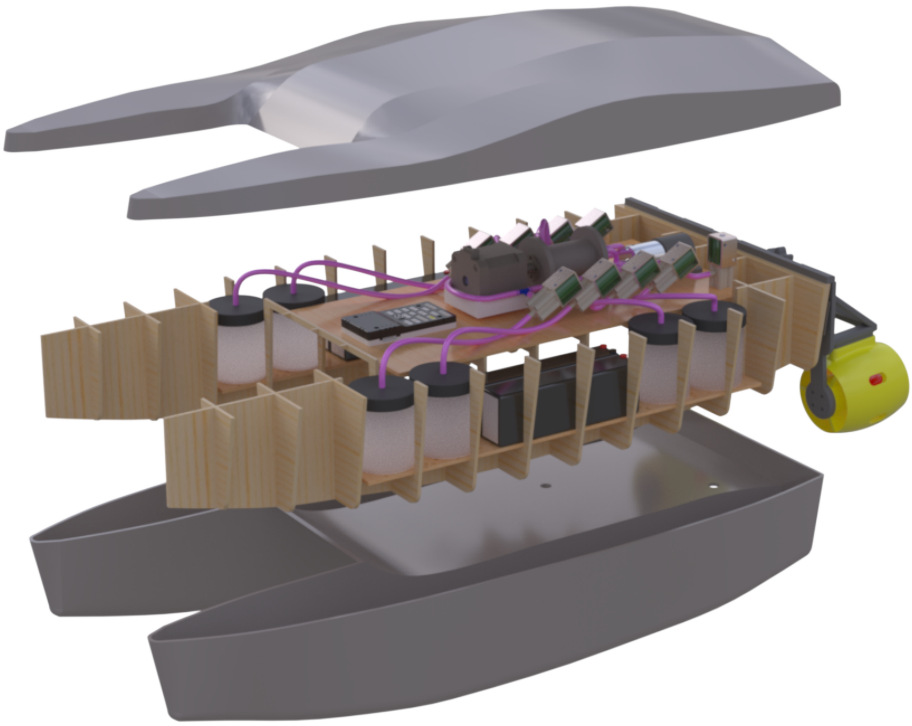
On The Feasibility of Remote-Controlled Boats for Water Sample Collection



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ENGI 3351   OVJL1

December 2024

Executive Summary

Ensuring high water quality standards is a critical responsibility for local councils, water companies, and environmental agencies. Effective water quality monitoring requires rapid and accurate sample collection from various locations and depths. Traditional sampling methods, which involve manually visiting sites to collect samples, are labour-intensive, time-consuming, and operationally inefficient. This report explores the feasibility of using boats as a modernised approach to water sampling at various depths. The proposed solution for this project is a remote-controlled boat with a catamaran hull powered by twin outboard motors designed for manoeuvrability and stability. The sample collection system consists of a weighted pipe on a winch and the sample storage system is a pump-valve array. These design decisions were influenced by engineering mathematics with a focus on sustainability. The projected break-even point will be after 25 unit sales and with £46,000 net profit after 50 sales. This report covers the project's background, scope, and objectives. Initial design concepts are proposed and analysed. A proposed solution is chosen, and the future schedule for the project is presented. This innovative approach to water quality monitoring has the potential to enable rapid and precise sampling, paving the way for pollution mapping and sustainable water resource management.

Contents

1 Background and Project Scope (JM)

Water companies, environmental agencies, local councils and other organisations are obliged to maintain high water quality. Conventional water sampling methods often involve manual sampling by hand. This is labour intensive, costly, and constrained by limited by accessibility to remote or hazardous locations [1]. This project aims to streamline the water sampling process to enhance environmental monitoring practices. The scope of this project is to design and prototype a remote-controlled boat for water sampling at various depths; allowing organisations to efficiently analyse samples in existing laboratories.

Although on-board testing and analysis were considered; a full lab analysis is more accurate and would allow for more samples to be collected [2]. Thus, sample analysis is out of scope for this project. Also out of scope are collections of riverbed sludge samples, and commercial deployment strategies. This project assumes that organisations already possess the required infrastructure for sample analysis; and thus on-board analysis is not considered.

To perform effective water sampling, samples must have representativeness and integrity. To acquire representativeness, vast quantities of samples must be collected, with each sample having sufficient volume as to be properly analysed. As with any statistical sampling, the larger the sample size, the more accurate the conclusions about the population [3]. Furthermore, the majority of errors found in water analysis laboratories stem from incorrect sampling procedures [1]; contamination control must be in place to maintain sample integrity.

Whilst similar products are on the market, those that use drone technology are limited by battery life, maximum payload, and harsh legislation compliance; making them unfeasible [4]. Current solutions that utilise boat technology lack efficiency and high prices make them inaccessible to the general market [5]. **Fundamentally, the current solutions do not address the main issues of representativeness and integrity.** The design proposed in this report solves these issues by creating an affordable vessel that can operate effectively in harsh environments while sampling reliably at various depths. This report aims to comment on the feasibility of such a project while making informed design choices based on sustainability and engineering calculations.

This project will comply with all relevant **legislation**. Key documents include ISO 9000 - Quality Management Systems; ISO 18131 – Ships and Marine Technology; ISO 20400 - Sustainable Procurement; ISO 14000 - Environmental Management.

The goal for this project is to develop a remote-controlled boat to collect water samples for laboratory analysis. The boat will be capable of conducting autonomous routine inspections, collecting water samples, and providing real-time feedback to maintenance teams. The team of engineers will collaborate across many engineering disciplines to design the boat, navigation systems, and water sampling components. Leveraging existing technology, research, and communication with experts in their field will enable the creation of a sustainable, feasible, and cost-effective solution for collecting water samples.

The proposed **project schedule** following the release of this feasibility report is for a progress presentation to be delivered to interested stakeholders on 25th February 2025, and subsequently the release of a final design report, initial prototype, and technical & marketing video on 9th June 2025.

2 Market Analysis and Business Case (OM BW)

To enhance the decision-making process, an analysis of the internal, near and far business environments is important. The internal environment focuses on the **operational strengths and weaknesses** and stakeholder involvement. The near environment includes the immediate market landscape, competitive forces, and customer behaviours. The far environment examines broader long term trends, such as regulatory changes and the socio-economic landscape.

2.1 Near Environment (OM)

Porter's Five Forces is a framework to identify the competitive forces in an industry; and analyse the near environment. For this project, the key factors are presented below in Table 1 [6].

Table 1: Porter's Five Forces

Force Name	Key Factors	Impact Level
Threat of New Entrants	Technical expertise needed in vessel design and water sampling. Increased focus on sustainability and water quality may attract new entrants.	Low
Competitors	Existing Competitors provide water sampling technologies, opportunities for differentiation with superior technology, autonomy and eco friendliness. Local Competitors have the advantage of established relationships.	Moderate
Power of Suppliers	Many components are high volume and have many suppliers.	Low
Power of Customers	Buyers operating under budget constraints. Increasing regulatory pressure on water quality monitoring gives buyers more influence.	High
Substitutes	Drones equipped with sampling tools or low cost portable devices. Substitutes may be less effective in large scale or deep water environments	Moderate to High

Strategies can be implemented to address the **Power of Customers** impact. Creating features that are hard for competitors to replicate reduces direct alternatives while switching costs away from the product increases customer retention. Broadening the client base can reduce dependency on large, powerful buyers. The risk of customers choosing alternatives can be addressed by ensuring the differentiation of the product.

2.2 Far Environment (BW)

To gain an high level understanding of the problem space the **PESTLE** analysis tool is utilised in Table 2. This framework analyses factors external to the project which can impact strategy and influence business decisions.

Table 2: PESTLE Analysis for Remote-Controlled Boat for Water Sampling

Political	Incentives for water sampling from the council and wider government.
Economical	Focus on cost-effective automated solutions could drive demand from stakeholders. Rising labour costs drive up the value of automation. Funding opportunities from national water suppliers.
Social	Reduce risk to current operators by providing automated solutions. National focus on water quality (especially around beaches) drives customer interest. Growing societal awareness of environmental issues will encourage agencies and institutions to adopt this solution.
Technological	Advancements in autonomous navigation and sensor technology enable the development of cutting-edge solutions. Complexity in combining software, hardware, and environmental adaptability.
Legal	Work within regulatory frameworks and comply with environmental laws for operating in natural environments. Liability concerns should anything fail, recovery of the lost vessel to prevent environmental damage.
Environmental	Increasing global focus on climate change and water quality monitoring provides a strong market opportunity. Dependence on specific materials and components from across the world.

PESTLE allows for easier understanding of where the product is impacted by far environment influences. A key point for this product is the **national focus on cutting water pollution** [7], as institutions push to better water quality for the general public.

