump, and how well dispersed the water column is without excessive mixing sediment in the process. Therefore, both the initial and final prototype were tested in a lab environment, where a sampling base was attached to each design, 2-3 inches of sediment was added to the bottom. Then, water was filled to the top of each chamber, and the pump was run at varying voltage levels ranging from 1.6 to 12. With a syringe, red dye was added to the mixing water, and the time required to distribute the dye was recorded, along with a visual identification of the sediment dispersed in the process. The range of sediment disturbance was taken by a visual measurement, with 1 being clear water, and 5 being cloudy and seeing sediment being brought into the water column. The range for the sediment disturbance visual measurement was shown below in Figure 23.

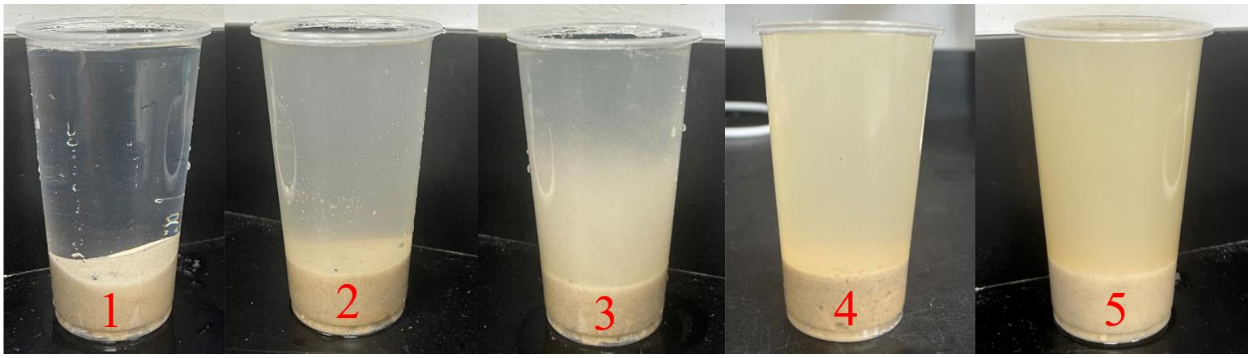

Figure 23. The initial prototype (left) and the final prototype (right) sediment distribution and water column mixing test.

Prototype Testing Results

After the performed tests to evaluate the performance of the benthic chamber designs were completed, data was analyzed. First, the temperature data over time of the benthic chamber and surrounding water was plotted. Ideally, the temperature inside the benthic chamber will remain comparable to the surrounding water temperature, but due to the isolation of the water, color of the midsection or transparency of the lid, this temperature measured inside the chamber may vary.

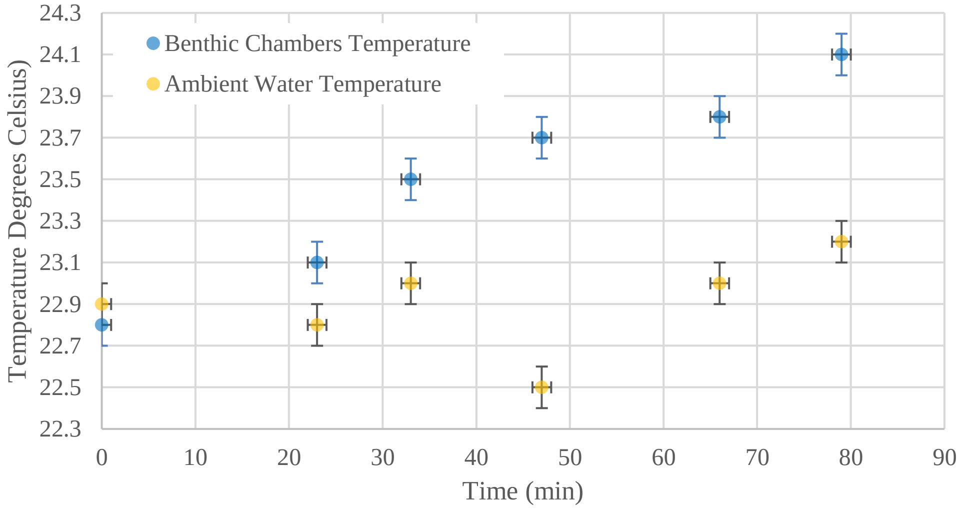

Figure 24. The initial benthic chambers prototype temperature data.

