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SolarCyanoSlayer

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WHEN YOUR WATERWAY IS IN DISTRESS,

YOU WILL NEED AN SCS

Video of Working Design Prototype:
https://drive.google.com/file/d/1yedd0Og-AewmtjoDvAkbHRciDvOXC93G/view?usp=sharing

TABLE OF CONTENTS

BIOGRAPHY

I have always had an intrinsic appreciation of the water, and curiosity for the world which lives below the waves. I spend most of my time immersed in nature, particularly in the water or hiking over it, and it is from these experiences that I have been inspired to conduct research into cyanobacteria. I often participate in our national cleanup Australia Day campaign as well as various local beach and wetland cleanups, as the issue of water preservation is very important to me and something I am passionate about. This first-hand immersion coupled with my love of science has led me to conduct research into cyanobacteria blooms as it's my vehement belief that it is up to us, the emerging generation, to make real change in the world we live in. Alas, water is a commodity that is often undervalued and neglected, which greatly worries me. Hence, I hope that my research and experimentation can greatly improve our understanding and appreciation of water, our world's most essential resource.

INTRODUCTION

Cyanobacteria, or commonly blue-green algae, are photosynthetic, gram-negative bacteria which naturally occupy waterways in low, restrained populations. However, human induced nutrient enrichment, namely that of phosphorus (P) and nitrogen (N), in conjunction with favourable proliferation conditions exacerbated by climate change, has resulted in overpowering populations observable from space satellites. *Figure 3*. (USGS, 2019). On farming dams, ideal proliferation conditions are created as a result of excess crop fertilisation and livestock manure. Further, climate change has increased the devastation of droughts and floods which exacerbates nutrient runoff as minerals are washed from the damaged soil into waterways, a condition known as eutrophication.

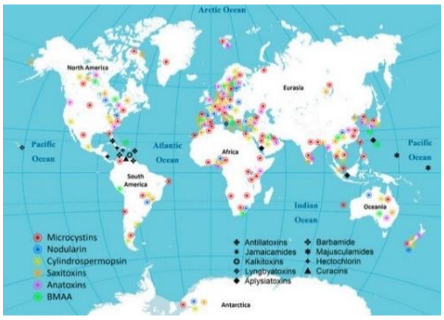


Figure 1. Global map depicting prevalence of cyanobacteria blooms.

Figure 2. Photograph of cattle at farming dam dead due to cyanobacteria bloom event

Figure 3. Satellite photograph of major cyanobacteria bloom event in Australia. Source: CSIRO.

Figure 4. Photograph delineating impact of bloom on organisms.

Eutrophic environments facilitate the exponential biovolume increase of cyanobacteria which proportionally increases turbidity levels in water. These high cell densities are a result of cellular fission reproduction by which one vegetative parental cell divides into two genetically identical daughter cells. (Khan, 2016). During large bloom events bioactive substances are released and in over 75% of blooms cyanotoxins are released (Chen, Burke & Prepas, 2011). Cyanotoxins can either be extracellular (excreted whilst the bacterium is alive) or intracellular. Intracellular toxins excreted upon cellular lysis, alongside P and N utilised to fuel the succeeding bloom creating uninhabitable "dead zones" for all organisms. Organisms may develop paralysis due to high exposure to cyanotoxins or fecundity in lower concentrations. In humans, toxins are transmitted orally (through consumption of contaminated food, including meat from livestock, and water), dermally (through recreational engagement with a contaminated waterways), or through inhalation present as hepatocyte or podocyte damage, gastrointestinal distress, cytotoxicity, and neurotoxicity. (EPA, 2022). *See Figure 5*. Once cellular lysis has occurred and intracellular cyanotoxins are released into the waterway, standardised water treatment is ineffective.

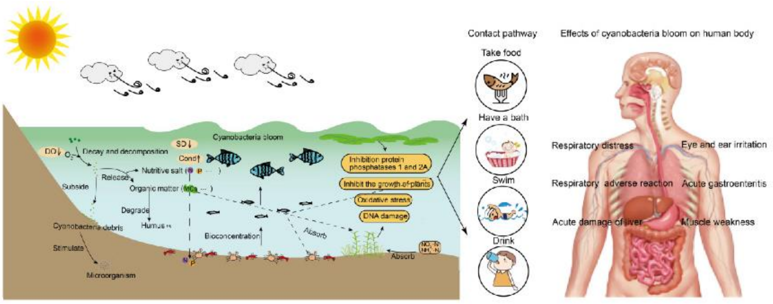


Figure 5. Diagram demonstrating the major health risks associated with a cyanobacteria bloom upon water bodies, impacting aquatic organisms, and the human body. Source: MDPI.

Cyanobacterial cells range in size from 0.5-1 µm to 40 µm in diameter, therefore accentuating the exponential cellular fission which occurs in lakes and rivers necessary for blooms to be observed by the naked eye. (Britannica, 2017). These cells best populate in slightly alkaline environments of a pH between, 7.5–8.5, but populate freshwater, brackish, and marine ecosystems globally. (Zanchett; Olivera-Filho). HAB events are visually observable as a blue-green surface coating. However, cyanobacteria undertake buoyancy regulation through their gas vesicles meaning the bacterium will migrate towards water depths housing optimal growth conditions. In stagnant waterways, the ability to move within the water column provides an advantage over other microorganisms competing for nutrients and light. (WHO, 2015).

In water temperatures which exceed 25 degrees (often in summer months or open waterways with limited shading), cyanobacteria proliferate most predominately as they are not competing for food sources with other phytoplankton. *See Figure 6.* A major harmful algae bloom (HAB) also prevents zooplankton grazing, inhibiting growth and reproductive rates and ultimately altering the ecological community structure and composition. (Paerl, 2018).