2.3 Stakeholder Analysis (OM)

Table 3: Stakeholder Analysis

Type	Example	Involvement	Mendelow Matrix			Priority
			Interest level	Influence level	Action	
Competitor	DJI, Hydro Terra, Ocean Alpha	Provide technology used in water sampling.	Low	Low	Monitor	Peripheral
Customer	Northumbrian Water, Research Institutions	Providers of water services and research entities that could be directly affected by project outcomes.	High	High	Manage Closely	Key
Environmental Group	Natural England, Rivers Trust WWF, RSPCA	Regulate and monitor the natural environment and adovcate for sustainabilty.	High	Low	Keep Informed	Important
Indirect	Tourism Operators, Local Communities, Fishermen	Impacted by water and environmental changes, dependant on local ecosystems.	High	Low	Keep Informed	Peripheral
Internal	OV, JL, Team Members, Durham Engineering Dept	Directly involved in daily operations and project execution. Provides technical support & resources.	High	High	Manage Closely	Key
Regulatory Body	Drinking Water Inspectorate, Environment Agency (UK), IEEE, UK Govt	Ensures safety and quality standards for drinking water. Provide technical standards for engineering. Sets national policies that impact the project.	Low	High	Keep Satisfied	Important
Supplier	Ardupilot, Pixhawk, Parts Manufacturers	Supplies software, hardware and necessary products for project exectution.	Low	Low	Monitor	Important

Stakeholders can be analysed using the Mendelow matrix to create an appropriate monitoring and action plan, see Table 3 [8]. If the project were in a commercial environment, **Communication** is important. Stakeholders with a **Keep Informed** status would receive regular email newsletters. Stakeholders with a **Keep Satisfied** status would have access to project details to ensure regulatory compliance. Those with a **Monitor Closely** status would meet with internal stakeholders to track progress three times a week. Stakeholders with **Key** priority are considered critical to the success of the project.

2.4 Summary of Viability (BW OM)

The **ANSOFF** matrix is utilised to determine the risk associated with different growth strategies. It is applied to distinguished between existing and new, products and markets. Performing this analysis highlights that products such as Oceanalphas's ESM30 [9] provide a similar concept. The autonomous sampling market also exists, Northumbrian Water tested water quality drone flights in January 2024 [10]. Therefore the ANSOFF matrix determines that the initiative is **"low risk"**.

As this is a **"Market Penetration"** initiative, the product needs to be distinguished from its competitors with distinct capabilities forming the USP. By accommodating 8 samples to be taken in a single mission (**URS7**) this supersedes the closest competitor's 4 samples. Furthermore, the ability to take accurate discrete samples at a range of depths (**URS8**) is novel to this product and will appeal to agencies monitoring water quality.

It can therefore be concluded that the product is viable for market entry. With a strong USP, increased national focus on water quality and keen stakeholder interest, the project is well positioned to exploit the market gap.

3 Project Environment and Requirements (BW JM)

3.1 Operating Environment (BW JM)

Data analysis on potential operating conditions is necessary to fully define the project requirements. Publicly available data [11, 12] is aggregated, comparing the **flow speed and river level** for a range of small (River Wear, Durham) to large (River Thames, London). This analysis gives valuable insight informing the User Requirement Specification, for example the aim is to operate in 90% of conditions present on a given river so dashed lines are added to Figures 1 and 2 to illustrate this bound. It is seen there are **diminishing returns in the need to to operate in speeds greater than 2m/s** for the vast majority of conditions in multiple rivers. Conversely the variation in river depth is greater; hence a larger sampling depth is required to satisfy this condition in most rivers.

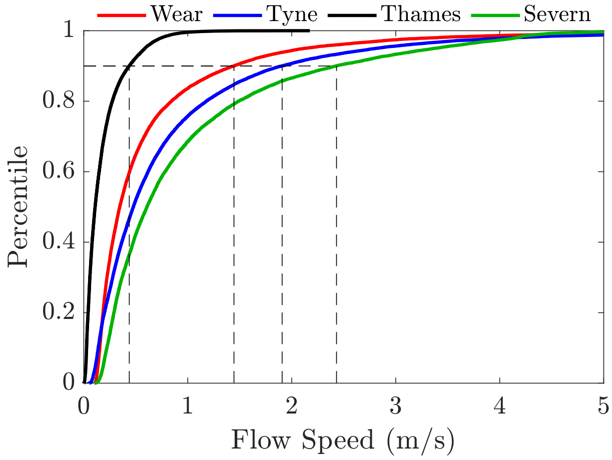

Figure 1: Flow speeds as percentile plot

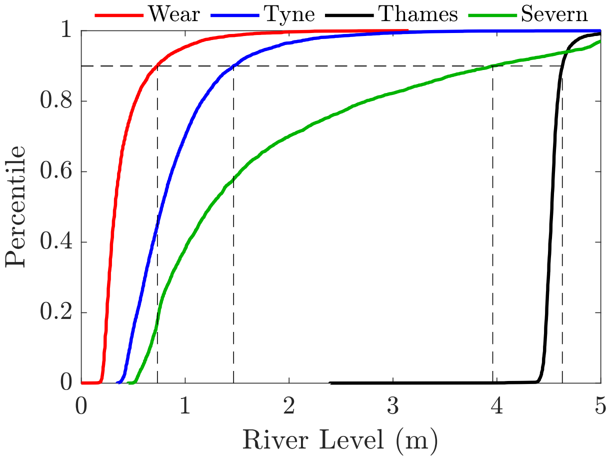

Figure 2: River depth as percentile plot

3.2 User Requirement Specification (JM)

With the scope of the project fully defined, and sufficient analysis of potential operating conditions; a User Requirement Specification is required to create quantifiable objectives that the final design Must or Should achieve. This is displayed below in Table 4 and defines the project requirements.

Table 4: User Requirement Specification

Reference	Requirement	Priority
URS1	Ability to sail steadily and operate effectively in water with a minimum depth of 0.20m, flow velocity 1.4 m/s, and waves of height 0.20m.	Must
URS2	Minimum 2 hours battery life	Must
URS3	IP rating of 67 and operational temperatures 0°C-40°C	Must
URS4	Ability to operate 1km away from the controller.	Must
URS5	Maximum manufacture cost £2000 per unit	Must
URS6	Ability to travel at boat speed of 3m/s	Must
URS7	Storage capacity for a minimum of eight 100ml non-contaminated samples per trip and the ability to identify where each sample is from	Must
URS8	Ability to sample at different depths with maximum sample depth at least 5m	Must
URS9	Sensors and pathfinding to detect and avoid obstacles within a 10m range	Should
URS10	Ability to perform completely autonomous sampling missions	Should

4 Initial Design Development (ALL)

With the project scope and user requirement specification defined, initial ideas can be generated to meet these requirements. To solve the overall problem the project is abstracted into four distinct systems which when integrated together perform effectively to solve the problem. These systems are: **Sampling Collection System**, required to extract water at different depths and deliver a sample to the boat. **Propulsion Design** comparing solutions for powering the movement of the boat. **Hull Design**, where the pros and cons of different configurations are analysed. Finally the **Sample Distribution System**, where systems to distribute samples into separate containers are compared. **Design decision matrices (DDMs)** are used to quantify the choice of solution for each system against a range of criteria with weighting and scoring informed by the URS and engineering calculations.

4.1 Hull Design (ST BW)

Hull design is a compromise in the limitation of both hydrodynamic and windage drag as well as ease of implementing the proposed systems and manufacture.

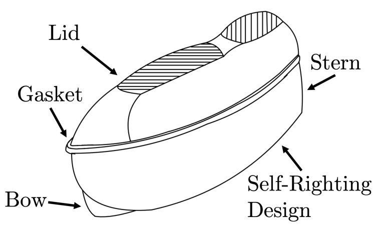

Figure 3: Monohull

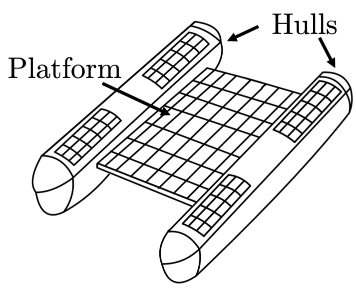

Figure 4: Pontoon

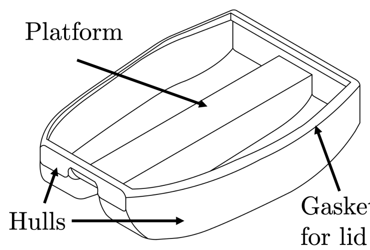

Figure 5: Hybrid Catamaran

The first and most widespread hull concept is a **Monohull** illustrated in Figure 3. The singular sealed hull would be designed to be self righting and a single pointed bow prevents entanglement with debris found on the river. However, the monohull is more susceptible to capsizes as its metacentric height is lower than that of a similarly size catamaran [13], hence it's stability is scored lower within the DDM, Table 5. With no platform to launch a sample collection device and less available space for batteries and electrical components, the ease of system integration is another criterion in which the monohull performed poorly.