The temperature measurements from the initial benthic chamber design, shown in Figure 24, displayed an increase in the test section temperature over time. This increase could be a result of the black midsection, which absorbs heat at a greater rate than the surrounding water. The surrounding water had an average value of 22.9$\pm$0.1$°C$, while the benthic chamber temperature ranged from 22.9$\pm$0.1 $°C$ to 23.2$\pm 0.1°C$. This increase in temperature can lead to an inaccurate percentage of dissolved oxygen in the water, given that the increased heat can often lower the amount of dissolved oxygen in the test sample [10].

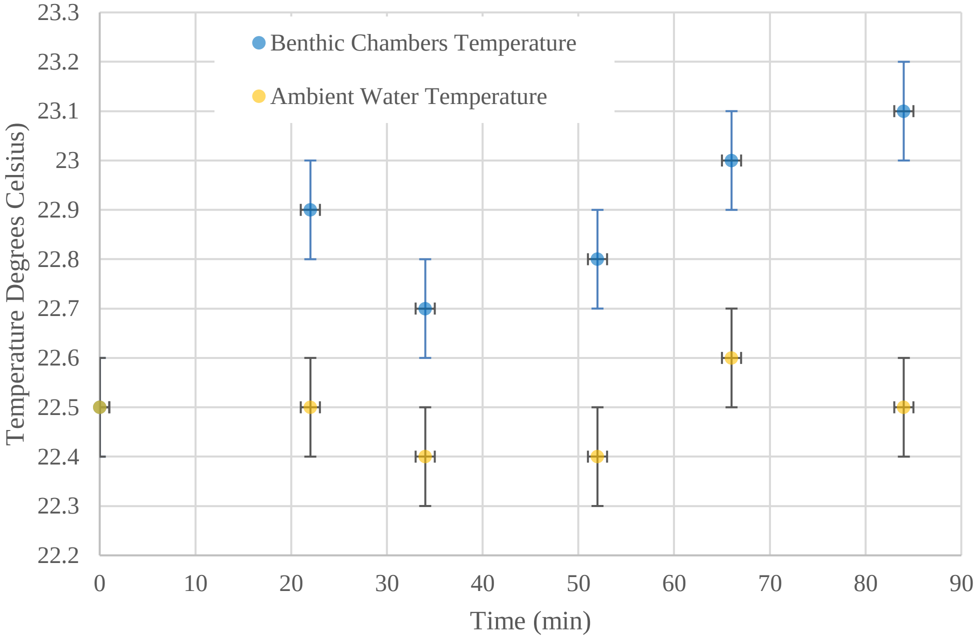

Figure 25. The final benthic chambers prototype temperature data.

The temperature measurements from the final benthic chamber design, shown in Figure 25, displayed a slight increase in the test section temperature over time. This increase could be a result of the smaller volume of water that is set in the test section, which may have a greater temperature change than the surrounding water. However, the temperature stays within a range of 0.7±0.1°C, which can be a result of the transparent midsection and lid, which allows light to enter the benthic chamber around the same amount as the surrounding water.