Additionally, this higher temperature range enhances the activity of cellular catalysts and reduces the solubility of oxygen in water, further decreasing oxygen concentrations. (Karbowiak, et al., 2018). *See Figure 7.*

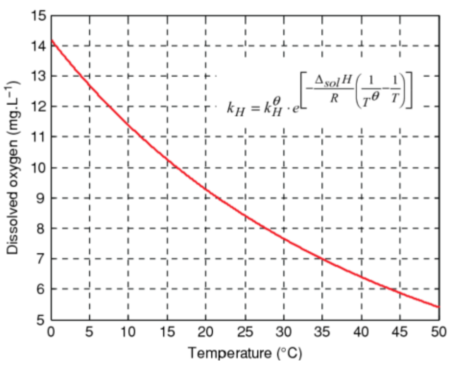


Figure 6. Graph displaying the relationship between dissolved oxygen solubility and temperature. Source: ResearchGate.

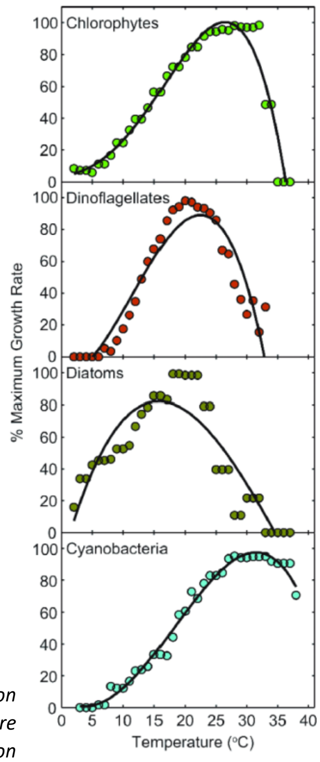


Figure 7. Graphical comparison of growth rate and temperature across major phytoplankton groups. Source: ResearchGate.

CELLULAR PROCESSES

Cyanobacteria are aquatic photo-troughs. They convert solar energy into chemical energy to maintain cellular function through light delivery. Photosynthesis provides oxygen and essential food sources as ATP energy and carbohydrates. However, cyanobacteria are a principal agent for N_2 fixation, which depends on the O_2 sensitive catalyst nitrogenase. (Stal, 2015).

Consequently, under high sulfide concentrations the bacterium will utilise hydrogen sulfide as a photosynthetic electron donor, as still allows essential ATP and carbohydrates required food sources to be obtained. (Biello, 2009). *See Figure 8.* The result is hypoxic (<2-3mg of O_2/L) or anoxic (No O_2) environments, which are maintained by cyanobacteria for 3 weeks, before cellular lysis occurs and the process repeats. In these conditions to maximise photosynthetic abilities cyanobacteria blooms on the surface of water, obstructing sunlight, thus preventing oxygenic photosynthesis for other organisms. This contributes to dead zones, of oxygen depletion, fatal to aquatic species, observable as major fish kills. But cyanobacteria thrive in anaerobic conditions and utilise decaying matter as a food source. (Chen; Zhou; Zhang, 2022).

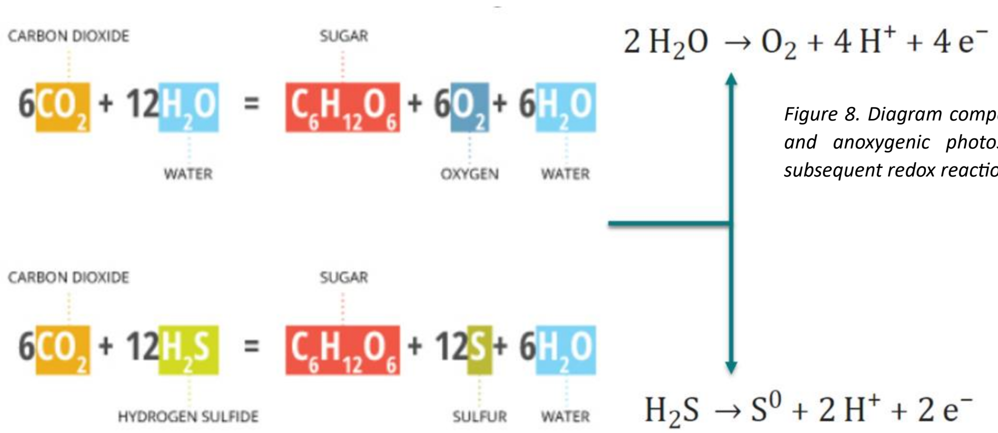


Figure 8. Diagram comparing oxygenic and anoxygenic photosynthesis and subsequent redox reactions.

Cyanobacteria's circadian clock coordinates metabolic processes to allow for the fixation of N_2 by determining the electron donor utilised in photosynthetic reactions. N_2 fixation is the chemical breakdown of atmospheric nitrogen, into nitrogenous compounds (NO_2^-, NO_3^-) and ammonia via redox reactions. (Stal, 2015)

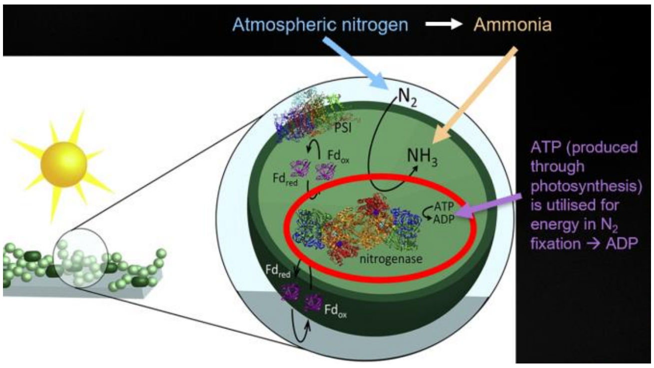


Figure 9. Diagram demonstrating the cellular components, and reaction of N_2 fixation. Source: ScienceDirect.