Another simplistic design is the **Pontoon** illustrated in Figure 4, here two parallel hulls have a platform suspended between them. The addition of a second hull, increasing the overall beam, improves the stability and adds the option of steering via two motors negating the need for a rudder and hence improving manoeuvrability. The simplicity provides an easy manufacturing process and the platform is a clear location to place any systems for sampling collection and distribution. The blunt bows and the space between the hulls does allow for potential entanglement with sticks and other debris.

Finally, a **Hybrid Catamaran** design, illustrated in Figure 5, between the two extremes is developed. This takes the best in water tightness, and entanglement mitigation from the monohull and combines it with the space for system integration and stability of a pontoon. Hence this option with more streamlined hulls while reducing the gap between them scores highly in all specified criteria shown in Table 5.

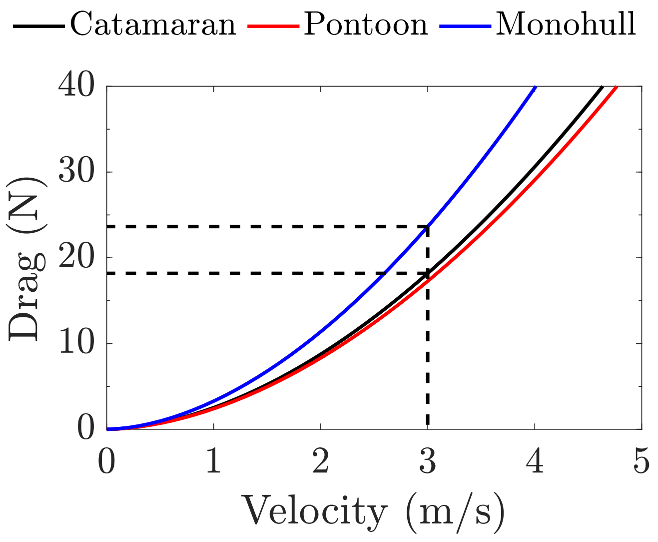

Figure 6: Total Drag Force for Various Hull Designs

To compare the drag and therefore the kinematic efficiencies of the Monohull, Catamaran and Pontoon designs for the hull, the geometries are compared at 3m/s boat speed in stationary water; the maximum boat speed defined from (**URS6**). Resistive forces on the hull are dominated by water friction and wave-making drag, with air friction negligible [14]. This is modelled by Equations (1)[15]. Wave-making drag is more complex and must be found experimentally through the use of flow rate sensors, accelerometers and motor power data. However, it can be modelled as roughly half of the total drag, so an estimation of total drag is computed by doubling the hydrodynamic friction drag [16].

$$D_{aerofriction} = \frac{1}{2}C_{d(aero)}\rho_{air}A_{aero}v_{wind}^2 \qquad D_{hydrofriction} = \frac{1}{2}C_f\rho_{water}A_{wet}v^2 \qquad C_f = \frac{0.075}{(\log_{10}(Re) - 2)^2} \tag{1}$$

Using this analysis, the **Monohull design has a** 30.6% **increased total drag force compared to the Catamaran design**, as illustrated in Figure 6. This is due to the larger wetted surface area of the boat, as the monohull design requires more submerged displacement and so more wetted surface area to be stable. These drag computations are reflected in the DDM scores.

Table 5: Hull Design Decision Matrix

Criteria	**Weight**	**Monohull**	**Pontoon**	**Hybrid Catamaran**
Stability	0.1	3	3	4
Self Righting Capability	0.15	4	0	0
Ease of System Integration	0.2	2	4	5
Entanglement Mitigation	0.15	4	2	3
Manuverability	0.1	2	3	4
Ease of Manufacture	0.2	2	5	4
Drag Consideration	0.1	2	5	4
Score	1.0	2.7	3.2	**3.45**

Hence, **Hybrid Catamaran** is chosen as the design due to its superior system integration and greater stability.

4.2 Propulsion Design (ST)

The propulsion method is key to delivering many of the User Requirement Specifications. **URS1** and **URS6** rely on the boat having sufficient propulsion power to overcome both drag and resistive river flow. **URS2** and **URS4** specify the boat must have sufficient kinematic efficiency to operate for the length of time and to travel the distances needed to usefully gather water samples.

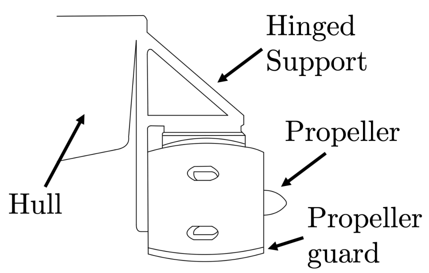

Figure 7: Outboard

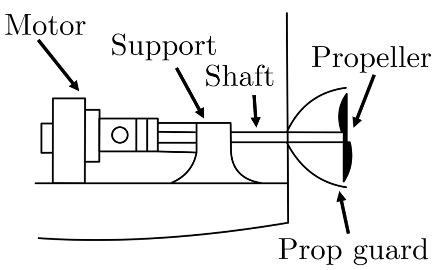

Figure 8: Inboard

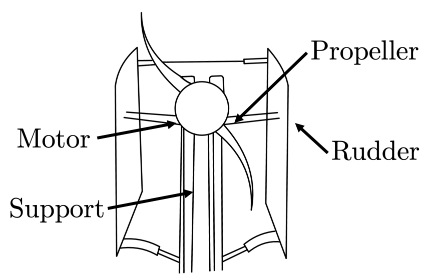

Figure 9: Air Propeller

The **Outboard Motor**, illustrated in Figure 7, performs well against all criteria. Specifically in "Efficiency and Thrust"; due to the use of brushless motors which have efficiencies of up to 75-80% at typical cruising speeds, and the hydrodynamically optimised motor and propeller pairings [17]. Outboard motors are inherently waterproof; the only waterproofing concern is wiring and sealing the ESC's into the boat. This produces a high "Water Mitigation" score in the Design Decision Matrix (Table 6). A more complex design and therefore higher cost negatively impacts this score. However, this results in a high ease of installation score, since the system is already assembled and calibrated. Entanglement remains a concern, since the propeller guard cannot protect against all types of debris.

To better understand the suitability of an outboard motor, the thrust, efficiency, and battery performance are analysed. This analysis shows that two motors on the market [18] with thrust of approximately 125N and 1.5 kW of power can achieve a a maximum boat speed of 8 m/s and optimal efficiency at 1.06 m/s, with enough thrust to reach the top speed and operate in the river conditions in **URS 1** and **URS 6**. The performance of such a pairing of outboard motors is illustrated in Figure 10. Manoeuvrability and turning is achieved via asymmetric thrust signals to the two motors to create a turning moment.

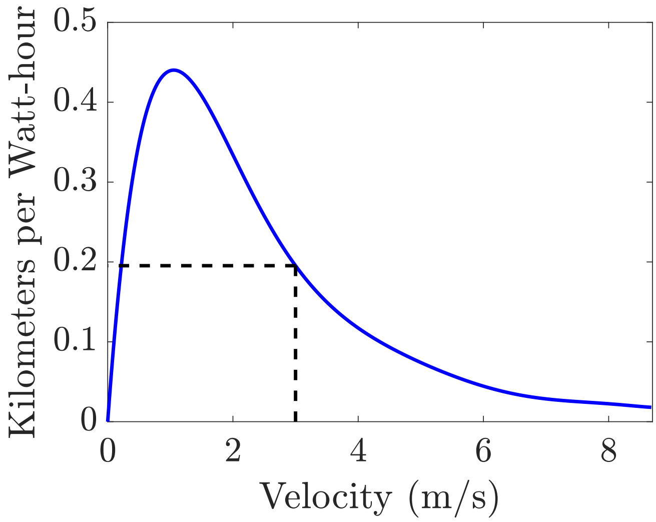

Figure 10: Efficiency curve of hull, motor combination against velocity. Lines drawn at 3 m/s to represent typical velocity

The **Inboard Motor** illustrated in Figure 8 also has a high efficiency of 75-80% and thrust,[17], again due to the use of brushless motors. However, it suffers from less hydrodynamic design and the need for experimental analysis to optimise the efficiency. This design does requires parts with less complexity, resulting in a cheaper cost to produce. However, since both wires and the the propeller shaft need to be waterproofed, the inboard motor is more difficult to make watertight. Water ingress is a significant concern due to the high rotational speed of the shaft creating localised areas of high pressure, increasing the likelihood of ingress. Inboard motors have similar issues of entanglement as outboard motors, but suffer in ease of installation due to the complexity of waterproofing moving parts through the hull.