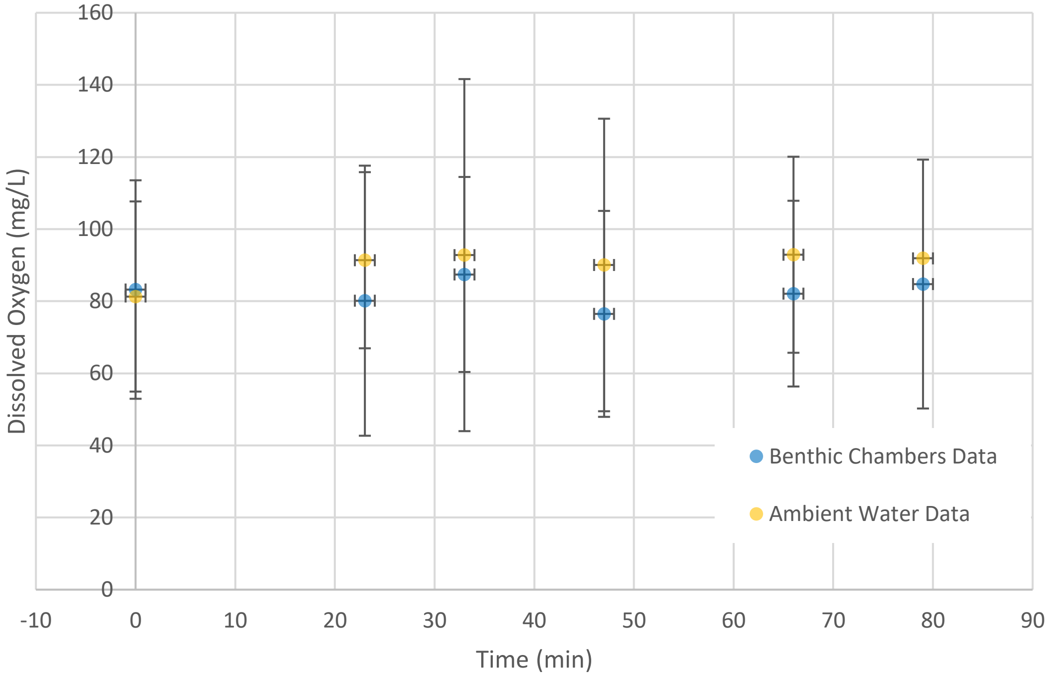

Figure 26. The initial benthic chambers prototype DO data.

The initial benthic chambers DO data had a relatively high uncertainty, reaching up to a maximum of ±34.57°.

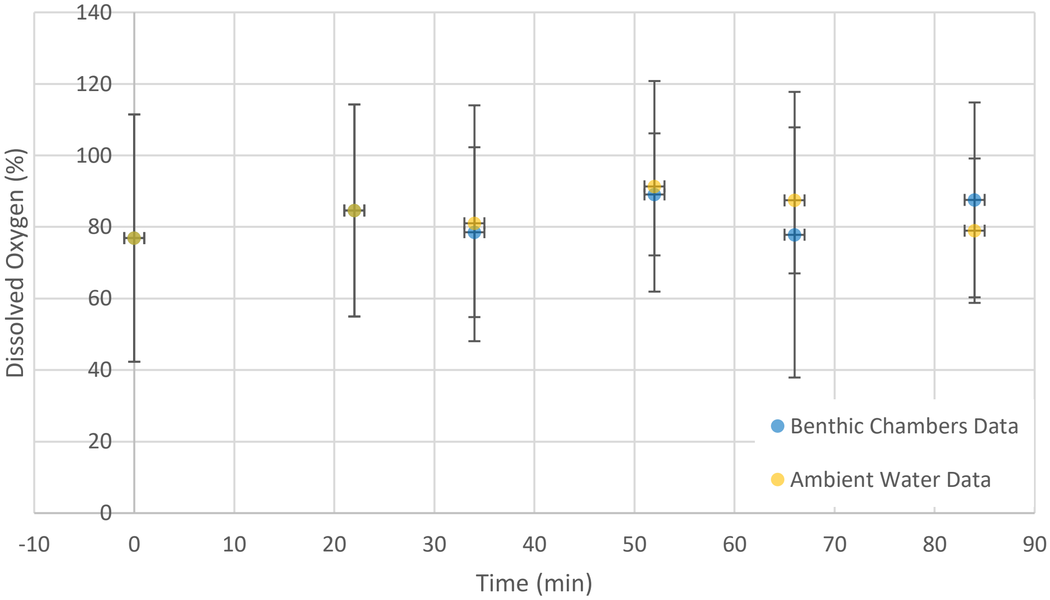

Figure 27. The final benthic chambers prototype DO data.