Cyanobacteria produces nitrates, nitrites, and ammonia through nitrogen fixation. Equilibrium reactions occur when these nitrogenous compounds come into contact with oxygen reactions, meaning that their macroscopic quantities will not change, (products are formed at same rate as reactants). (CK-12, 2014). Le Chatelier's principle abides with the idea that an equilibrium system will always try to counteract a change imposed upon it, detailing that an addition or removal of a product or reactant in an equation results in a shift in the equilibrium.

CURRENT TECHNOLOGY

Primarily, it is important to note that cyanobacteria, in healthy populations, support the ecological stability of waterways, and that it is only through nutrient-enrichment and in dominating populations that the bacterium becomes an environmental threat. Thus, my aim was to design a system which prevents exponential and dominating cyanobacteria populations, whilst allowing for natural proliferation of cyanobacteria and other phytoplankton.

After conducting research on the issue, I discovered the difficulty and expense in removing intracellular cyanotoxins. Standardised water treatment has been modified to facilitate the removal of low extracellular cyanotoxin concentrations, however this occurs subsequent to ecological devastation of waterways, and solely focuses on filtration for drinkable water. (EPA, 2023). Thus, I hoped to develop a system which can be implemented to counter cyanobacterial blooms before they initiate, thus, ensuring water is suitable for aquatic ecosystems and human recreational use. Therefore, my design would ensure water from the waterbody could safely enter mainstream water treatment plants, hence eliminating the barriers of human consumption.

Figure 10. Photograph of aerator deployed in waterway. Source: WaterQuality Solutions.

Currently, limited technology exists which achieves the above criteria. The lake and pond aeration system provides dissolved oxygen to the waterway. *See figure 10.* Aeration is an effective practice in diminishing the necessitation for chemicals to improve O_2-poor waterways. Low oxygen levels in a waterbody induces the unregulated proliferation of cyanobacteria, which contributes to deficient water clarity, foul odour, fish kills, accumulation of muck and midge swarms. *See Figure 11.*

Figure 11. Photograph of major fish deaths in eutrophicated waterway due to low O_2 concentration. Source: CSIRO.

By osmosis, the diluted oxygen will move from the area of high concentration to low concentration, until a concentration equilibrium is obtained between oxygen is being utilised by aquatic life and oxygen added by the aerator. (Eriksson, 1991). Additionally, the added oxygen reduces water alkalinity to stabilise pH, creating unfavourable cyanobacterial bloom conditions, whilst directly improving water quality.

Although effective in improving water quality, the aeration system does not circulate the water to prevent cyanobacteria from proliferating, nor filter unwanted toxins and chemicals from the waterbody. Furthermore, implementation is difficult, as these systems are situated on the streambed, meaning that the design is difficult to implement and regulate and can cost upwards of $5000. (WaterQualitySolutions, 2023). Ecological considerations of the design itself were also poor, as were either powered electrically or chemically, which makes setup more difficult and less environmentally friendly.

The SolarBee is a circulation system that operates on solar energy. Water is extracted from the depths of the waterbody and creates a horizontal induced flow as well as vertical mixing through water movement. This flow of water facilitates the distribution of oxygen and prevents stratification of the waterway. *See Figure 12.* The system is powered by solar panels which is very efficient for the large open waterways by which the design will be applied. (IXOM, 2017).

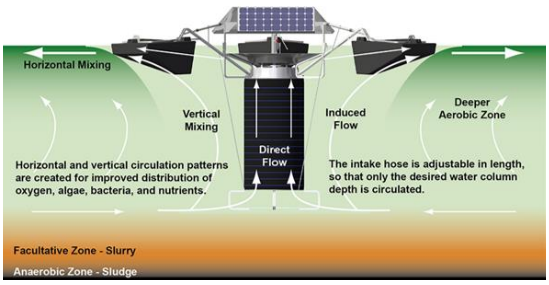


Figure 12. Diagram of circulation pathway created by SolarBee. Source: IXOM Watercare.

However, between 2013-2015, nearly $3 million has been spent on manufacturing and implementing the design, and the result was unsuccessful. (Fitzsimon, 2016). Upon further investigation, I have concluded that the major downfalls of the design have been the sole focus on filtration, which circulates nutrient rich water without any treatment for the eutrophic conditions. Both the above solutions are also very expensive and thus cannot be considered as an affordable solution to cyanobacteria blooms.

APPARATUS JUSTIFICATION

Apparatus	Reason for Choice	Quantity	Cost
PVC piping (32mm)	Inexpensive, accessible, and recycled. Narrow to generate waterflow, but thin enough to ensure water pressure continues at a high rate.	20mm, 750mm, 2x100mm, 2x120mm	$5
PVC piping (50mm)	Inexpensive, accessible, and recycled. Wider to act as the flotation for the entire design.	75mm, 245mm, 2x190mm, 2x135mm, and 3x20mm	$5
4-way PVC Cross Connector	Inexpensive, accessible, and recycled. Disperses and aerates water along 4 different routes	2	$2
PVC 90-degree join (50mm)	Inexpensive, accessible, and recycled. Used to connect base	4	$1.67
Polycarbonate Layer	Eco-friendly, as is a thermoplastic, which can be heated to a point where it becomes a liquid, thus can be easily and efficiently recycled with low embodied energy.	250mmx350mm	$1.75
Hosing	Recycled from garden hose. Due to the large amount of garden hoses, which are irresponsibly discarded as are difficult to recycle, my design repurposes the wasted resource.		Negligible – At home
Bio-Foam	Environmentally friendly method of filtering phosphates and nitrogen, from the water, and is CO_2 neutral.	2 sheets	$3.50
Pump	Creates waterflow in stagnant waterbodies, but not too rapid to disturb the current ecosystem.	1	$50
Oxygenator/ Aerator	Increases oxygen levels and stabilises oxygen-sensitive nitrogenase	1	$30
Photovoltaic (PV) Panels	Solar energy will be most prominent in open and stagnant water ways, thus will be effective in their location. PV cells are responsible for transferring waves of light energy from the sun to a form of usable electricity, replacing fossil fuels, as it is a non-polluting energy source and environmentally devastating forms of energy.	2	Included in price of Pump and Oxygenator/ Aerator
Hand Saw	Cutting PVC piping	N/A	N/A
Hot Air Gun	Warping the piping to a certain angle.	N/A	N/A
PVC glue	Used to join PVC piping.	N/A	N/A
White Water–Sealing Paint	Prevents any water from entering PVC piping which would prevent it from floating. White in colour as it reflects sunlight, thus reducing warming of the water whilst being filtered throughout the design, as warm water promotes cyanobacteria growth.	N/A	Negligible – At home
		Total	**$98.92**