The **Air Propeller** illustrated in Figure 9 can be designed to achieve high efficiency and thrust of approximately 80% [19], again due to the use of brushless motors. However, due to the size of propeller and mounting height of motor needed to generate the requisite thrust, the design becomes vulnerable to hull instability. The required propeller size is also expensive, but does not require any waterproofing hardware as it operates above the water and water mitigation is only required against splashes, and so it scores highly. In the same way, entanglement is not a concern. The single motor design requires a rudder, increasing complexity of installation.

Finally a **Water Jet** design, despite having a theoretically higher maximum efficiency than propellers, at typical cruising speeds of 3.0m/s and below, water jet efficiency is poor (30%)[20]. As it is a novel technology, the complexity is also very high, subsequently increasing cost, making the installation difficult and resulting in the penalisation. Furthermore, water mitigation and entanglement is challenging due to the high pressures and velocities created by the nozzle and geometry. Finally, it scores highly on manoeuvrability; however, this quality has a low weighting for this use case.

Table 6: Propulsion Design Decision Matrix

Criteria	**Weight**	**Outboard**	**Internal**	**Water Jet**	**Air Prop**
Efficiency and Thrust	0.3	4	4	2	4
Cost	0.25	3	4	1	3
Water Mitigation	0.2	4	2	3	4
Manoeuvrability	0.1	4	4	5	1
Entanglement	0.1	3	3	2	4
Ease of Installation	0.05	5	2	3	3
Score	1	**3.6**	3.4	2.3	3.4

The **Outboard Motor** is therefore chosen after evaluating the DDM.

4.3 Sampling Collection System (BW)

The sample collection system is a major design component, this system is required to submerge precisely to a variety of given depths to retrieve a sample of water (specified in **URS8**). Four major solutions are compared below.

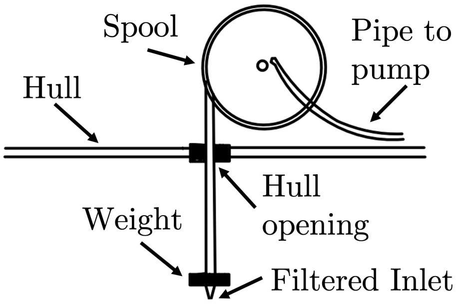

Figure 11: Weighted Pipe

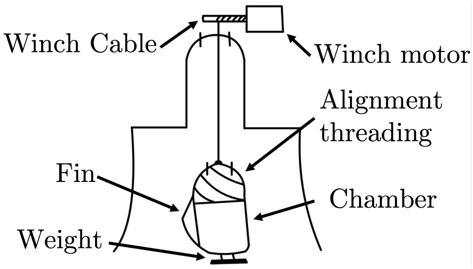

Figure 12: Sub Chamber

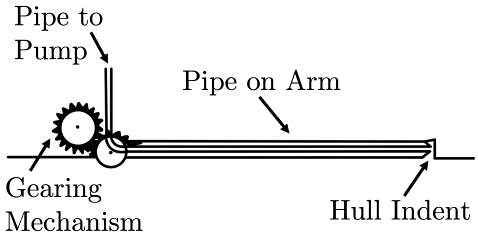

Figure 13: Retractable Arm

The **Weighted Pipe** concept, illustrated in Figure 11, features a pipe wound around a spool controlled by a stepper motor for precise depth sampling. A mass is located at the inlet of the pipe to limit sway when submerged and increase the rate of submersion. The design is evaluated in Table 9, where it is found to be easy to implement and maintain, with rapid sampling times due to the reduced number of moving parts. However, the design has limitations in scalability. The maximum sampling depth is constrained by the pump head chosen and the size of the spool. The time taken and maximum depth can be calculated assuming the following spool geometry: $d_{internal} = 30mm$, $d_{outer} = 60mm$, $d_{mean} = \frac{60-30}{2} + 30 = 45mm$, $L_{hub} = 60mm$.

$$\text{Depth}_{\text{pipe}} = \frac{\pi L d_m (d_o - d_i)}{2d_p^2} = 3.39m \qquad t_{\text{pipe}} = t_{toBoat} + t_{toContainer} = \frac{L_{pipe} \times A_{pipe}}{\dot{V}} + \frac{V_{container}}{\dot{V}} = 14.22s \tag{2}$$

The **Submersible Chamber** concept, illustrated in Figure 12, involves a watertight container mounted on a winch within the hull. The chamber is weighted to ensure it sinks. It has a remotely operated valve that opens once the stepper motor lowers the chamber to the specified depth. After the sample is collected and the chamber is full, as indicated by a level sensor, the valve closes and the chamber is returned to the surface. The chamber also has a threaded top that aligns with the docking point, allowing the valves to transfer the sample into the distribution system. This design is more complex, requiring waterproofing for sensitive solenoid valves and wiring, as well as precise alignment to return the chamber onboard. However, it is scalable to much greater depths because it does not require a pump, earning high marks in the scalability criterion of the DDM, as shown in Table 8. The maximum depth and time to collect a sample are quantified using the Darcy-Weisbach equation where Q=$A\sqrt{2gh}\ m^3/s$ [21]. The time taken to flood a 100ml cylindrical chamber with valve area of 2.83×10^{-3} is calculated and this is then summed with the time taken to return the chamber to the boat using stepper motor, with $\omega = 50rpm$, before the sample is transferred into a container on the boat.

$$\text{Depth}_{\text{chamber}} = 84.8m \qquad t_{chamber} = t_{flood} + t_{toBoat} + t_{pump} = \frac{V_{Chamber}}{Q} + \frac{2 \times \text{depth}}{d_m \omega} + \frac{V_{sample}}{\dot{V}} = 0.8 + 8.49 + 10 = 19.29s \tag{3}$$

Finally, the **Retractable Arm**, illustrated in Figure 13, is considered for sample collection. This design comprises a hinged pipe stored at the bottom of the hull. The system is operated by gears to angle the pipe, allowing for sampling at different depths. While this design is easy to implement and maintain, its scalability is a major drawback. The maximum depth is limited by the length of the pipe and, consequently the length of the hull. The maximum depth and time to collect a sample are quantified assuming a typical RC boat of 1.2 m in length, which limits the retractable arm to approximately 1m. This depth is displayed as a comparison to the other concepts in Table 7, therefore resulting in a low score against the scalability criteria in Table 8.

Table 7: Comparison of Parameters for Different Methods

Collection Method	Maximum Depth (m)	Sample Time (s)
Pipe	3.39	14.22
Chamber	84.8	19.29
Retractable Arm	1	11.96

$$\text{Depth}_{\text{Arm}} = 1m \qquad t_{arm} = \frac{\pi(\frac{D}{2})^2}{\dot{V}} = 11.96s \tag{4}$$

The results displayed in Table 7 also compare the maximum depth of sampling with the sampling speed for a depth of 1m. The **Submersible Chamber** has significant maximum depth, but slow sampling speed which causes problems for energy consumption and operation in fast river flow. The **Retractable Arm** has fast sampling speed but very shallow maximum sampling depth. These two concepts therefore both have significant drawbacks limiting their scoring in the DDM below.

Table 8: Sampling Collection System Design Decision Matrix

Criteria	**Weight**	**Weighted Pipe**	**Sub Chamber**	**Retractable Arm**
Ease of Implementation	0.25	4	2	5
Accuracy of Sampling	0.3	4	4	3
Maintenance Requirements	0.05	5	2	5
Cost	0.1	4	3	5
Depth	0.2	3	5	1
Sampling Speed	0.1	5	2	5
Score	1	**3.95**	3.3	3.6

Hence, the **Weighted Pipe** is the chosen solution for the sample collection system. This is due to the superior all round score performing in all criteria areas where other concepts fail to meet some criterion, reducing their score.

4.4 Sample Distribution System (OM)

With the sample collection system bringing water to the surface, there needs to be a system to distribute water between the eight samples as specified in **URS7**. Three solutions are proposed: a leadscrew method, a series of solenoid valves and a rotational selection method.