The DO data taken for both the initial and final benthic chambers prototype, shown in Figures 26 and 27, were relatively unclear. The method of removing a sample to gather DO and temperature data, while replacing that volume of water with the surrounding water may have diluted the readings for DO. The surrounding water on each plot is slightly greater than the benthic chambers water data, which may indicate expected drops in the DO. However, more testing was performed to observe the performance of the benthic chambers. A parameter that is used to weigh the success of the design is the ability of the pump inside the benthic chambers to properly distribute the water column in a reasonable time, while still preventing the sediment from being disturbed. Therefore, a test was performed, and data was recorded for both the initial and final prototype, which is shown below in Figures 28 and 29.

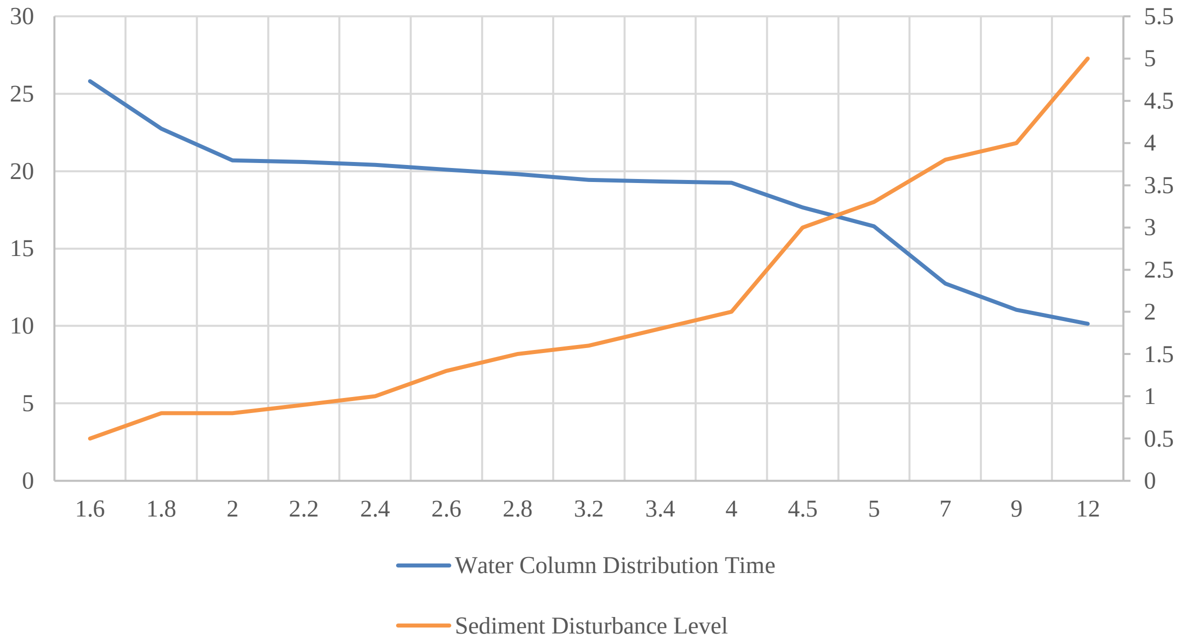

Figure 28. The initial benthic chambers prototype water column distribution time and sediment disturbance level as a function of voltage applied to the pump.