DESIGN SKETCHES

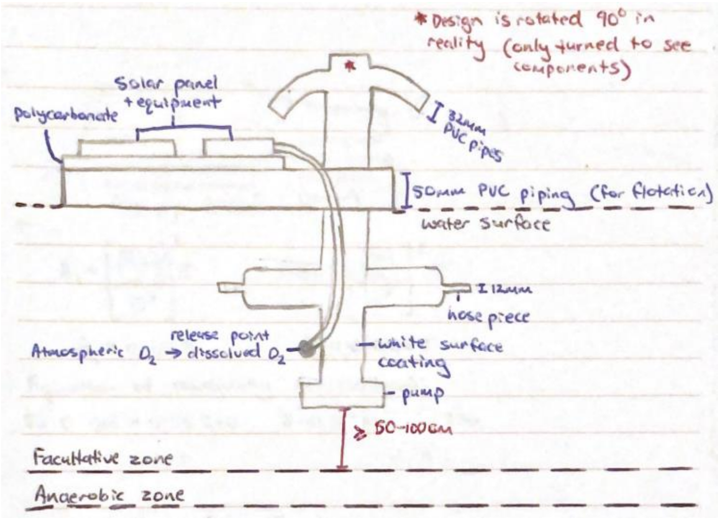


Figure 13. Diagram of final design sketch which elucidates the major structural components of the design.

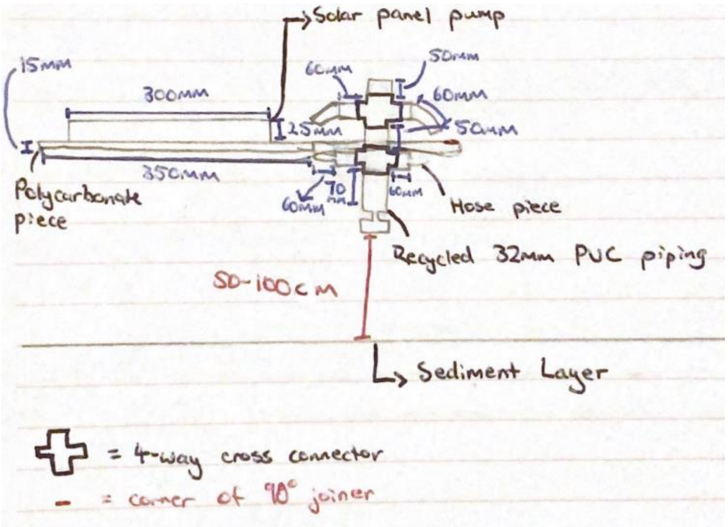


Figure 14. Diagram of measurements of design prototype

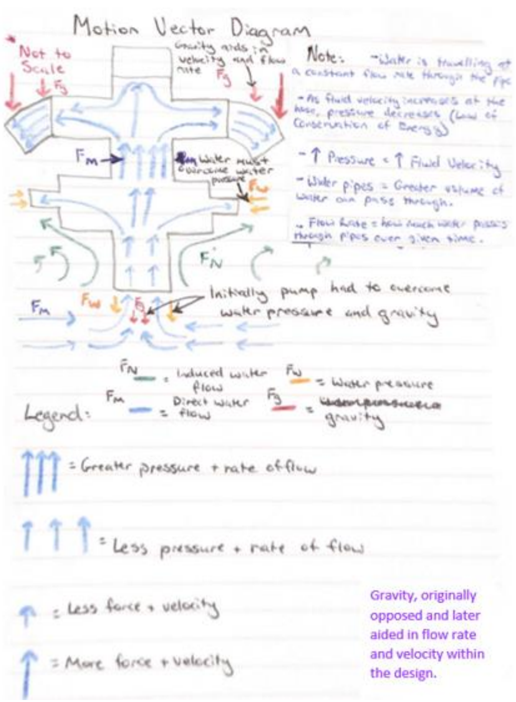


Figure 15. Motion vector diagrams of forces acting upon and within the PVC piping

MAJOR DESIGN COMPONENTS

From my research into current technology, I have decided that my design will have a competitive advantage if I isolate and mitigate the conditions which promulgate cyanobacteria growth.