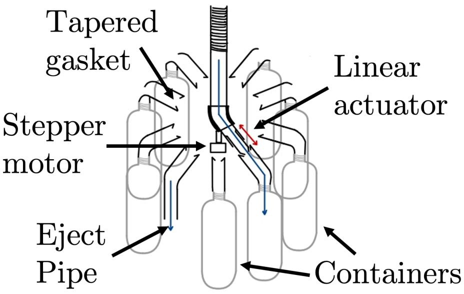

Figure 14: Rotational Selector

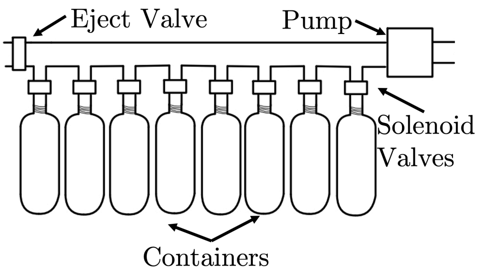

Figure 15: Valve Array

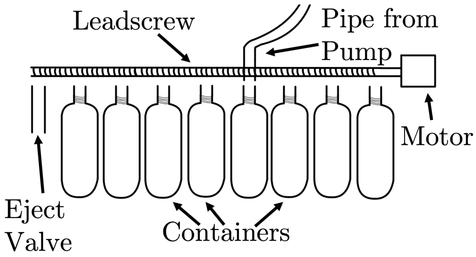

Figure 16: Leadscrew Selector

The **Rotational Selector**, illustrated in Figure 14, uses a stepper motor to rotate an L-shaped pipe to select each container. A linear actuator extends the male end of the fitting to form a seal using a tapered rubber gasket. The DDM for the Sample Distribution system is presented in Table 9. For this design, due to the complication of keeping the moving parts involved watertight, reliability and ease of integration score lowly. However, because the selector is separated from the containers it is easy to flush the system so it scores highly in contamination mitigation.

The **Valve Array**, illustrated in Figure 15, uses a self-priming pump to deliver water along a main concourse, with solenoid valves lining the route that can be opened to fill each container. With the relative simplicity of the system and limited moving parts involved it scores highly in the DDM on reliability, cost, ease of integration and scalability. However, due to water for each sample running through the same pipe and the potential for contamination is high.

The **Leadscrew Selector**, illustrated in Figure 16, uses a motor driving a leadscrew to distribute between containers. The cost of the parts is relatively low and integration is easy. However, with the requirement of a great deal of travel in one direction, space becomes limited and the ability to scale up is poor. Additionally, each of the containers is left open to the surroundings increasing the chance of contamination of the samples. This reasoning is reflected in the quantification of results in the DDM below.

Table 9: Sample Distribution System Design Decision Matrix

Criteria	**Weight**	**Turntable**	**Valve Array**	**Lead Screw**
Reliability	0.2	2	4	3
Ease of Integration	0.2	2	5	4
Cost	0.1	3	5	4
Scalability	0.2	1	5	3
Contamination	0.3	5	2	2
Score	1	2.8	**4.2**	3

Hence, the **Valve Array** is shown to be the natural choice, consistently outscoring the other options in key criteria.

4.5 Concept Selection (SR)

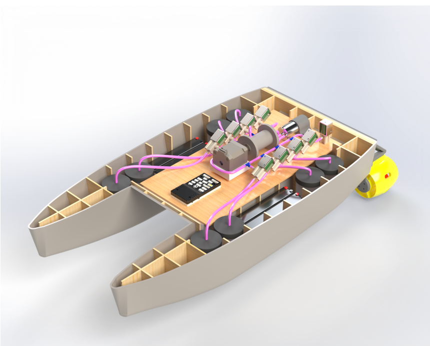

Figure 17: Integrated Design

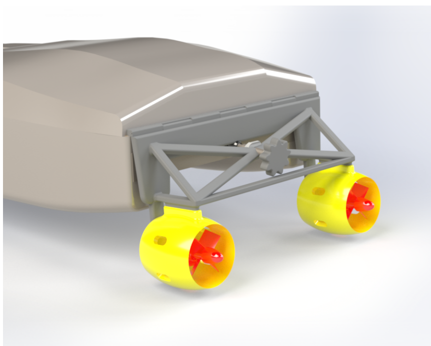

Figure 18: Propulsion System

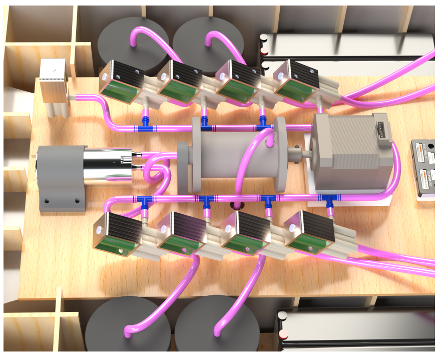

Figure 19: Sample Collection System

After comparing and evaluating the effectiveness of solutions for the four systems, the chosen methods for each system are combined in the final design, selected from the concept which scored the highest in the respective design decision matrices.

Therefore, the proposed solution, illustrated in Figures 17 to 19, will have a hybrid catamaran-style hull with outboard motors, a weighted pipe water collection system, and a valve array distribution system.

5 Proposed Solution (SR JM)

5.1 Outline of Solution (SR)

The base of the design is the **"hybrid hull"** illustrated in Figure 20. The shape has been modified to maximise efficiency in the water and ensure that the hull provides enough buoyancy to support the weight of the components and hull itself. Also considered is how the components must fit into the hull and the effects this has on the shape of the final hybrid hull design.

The lid, illustrated in Figure 21, is fully sealed via a rubber gasket with fastenings between the lid and hull to prevent any water ingress; but is removable to allow for battery change, sample removal and modifications to the electronic components inside. Further refinements can be made at a latter stage of the design such that samples and batteries can be taken out independently of the lid.

To strengthen the hull and add mounting points for the components inside, ribs and stringers form a support structure which is moulded around the shape of the hull, they are fastened to the hull with epoxy. The transom (on the stern) forms a mounting point for the propulsion system while the base of the hull and on top of the "bridge" of the hull there is support for the electronic and water sample system components, illustrated in Figure 22.

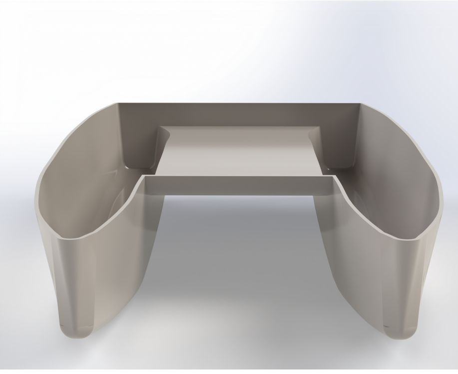

Figure 20: The Hybrid Hull Design

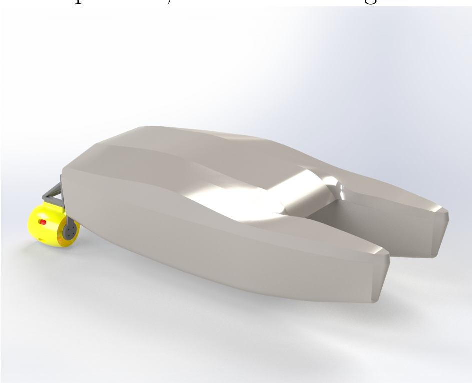

Figure 21: The Hull With Lid

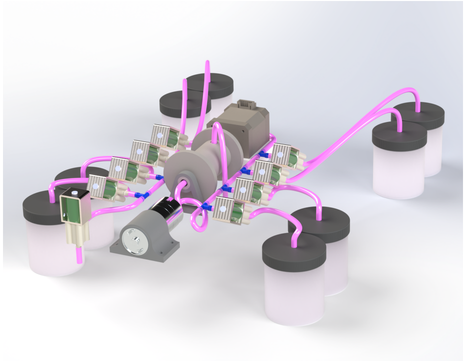

Figure 22: Sample Collection and Distribution Systems

The boat is propelled by two brushless underwater outboard thrusters that are mounted on the back of the boat to the transom on a hinged mechanism, illustrated in Figure 18. This mechanism has a lead screw adjustment system which allows the pitch angle of the motors to be adjusted by hand to maximise the efficiency of propulsion and correct how the boat sits in the water.

To prove these thrusters meet the requirements set out in the URS, the power consumption and range has been computed. With an 80Wh battery, 15W continuous passive electronics usage, an efficiency of 0.2km/kWh at 3.0m/s (Figure 10), and a total distance of 3km, the run-time can be estimated.

$$E_{motor} = \frac{Distance}{Efficiency_{(3.0m/s)}} = \frac{3.0}{0.2} = 15.0Wh \quad E_{total} - E_{motor} = 80.0 - 15.0 = 65.0Wh \quad t = \frac{E_{total} - E_{motor}}{P_{passive}} = \frac{65}{15} = 3.33 \text{ hrs}$$

Therefore, the boat can operate for well over the 2 hours needed to satisfy **URS2**, and satisfy the range needed by **URS4**, which proves the feasibility of the propulsion system. Additionally, the range could be extended by moving at a more efficient speed, such as 1m/s or using additional batteries in parallel, assuming that excess weight does not cause a buoyancy problem.