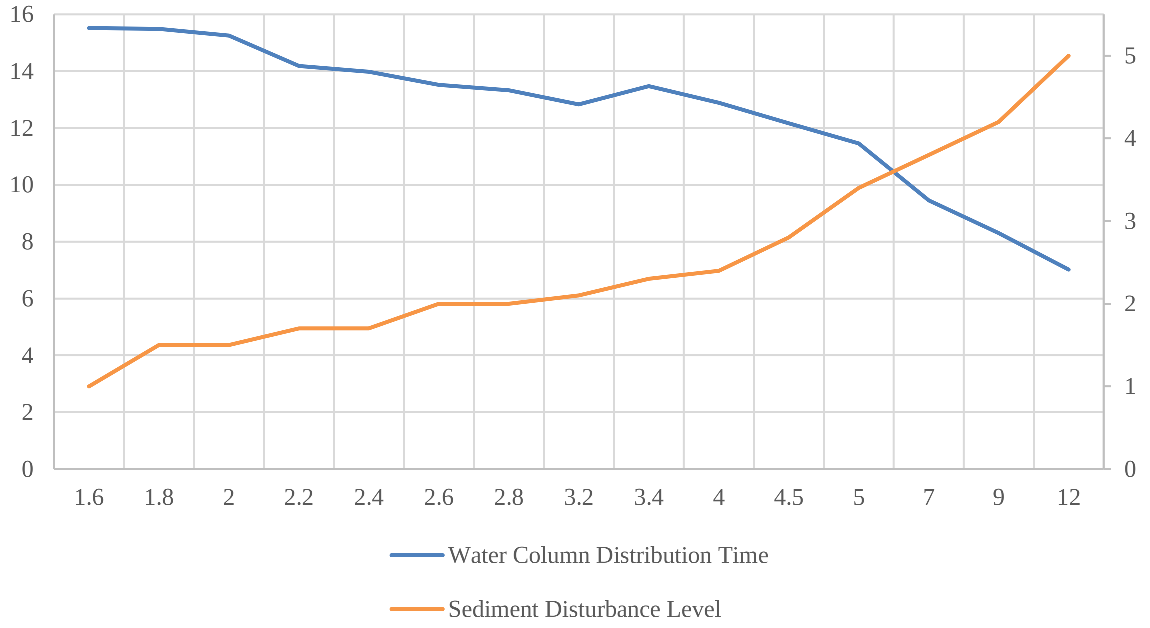

Figure 29. The final benthic chambers prototype water column distribution time and sediment disturbance level as a function of voltage applied to the pump.

From the data gathered, it was shown that the initial benthic chamber required a greater time overall to distribute the water column, but allowed a greater voltage before sediment was disturbed at a visual level of 3 from Figure 23. The initial prototype can tolerate a voltage of 3.5 volts before becoming too turbulent within the test section, while the final prototype can only tolerate 2.5 volts. This quality was likely a result of the pump location, which was mounted on the side of the midsection and directs water in a circular motion in the chamber. Since the pump was located approximately 5 inches from the sediment, it was less likely to disturb sediment at a higher voltage. The final prototype used a pump angled at 30° towards the sediment but was located on the lid of the chamber. Therefore, this downward direction likely allowed for water to be more effectively distributed but disturbed the sediment more easily. Overall, the tests performed displayed helpful information concerning each prototype of the chamber, as well as the potential for further testing.

Future Work

The topic of benthic chambers is a widely researched topic in the field of sediment denitrification. The redesign and testing performed on the prototypes provided direction for the future work of the benthic chambers. The final prototype will be evaluated in pilot testing to determine the capabilities of the component. Although DO, temperature, sealing ability, water column distribution and sediment disturbance data was gathered and compared to that of the initial prototype, tests with more accurate methods of gathering each of these components will be performed. With more resources, the DO data can be taken in more accurate means, with limited uncertainty to compare against previously published data.