1. Circulation – offers both direct and induced waterflow at a variety of depths through consideration of cyanobacteria's buoyancy regulation capabilities.
2. Oxygenation – dispels dissolved oxygen throughout the waterway which prevents the formation of hypoxic or anoxic water conditions. Dissolved O_2 is also a measure of the health of a waterway, can regulate pH, but ultimately essential to aquatic respiration.
3. Filtration – counters eutrophicated conditions because of mineral runoff. Simply without these unsafe levels of nutrient enrichment, cyanobacteria would not be able to bloom exponentially, and hence cyanotoxins would not be released.
4. White Coating – unlike other zooplankton and other microorganisms, higher temperatures enhance cyanobacteria growth. Alongside a temperature increase, the solubility of oxygen in water decreases and inversely the rate of cyanobacteria's catalytic activity increases. Thus, the design is coated in white, as reflects all wavelengths of visible light, so solar radiation is not converted into heat and the temperature of the object and subsequently the water flowing through it does not increase.
5. Solar-powered – The design will be solar powered, allowing for solar energy to be harnessed and utilised in the large open spaces of rivers and dams, increasing the efficacy of the design relative to its location of implementation and decreasing the designs ecological footprint.

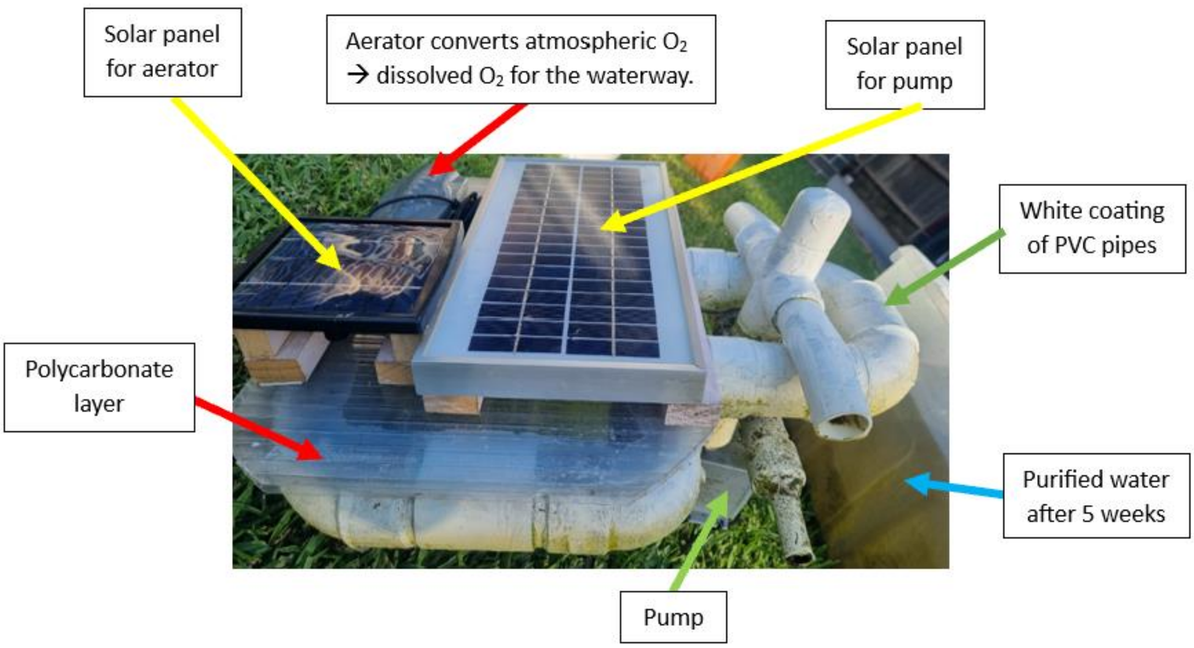


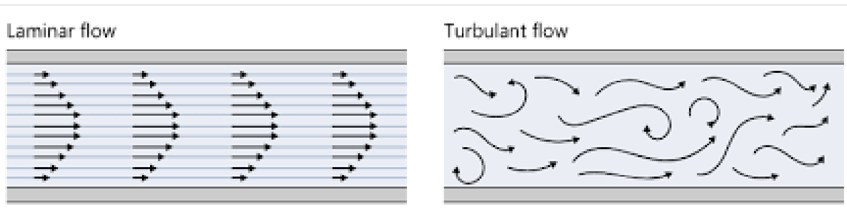
Figure 16. Labelled photograph of major design components of the SolarCyanoSlayer

FLUID DYNAMIC PRINCIPLES

Fluid dynamic principles were closely considered to maximise the SolarCyanoSlayer's water circulation, a steady state fluid system. Water circulation creates unfavourable conditions for cyanobacteria growth as facilitates an increase in O_2 concentration, through the conversion of atmospheric oxygen, from aerating winds, into dissolved oxygen for surface water.

Pressure differentials are responsible for water transport. The pump system is located at least 50cm above the streambed to ensure that the anaerobic and facultative zones of nutrient-rich matter are not unearthed, as would fuel cyanobacteria proliferation. The pump system, despite counteracting forces of water pressure, creates axisymmetric laminar flow, which reduces energy lost to friction due to the steady propulsion of water throughout the system. (CFD, nd)

As the water exists the pipe, the added propulsion of gravity, as a pressure differential results in a transition to turbulent water flow. As turbulent flow has stronger inertial forces (numerically depicted as a Reynold's number) acting upon it, it will more effectively combat surface stratification, conducive to cyanobacteria proliferation. However, a higher Renyold's number (Re) complementary with turbulent flow subsequently results in greater skin (surface) friction, due to the higher velocity gradient near inner walls of the pipe. Hence, alongside the law of conservation of energy, transportation throughout the pipes in this form would be largely inefficient. *See Figure 18.* Additionally, turbulent flow results in a high heat transfer as a result of active mixing, which is not efficient within the body of the SCS. (Altair, 2021)



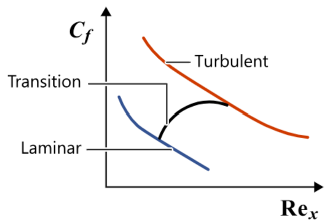


Figure 17. Diagram comparing streamlines of laminar and turbulent flow. Figure 18: Graph displaying relationship between C_f (skin friction coefficient) and Re_x (localised Reynold's number) Source: Atlair AcuSolve.