The outboards are controlled by two ESC's connected to the Pixhawk flight computer. To turn the boat, thrusters work in opposing directions, creating a turning moment. A 3D printed spool is controlled by a stepper motor which moves by set rotations to achieve different sample depths. The pipe has a mass on the bottom to ensure it sinks and remains as vertical as possible. The outlet of the spool is connected to a diaphragm pump via a rotary fitting forcing water from the pipe to the distribution network.

The distribution system consists of solenoid valves controlled by PWM signals, directing flow to each sample container and to an exhaust pipe for system flushing. Initially, as the pipe lowers into the water, the eject valve is open to flush the system out for a period of time, ensuring the sample is not contaminated. At the desired depth the eject valve closes and a collection container's valve opens, filling the container until the level sensor in the container activates, switching off the pump.

5.2 Software (JM)

The external Ground Control Station (GCS) utilises the **Ardupilot Rover** firmware to control the boat. It is necessary to integrate Lua scripting alongside Ardupilot for the advanced component control that this project requires. Lua scripting allows the boat operator to perform simple and efficient water sampling. By selecting the locations and depths of required samples before launch, the boat can **autonomously** travel to the sample destination and collect a sample. Or, if sampling is performed manually, the operator can pilot the boat to the correct location, enter the selected sample depth into the GCS, and the combination of Lua and Ardupilot retrieves and stores the sample. Sample storage is also managed via Lua. Each sample collected is stored in a specific container. The container number, time, location, and depth of sample is stored locally as a JSON file. This gives the operator all the required sample information before it is taken for testing. Lua scripting is also utilised to create a log of all missions. This log stores data such as operator inputs, telemetry data, and software executed; allowing for troubleshooting and mission analysis.

5.3 Cost and Budget (JM EAA)

The total budget allocated for the design of this project is **£39,000**. This equates to one year of research, design, and prototyping before the product can be brought to market. A breakdown of these costs is displayed in Figure 23. Product development and research costs are the engineer's salaries based at £15 per hour for 400 hours, and prototype costs are £1,500 for materials and equipment. Production costs per unit are £1,700 and can be seen in Figure 24. The largest expense is £800 on direct labour at £16 per hour for 50 hours. The cost of raw materials is £700, accounting for bulk discounts from suppliers. £100 per unit will be spent on administrative costs such as sales, marketing, and indirect labour. A further £100 per unit will be spent on indirect overhead costs such as heating, electricity, manufacturing equipment, and any miscellaneous expenses. To determine the selling price, the break-even point is set at 25 unit sales. This results in a profit margin of 50% and thus a selling price of £3,400. After 50 sales, total revenue will be £170,000 with £46,000 net profit. The predicted revenue forecast is illustrated in Figure 25.

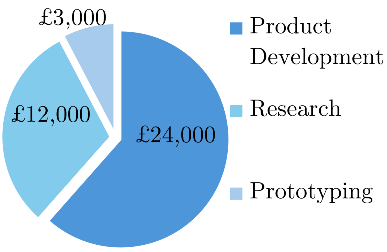

Figure 23: Total Design Costs

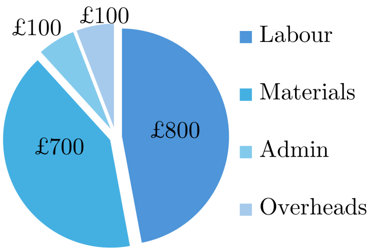

Figure 24: Unit Production Cost

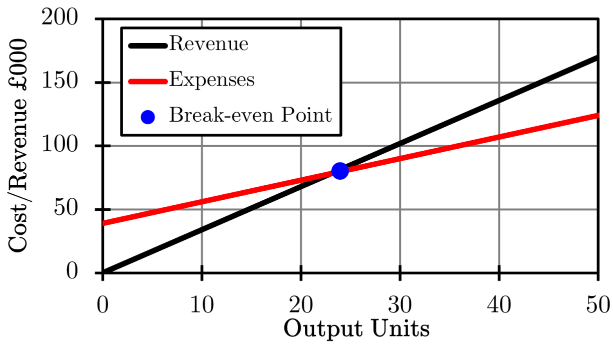

Figure 25: Revenue Forecast Per Unit

6 Design for Sustainability (EAA JM)

Sustainability must be a key focus throughout the design process to ensure the product meets all user requirements while remaining environmentally, economically, and socially responsible. This section examines how these three dimensions of sustainability have influenced the design.

To better understand the environmental impact of the proposed design, an investigation of the materials used is conducted using **"sluicebox.ai"**. This tool analyses the carbon dioxide emitted (CO_2e) in the manufacturing process.

Switching a materially stronger carbon fibre to injection-moulded glass-fibre-reinforced plastic (GFRP) reduces the CO_2 impact by 116 kg CO_2e per unit [22]. GFRP provides an optimal balance between functionality and sustainability. The choice of batteries is also influenced with sustainability in mind. Using **Lithium-Ion** over Lithium-Polymer batteries reduces the carbon footprint by 103kg CO_2e per unit [22]. Furthermore, reusing batteries across products enhances recyclability.

The frame also raises environmental concerns, illustrated in Figure 28. In the final design, the frame uses recycled instead of standard plywood reducing the CO_2 impact by 159kg CO_2e per unit [22]. Furthermore, GFRP requires minimal support, so less material is used, further reducing the impact. To further reduce emitted CO_2 from component choices, electrical batteries are preferred over fossil-fuel-based motors; the use of adhesives is limited; and electronics have standard fittings allowing for reuse in other designs. Sluicebox also allows for analysis of the electricity required in the manufacturing phase; totalling 48kg CO_2e per unit, illustrated in Figure 26 [22]. Conducting manufacturing stages in the UK will utilise the UK's green energy grid; reducing the carbon footprint by 93kg CO_2e [22].

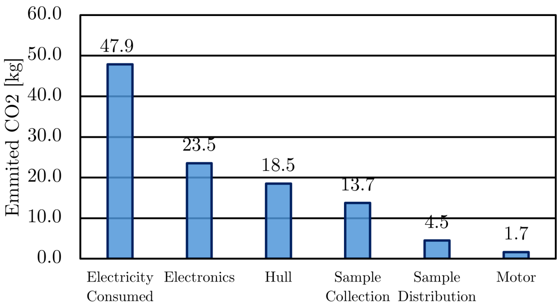

Figure 26: Breakdown of CO_2 Emitted from Production

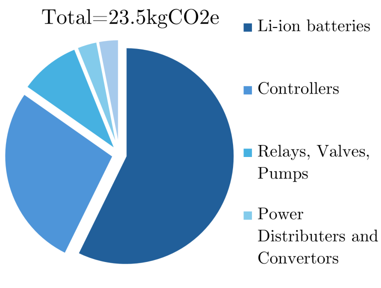

Figure 27: Breakdown of CO_2 Emitted for Electronic Components

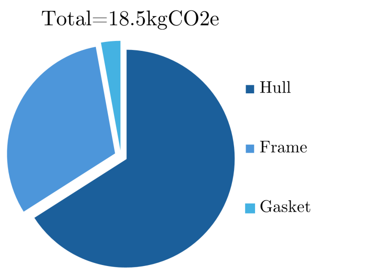

Figure 28: Breakdown of CO_2 emitted for Hull Components

Environmental sustainability not only influences the component choices in the design but also the required sampling method. A remotely-controlled boat reduces the number of trips required by a sampler. This enables samples to be taken in more remote locations while reducing time and carbon emissions, over the current manual sampling method. A remotely-controlled boat with sufficient range will significantly limit manual transportation between sampling locations via fossil-fuel-powered cars. Additionally, the low profile of the boat results in less disruption of wildlife habitats than current methods with a larger footprint.

Economic sustainability also has to be considered for a feasible project. In the manufacturing stage, British-based production will create local jobs; aiding the economy. Bulk purchasing and material optimisations allow for reduced component costs. Furthermore, a simplified and modular design facilitates scalable manufacturing and maintenance. The operational efficiency of the design reduces labour costs associated with manual sampling and extends sample reach and volume without proportional cost increases. The break-even points of 25 units and 50% profit margin ensure economic feasibility.

Social sustainability also influences many design decisions. As product designers, there is an obligation to ensure that operators remain as safe as possible. Autonomous sampling and remote-controlled operation significantly limit an operator's exposure to hazardous environments. Furthermore, safety features on the boat such as propeller guards, alongside a detailed risk assessment in Table 11, further increase operator safety. Moreover, the product's competitive pricing increases the accessibility of water sampling to smaller organisations and agencies. By increasing the efficiency and accessibility of water sampling; water resources can be better maintained. This helps wildlife and promotes environmental awareness.