In addition to further testing, functionality will be added to the benthic chambers. A battery support was drafted to allow users to safely operate the benthic chambers, and to have the opportunity to easily gather data. This concept was drafted to utilize a mount on top of the benthic chamber, shown below in Figure 30, but after some testing this concept was determined to add more complication to testing. Therefore, other methods of battery support will be researched and used. Secondly, the battery voltage adjuster will be upgraded to allow users to easily change the voltage of the running pump. Currently, a flat head screwdriver is required to change the voltage of the battery, and the voltage used can only be recorded with a voltmeter. Therefore, a voltage adjuster with a display will be acquired to improve the user experience.

Figure 30. Battery support concept design.

Aside from further testing and added functionality, the future plans of the subject research project are to manufacture four additional chambers with the final prototype design. These chambers will be used to deploy multiple tests in a single sampling location or can be separated depending on the need of sediment denitrification research.

Conclusion

The benthic chamber optimization process significantly improved the performance, enhanced the functionality, and lowered the cost of the design. With input from knowledgeable users, the final prototype was simplified and had an improved performance from initial concepts. In past designs, issues concerning the ability of the chamber to effectively hold water and gas without leaks were presented, and in the final design, the potential leak points were significantly decreased. Previously, a lid was fastened to the midsection, the midsection was latched to the sampling base, and the sampling base had a bottom fastened. In the updated concept, the lid was latched to the midsection, and a sampling base can be clamped to the midsection if needed. Internal threads were added to carry the tensile loads, also removing any unnecessary holes and potential leak points in the design. The materials used in the design were also changed, allowing for the sunlight to enter the test section and maintain a similar photosynthesis rate of the organic matter enclosed. The functionality of the design was improved, adding rubber latches to minimize injuries or complication during sampling, handles to provide the ability to easily carry the chamber if needed, and a lid handle to easily remove or add the lid. From the changes mentioned, the cost of the final prototype was lower than previous designs by approximately 64.0%.

To evaluate the final design of the benthic chambers, various tests were performed to gather data concerning the prototype’s performance. Data of the dissolved oxygen and temperature were measured in-situ to identify any potential trends between the final prototype and the initial prototype. From the data gathered, the dissolved oxygen data gathered in the benthic chambers was not indicative of the predicted trend, which indicates that due to the performed chemical reaction of denitrifying microbes in the test sample (1), the oxygen should decrease over time. However, the DO inside the benthic chambers was overall lower than the surrounding water by an average of 9.33% for the initial prototype and 1.16% for the final prototype. The temperature data, however, indicated that the initial prototype increased in temperature over time more than the final prototype, with the temperature of the initial prototype increasing by 5.70% and the final prototype only increasing by 2.67%. This result could be due to the dark material used in the midsection and sampling base of the initial prototype, as compared to the clear PVC used in the final design, as well as increasing temperatures due to the time of sampling. Additionally, a test to observe changes in the mixing rate and sediment disturbance as a result of the pump voltage was performed. Red dye was added to the benthic chambers, while the pump was powered with varying voltages, ranging from 1.6 volts to 12 volts, and the time required to fully distribute the red dye in the water column was observed, as well as the visual observation of the sediment disturbance. The data gathered displayed that the final design distributed the dye more quickly by an average of 31.1% over the various voltages but disturbed the sediment more by an average value of 43.9%. This difference was likely due to the pump being placed in the final prototype at a 30° inclination towards the sediment, which improves the mixing of the water column, but can disturb sediment at higher flow rates.

The research performed concerning the benthic chamber part design contributed to the concept and future work, including plans to thoroughly test the final design. Given that the final prototype has design features that differ from previous concept designs of the benthic chamber, a pilot study will likely be performed to establish the performance and capability of the component. Testing will be performed to gather DO data more effectively, in the plans of observing clear trends in DO decrease in the chamber over time. Additionally, functionality of the benthic chambers will be further improved, with a battery support added to allow the user to have a hands-off approach during testing.

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