The turbulent waterflow entering the pipe abides by the Energy Cascade principle. Water travelling as turbulent flow is composed of turbulent eddies, which range in size of scaled separation between the smallest and largest eddies. Due to the low viscosity of water, frictional forces are minimal as water transports throughout the pipes. Therefore, by the law of conservation of energy, all KE = GPE, or $\frac{1}{2}mv^2 = mgh \rightarrow \frac{1}{2}v^2 = 9.8h$. Therefore, when water is exiting the top pipe it will be travelling with its greatest velocity at its lowest height (before contacting the surface of the water). The high energy containing water molecules impacts the surrounding water, transferring kinetic energy to smaller eddies, but this strength decreases with depth due to opposing water pressure. The length scale is comparable to the flow dimensions. This process of energy transfer continues until the eddy size is negligible and energy is stabilised, known as the Energy Cascade. *See Figure 19.* (AcuSolve, 2021)

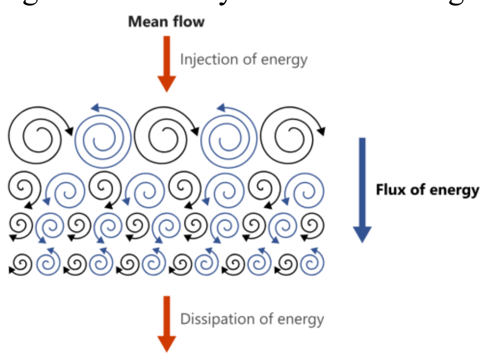


Figure 19. Diagram demonstrating process of energy cascade vertically, and motion of subsequent eddies. Source: Atlair AcuSolve.

Thus, the efficiency of the design must ensure that the smallest eddies still contain energy at a greater depth, but that this energy is not wasted in circulating the anerobic and facultative zones. This is because circulating these layers of the waterway will result in submerged nutrients becoming an available food source for the bacterium, whilst disrupting species which populate the streambed and the natural stratification of a waterway.

The equation of continuity states that the mass flow rate remains universal throughout an operating system. (UCF, 2016). This facilitated a determination of the velocity of the water moving through each portion of the pipe. Therefore, it can be mathematically deduced that as the cross-sectional area of the pipe decreases, its speed increases. This was a principle employed within the design to maximise the water's velocity exiting the pipes, to improve horizontal circulation at greater water depths.

Furthermore, Bernoulli's principle was used to justify the design's construction which prioritises the velocity of waterflow rather than the volume. When Bernoulli's equation is applied to a horizontal body, it explains that the pipe of smaller cross-sectional area has a higher velocity; therefore, there is a simultaneous decrease in pressure on the hose piece. *See Figure 20.* Low pressure on the body of the design ensures prolonged usage and abides by the law of conservation of energy, in that initial energy gained through the pump's uptake is maximised. (NASA, nd). Both consideration of Bernoulli's principle and the continuity equation have been employed to maximize the efficiency of the system and ensure prolonged counteraction of cyanobacteria blooms.

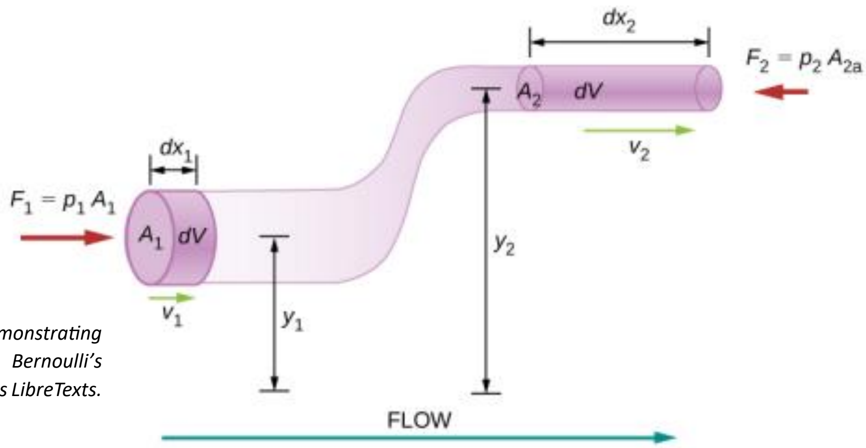


Figure 20. Diagram demonstrating the derivation of Bernoulli's principle. Source: Physics LibreTexts.

PRELIMINARY EXPERIMENTATION – FLUID DYNMAICS

I conducted preliminary testing to ensure that the system was generating sufficient flow rate and abiding by the above principles. The results are depicted in *Figure 21.*

Trial	Time (sec)	Volume (ml)	Flow rate (ml/sec) (5 significant figures)
1	15.37	3695	240.40
2	14.79	3580	242.06
3	15.81	3730	235.93
4	16.01	3785	236.41
5	15.03	3770	250.83
Avg.	**15.40**	**3712**	**241.13**

Figure 21. Tabulation demonstrating results of preliminary flow rate experiment to determine the circulation potential of the device.

The average flow rate is approximately 241ml/sec or 14.46L/min. I calculated this rate by placing tubs underneath the openings of the pipe and collecting the water that was released over a timed period (approx. 15 seconds). *See Figure 22.* This water was poured into a jug, which meant that parallax error had to be considered and avoided when taking a numerical reading. Parallax error states that when the observer and scale are not situated on the same horizontal plane, the distance between the scale and the pointer causes inconsistency in the perceived reading. (Physics, 2022). Thus, to prevent this random error I situated the jug on a table and levelled my eyesight to equal the water's height. The limit of accuracy of the scale and digital stopwatch were ±5ml and ±0.01second respectively. However, both the removal of the tubs of water and starting the stopwatch relied on human reaction time, and thus experimentation was conducted 5 times to increase the reliability and reduce random error, which may skew the results.