To conclude, environmental, economic, and social sustainability factors influence many design decisions. Environmental sustainability influence design choices in material selection, energy efficiency, and wildlife impact. Economic sustainability influences manufacturing and component decisions. Social considerations aim to improve the safety of water sampling and make it more accessible.

7 Prototyping (SR OM JM)

To validate design decisions and further improve the product via systems testing, an initial prototype will be made. This will be a scaled down, lower fidelity model to save on cost. This section will outline the detail of the prototype manufacture but this directly reflects on how the final product will develop.

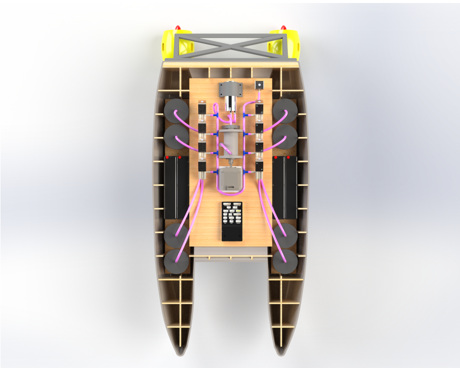

Figure 29: The Hybrid Hull Design

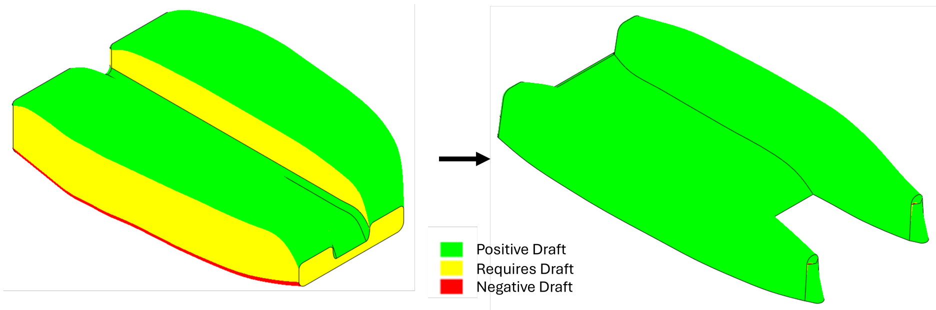

Figure 30: Draft Angles for Vacuum Forming (Initial to Final Design)

7.1 Prototype Manufacturing (SR)

At every stage of the design process manufacturing methods must be considered to maintain an efficient build process once the design in finalised.

Firstly, to manufacture the hull and lid which is 600mm long, 330mm wide at it's widest point and 130mm deep, sheets of 1.5mm High Impact Polystyrene (HIPS) will be vacuum formed around a mould. The mould for the hull and lid will be manufactured from 18mm MDF sheets which are layered and adhered with wood glue. This block will then be shaped using a CNC router which will follow the geometry set out in each of the CAD models. It is important that a 3 degree draft angle is considered in the design of the hull so that the mould can be separated when vacuum formed. Solidworks has a draft analysis tool and the changes made to accommodate this to the hull geometry between first and last iteration is illustrated in Figure 30. Because of limitations to the bed size of the CNC router and the vacuum former, the hull will be made from four moulds making four panels and these will then be joined together to form the final shape of hull. Similarly, the lid will be made in four parts and adhered after vacuum forming. 1.5mm thick HIPS sheets will be a sufficient thickness because of the supports formed by the plywood mesh.

A laser cutter will be used to cut-out the ribs, stringers and the base boards required to support components in the hull. SolidWorks will be used to compile the sketches in a drawing and this will be exported as a .dxf file to the laser cutter. The shapes will be organised as efficiently as possible to minimise wastage, then cut out of 3x400x600mm laser grade plywood sheets and adhered to form the plywood support mesh.

Table 10: Manufacture Methods for Various Parts

Part	**Hull and Lid**	**Support Ribbing**	**Outboard Motor Mount**	**Spool and Pump Holder**
Manufacture Method	Vacuum Forming	Laser Cutting	3D Printing	3D Printing
Material	HIPS	3mm Plywood	PLA	PLA

The spool to hold the pipe, the mount for the stepper motor and the holder for the pump will be 3D printed in department out of PLA. These parts have already been designed in SolidWorks, however it will be important to work out what density is required for the prototype.

The mount for the outboard motors will also be 3D printed in department. This will be hinged on the stern of the boat, fastened to the plywood transom. Adjustable pitch angles will be achieved with a screw and a knob that can be hand adjusted, moored in the stern of the boat and attached to the mount with a nut. The screw and knob will be bought in components but they will be integrated into the 3D printed propulsion mount part.

7.2 Electronics Hardware (OM JM)

A comprehensive wiring diagram, illustrated in Figure 31 is required to visualise how the various components are integrated. Two major processors are required to separate the role of the Pixhawk flight computer and the sampling system controlled by the Arduino Uno. The **Arduino** is chosen for the prototype due to its increased I/O and analogue connections. This provides a cost effective way to implement a complex system while ensuring redundancy in the build process. The independent systems do not interfere with each other in the event of an individual failure. The prototype implements four sample containers to avoid needing shift registers to increase I/O pins.

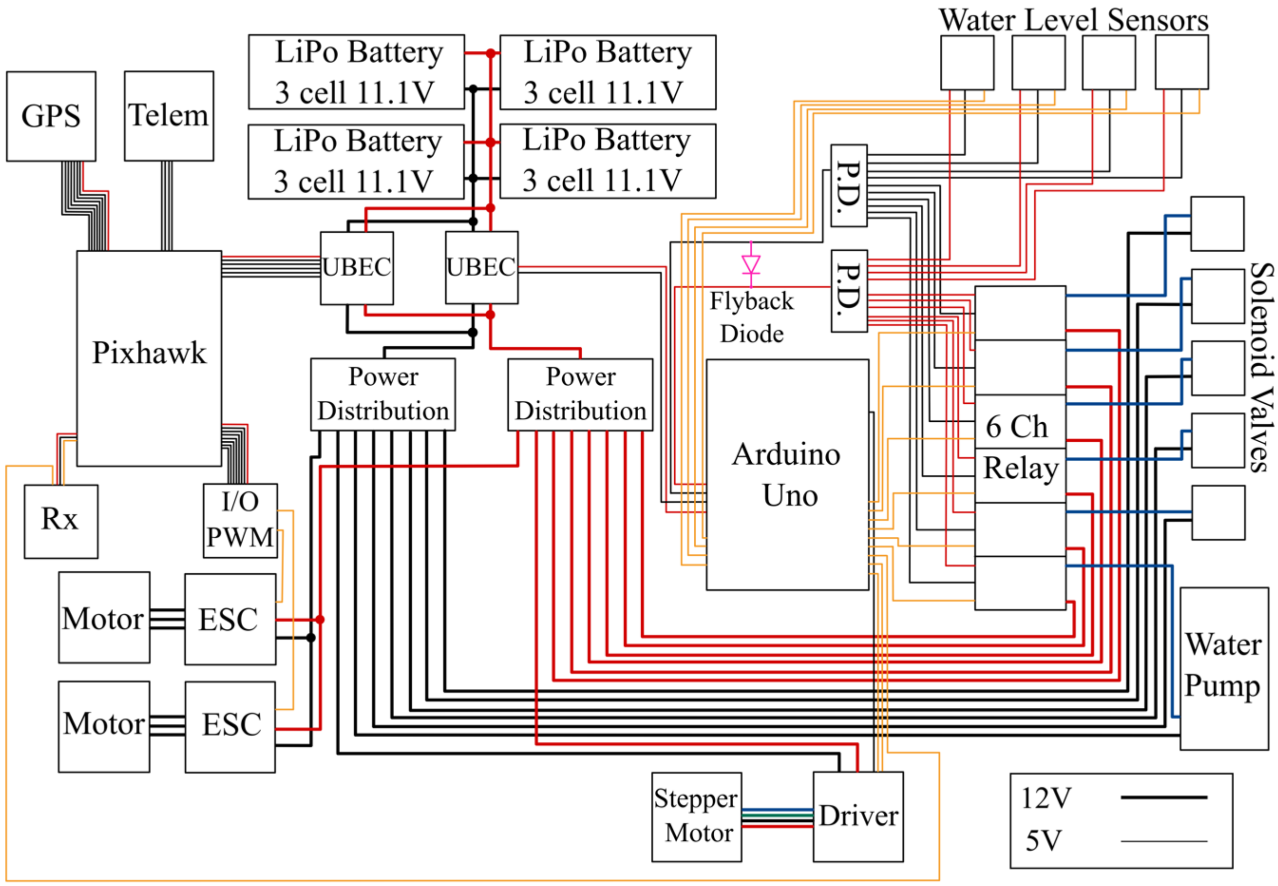

Figure 31: Wiring Diagram

7.3 Disassembly and Recycling (OM)

Subsequent to the building of the fist prototype, it must be disassembled and a re-use, disposal and recycling plan should be implemented. The build process will limit the use of adhesives to the construction of the hull and the supporting plywood mesh. This means all components can be removed easily by loosening mechanical fastenings. The electronic components are on loan from the department and will be returned for use on a variety of future projects. Additionally, where possible, wiring connections will be made with bullet connectors for ease of disassembly. Finally, the hull carcass and corresponding supporting plywood mesh will remain intact as a **building block** for future educational marine projects by the department.