From this reading, I applied the equation of continuity to determine the velocity of water exiting the pipe from a horizontal position. By the equation of continuity, the mass flow rate does not change at any given point throughout the design, and $p_1 A_1 v_1 = p_2 A_2 v_2$. As the density of water, remains at 997 kg/m³ throughout the entire body, the equation can be simplified to $A_1 v_1 = A_2 v_2$. The calculations delineate that the velocity is 2.6 times faster exiting the pipes.

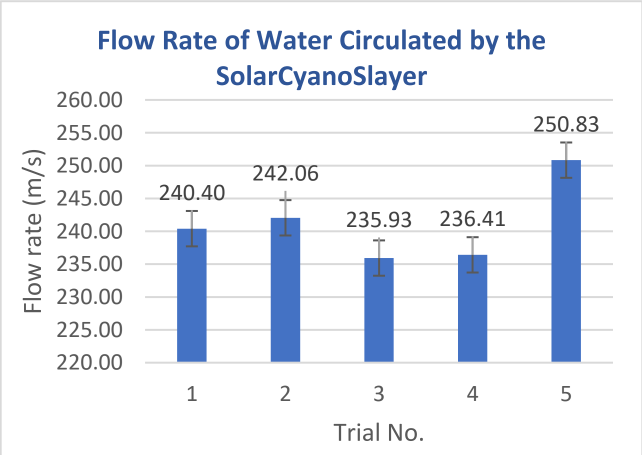


Figure 22. Graph denoting the flow rate (m/s) of water circulated by the SolarCyanoSlayer at any given time.

EXPERIMENTAL OVERVIEW

To determine the effectiveness of my invention, I set up comparative testing between water which remained untreated (control), and water treated by the SCS. These were labelled Tub A and B respectively and held 100L of eutrophicated water. Over the course of 5 weeks, I tested for the following: O_2 concentration, pH, phosphate, and monitored humidity levels as are conducive to cyanobacteria proliferation. The experiment was conducted weekly over a month-long period, and within each week each testing was conducted 3 times to ensure reliability.

EXPERIMENTAL AIMS

i. To quantitatively demonstrate the improvement in water quality as a result of the SCS in terms of nitrogenous compounds, phosphate, dissolved O_2-concentration, and pOH.
ii. To qualitatively demonstrate the absence of cyanobacteria growth as a result of the SCS

EXPERIMENTAL SETUP

Figure 23. Photograph of identical experimental setup for each water tub

EXPERIMENTAL VARIABLES

Water quantity and quality were universal, location was constant, and initial testing of the water depicted universal levels of eutrophication in both Tub A and B. With consideration to variables, and external conditions, the measurement paralleled theoretical and existing data. Furthermore, the control produced observable scum colonies of cyanobacteria, hence resolving the aim of the testing. In this regard, the results were valid.

FINANCIAL CONSIDERATIONS

The design is aimed to be affordable to all, and thus cost was minimal throughout the construction. However, more financial backing in the experimentation and equipment would have improved accuracy of the results.

ENVIRONMENTAL CONSTRAINTS

The most prominent feature of the design is the minimisation of the induced ecological harm of the construction of the SCS. Therefore, all materials were recycled, of a low carbon footprint and embodied energy, and most can decompose naturally without producing any waste or can be recycled again. Thus, this meant careful consideration of materials and the vast array of alternatives. Also, the location of the testing was my front lawn, which would not experience as much solar energy, as a dam or standing waterway. Additionally, when the design was implemented Sydney experienced weeks of thunderstorms and heavy rains, which are not conditions in which solar panels would function efficiently.

Moreover, whenever adding a foreign body into a natural waterway it is important not to disrupt the ecological stability of the area. Current technology disrupts the natural ecological conditions of a stagnant waterbody, alike to the large-scale water circulation generated by the SolarBee. Thus, my design will utilise a conjunction of oxygenation, filtration, and circulation to alleviate conditions which stimulate the growth of cyanobacteria, rather than significantly changing natural features of the waterbody.

RESULTS & DISCUSSION

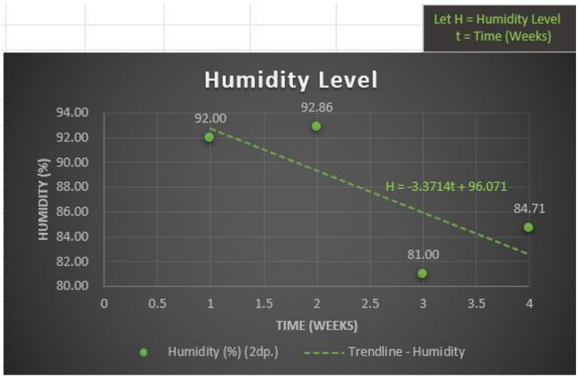


Figure 24. Graphical depiction of humidity levels, as an extrinsic factor impacting experimental results

The humidity levels whilst conducting experimentation were very high, averaging 87.64% across the month. *See Figure 24.* These humidity levels, alongside high rainfall across the February to April period of 2022, created extrinsic factors which promoted cyanobacteria growth. (Australian Bureau of Meteorology, 2022).

To ensure accuracy, the phosphate and pH results were tested utilising the WaterLink SpinTouch. The SpinTouch is a photometric device which shines visible light onto a disk filled with a reagent for each water maker to be tested. *See Figure 26.* The difference between the measurement of light transmission before the sample is altered (zeroing) and after UV light passes through the sample with added reagent provides a highly accurate numerical reading. (ITS, 2013). *See Figure 25.* The probe was also cleansed with a buffer liquid between each test to facilitate accurate results. This provided a degree of accuracy of 0.1pH for the pH reading, and subsequently a limit of accuracy of ±0.05pH, reducing systematic error. Compared to other testing methods, this device x10 more accurate than litmus strips which provide a ±0.5pH accuracy limit. Litmus strips provide categorical, rather than numerical data, and therefore the photometer is more accurate, as eliminates the subjectivity of the human eye.