8 Design for Manufacture Development (OM)

Turning a prototype into a final design for manufacturing involves refining the initial concept, optimising production processes, and ensuring the product is scalable and cost efficient. The hull of the RC boat is one of he most significant parts of the design. The initial prototype is built by using a one-off mould; however, for mass production, it is important to create a repeatable mould. A common method for creating hulls is laying up composites either wet or by resin infusion. This could accommodate creating multiple hulls from one mould making it an efficient and cost effective process for large production runs. The cost per unit and time to manufacture each hull decreases for every one created.

It is important that the wiring is organised and stable in in complex electronic systems like the RC boat. In the prototype phase, wiring looms are created manually, but for mass production, it is more efficient to produce wiring looms in bulk using pre designed templates. These templates ensure that the wires are cut to the correct lengths, properly routed, and efficiently assembled to enable them to be installed plug and play style when they go into the boat [23].

As production volume increases, **economies of scale** can be leveraged to reduce the per unit cost of components. Purchasing components like motors and sensors in bulk result in substantial savings. Additionally, a critical part of scaling the manufacturing is having the appropriate tooling to ensure that parts are consistently produced to the exact specifications. For example an important tool in the prototyping process in the 3mm ball nose bit for the CNC mill. While appropriate for the low quantities of MDF it will be working with, when scaling more durable tooling may be required. This can incur additional up front costs but will result in more consistent products over the production run [24].

Finally, to increase seaworthiness and enhance performance the boat can be designed in different sizes. The prototype is suitable for operating on the calm waters of the River Wear, but to handle more challenging conditions, such as the Thames, the boat will require greater stability. Scaling up might require adjustments to the hull design, thicker composite layers, or stronger components. These changes, while potentially increasing material costs, can be offset by manufacturing efficiencies and economies of scale.

9 Risk Analysis (BW JM EAA)

Table 11: Risk Assessment, here only highest risk level hazards are highlighted

Operating and Manufacture Risk Assesment									
Hazards	Those at Risk	Potential Harm	Uncontrolled Risk level			Mitigations	Controlled Risk Level		
			Liklihood	Impact	Level		Liklihood	Impact	Level
Propeller	Wildlife, Operators	Wildlife habitat destriction, cut operators if mishandled	4	3	12	Propeller guards	2	3	6
Electrical Components	Wildlife, Operators	Electric shock to wildlife or operators	3	3	9	Waterproof all areas of hazard, limit number of exposed electrical components	2	3	6
Plastic Hull	Wildlife	Pollutants can cause degregation of water and have health impacts on wildlife	4	2	8	Check plastic chosen degregation conditions. Limit these conditions and time in water.	2	2	4
Unqualified Operator	Boat, Widlife, Operators	Mishandling of boat could end up in crash or loss of vessel, disrupting widlife in crash. Unqualified operater could result in electric shocks with battery mismanagment.	4	2	8	Operators must be trusted and have reasonable competence to opereate the boat	3	2	6
Sudden Weather Changes	Boat, Widlife	Waves topple vessel resulting in crash or loss of vessel, disturbing widlife and requiring dangerous recovery.	4	2	8	Have thorough pre-mission checklist to verify operating conditons are safe for planned mission time.	2	2	4
Battery Depletion	Boat, Widlife	Crash or loss of vessel, disturbing widlife and requiring dangerous recovery.	4	2	8	Pre-mission check battery charged enough for planned mission	2	2	4
Body of Water	Operators	Drowning of operators	3	5	15	All operators must completed required swim test and feel confident around bodies of water	1	5	5
Dense Vegetation	Operators	Trip Hazard	4	3	12	Operators must wear sufficient footwear and be sure to tread carefully near the water's edge	2	3	6
Excessive Nosie	Operators, Wildlife	Hearing Damage, Wilflife habitat disruption	5	4	20	All noise has been measured so is below an acceptable threshold	1	4	4
Tooling	Engineers	Burns from the iron or solder itself. Inhalation of fumes.	4	4	16	All Engineers must follow the Standard Operating Procedures for manufacturing	2	4	8

Likelihood: 1 - A freak combination of factors would be required for risk to be realised (Almost Impossible). 1 - A rare combination of factors would be required for risk to be realised (Not Likely To Occur). 3 - Could happen when additional factors are present otherwise unlikely to occur (Could Occur). 4 - Not certain to happen but an additional factor may result in risk being realised (Known to Occur). 5 - Almost inevitable that risk will be realised (Common Occurence).

Impact: 1 - Inherently safe, unlikely to cause health problems or injuries (Insignificant). 2 - Minor, very short-term health concerns on recordable injury cases (Minor). 3 - Lost-time injuries or potential medium-term health problems (Moderate). 4 - Partial or medium-term, disabilities or major health problems (Major). 5 - One or more fatalities. Irreversible health problems (Severe).

10 Proposed Project Work and Schedule (BW SR)

A high level project Gantt chart for assigned hours is attached below in Figure 32, subtasks are not shown. The next step is to start prototyping. Initially, simulations will be conducted in SolidWorks. After that, bench testing will be conducted on the water collection, water distribution, and propulsion systems. This will ensure that the circuitry is correct, and each component works in isolation. Next, the individual systems will be integrated. The prototype will be safely **land tested** before a water test takes place. Prototyping will enhance the understanding of the circuitry and operation of the Ardupilot rover firmware. Testing will offer an opportunity to find design flaws and compare computational simulations to experimental results. This will further refine the product.

Week Beginning		28/10/24	04/11/24	11/11/24	18/11/24	25/11/24	02/12/24	09/12/24	16/12/24	23/12/24	30/12/24	06/01/25	13/01/25	20/01/25	27/01/25	03/02/25	10/02/25	17/02/25	24/02/25	03/03/25	10/03/25	17/03/25
Task	Hours																					
Project Planning	5	5							Christmas Break													
Problem Scope & Definition	15	10	5																			
Initial Research	65	10	13	12	20		10															
Calculations	10	4	3	3																		
Sketches	12	1	5	4	2																	
Initial Design	33	8	10	13	2																	
Hull Design	20		4	4	6	6																
Sampling Collection System	10			4	1	5																
Propulsion Design	12			4	2	6																
Sample Distribution System	13			3	3	3	4															
Developed Design	38			8	8	10	2	10														
Computer Modelling	65			5	10	10	12	8			10	10										
Bill of Materials	38				6	10	10	12														
Feasibility Report	120					30	40	50														
Simulations	36										10	10	10	6								
Final Report	240											10	20	4	8	5	5	5	3	40	60	80
Prototyping	240												50	45	45	30	25	15	10	20		
Testing	60													5	5	5	10	15	20			
Video	100															10	10	20	20	20	20	
Presenation	60															10	10	20	20			
Pulse Checks	8	2					2								2				2			
Total Hours	1200	40	40	60	60	80	80	80	0	0	20	30	80	60	60	60	60	75	75	80	80	80

Figure 32: Project Gantt chart

11 Conclusions (EAA)

In conclusion, this report has analysed the feasibility of using remote controlled boats for taking multiple samples at different locations and depths. A user requirement specification, and business case has been formed. From this, an initial design development was conducted. DDMs were used to assess the initial concepts and quantify decisions made in forming a solution. A hybrid catamaran was chosen for the hull as it offered good system integration and stability. For the propulsion, an outboard motor was chosen due to its strong performance at typical speeds. A weighted pipe was selected for the sampling collection system because of its ability to meet all the specified criteria. Finally, a valve array was picked for the sample distribution due to its relative simplicity and scalability. With all constituent systems chosen, the four systems were integrated. The hardware and software of the electronics were investigated. Out of this a prototype was developed that fits within the £300 budget. Lastly, the effects on design of sustainability and risk management concerns were discussed.

This report concludes that there is a sufficient gap in the market for this product. The proposed design is feasible and should be taken to the prototyping stage.

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