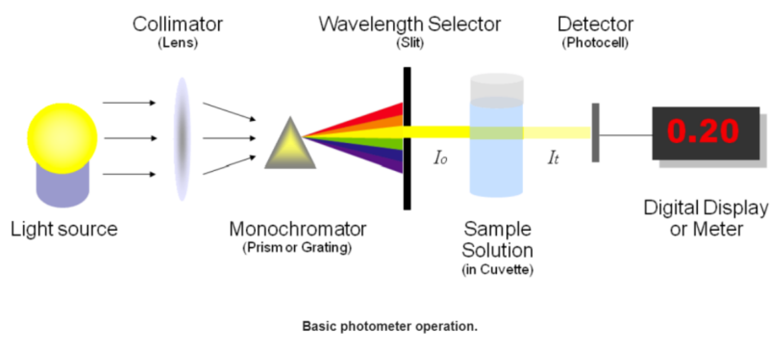
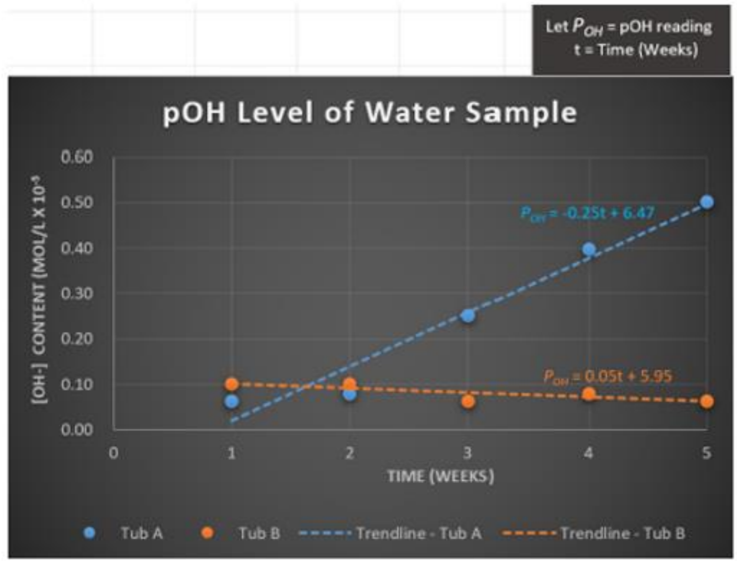


Figure 25. Diagram demonstrating process of basic photometer operation. Figure 26. Photograph of WaterLink SpinTouch. Source: WaterLink.

	WATER (BY TUB)							
	Tub A (Control)				Tub B (SCS)			
Time (Weeks)	Avg. pH	Avg. pOH	H^+ concentration (mol dm^{-3})	OH^- concentration (mol dm-3)	Avg. pH	Avg. pOH	H^+ concentration (mol dm^{-3})	OH^- concentration (mol dm-3)
1	7.8	6.2	1.58E-08	6.310E-07	8	6	1.00E-08	1.00E-06
2	7.9	6.1	1.26E-08	7.943E-07	8	6	1.00E-08	1.00E-06
3	8.4	5.6	3.98E-09	2.512E-06	7.8	6.2	1.58E-08	6.31E-07
4	8.6	5.4	2.51E-09	3.981E-06	7.9	6.1	1.26E-08	7.94E-07
5	8.7	5.3	2.00E-09	5.012E-06	7.8	6.2	1.58E-08	6.31E-07

Figure 27. Tabulation comparison of pH/pOH concentrations and resulting ionic molarities between Tub A and B.

pH regulation was not the primary incentive of the design but is reflective of effective oxygenation and filtration of hydroxide compounds. Thus, I calculated the H^+ and OH^- ionic composition of the waterway, with reference to the pH. The eutrophicated sample, in Tub A saw a decrease in H^+ concentration by 1.39×10^{-8}mol dm^{-3} and inversely increased OH^-, ions by 4.381×10^{-6}mol dm^{-3} improving water quality towards a neutral pH. *See Figure 27.*



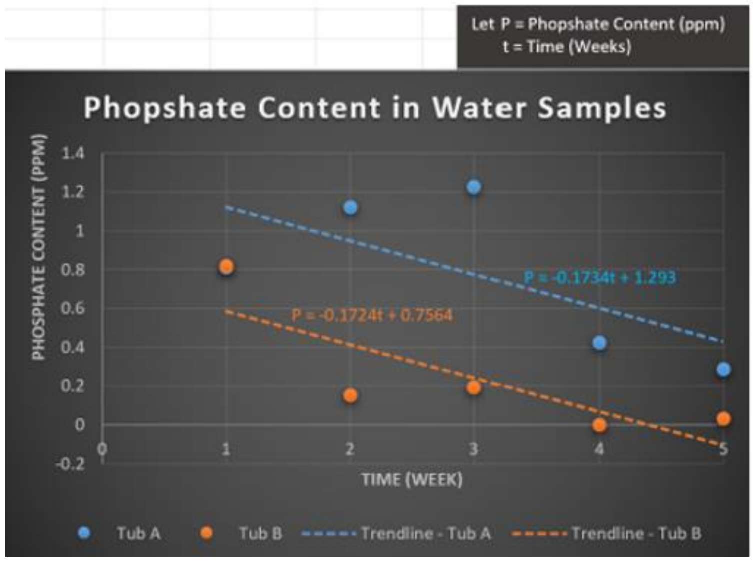
Trendline Formulas:

Tub A: P_{OH} = -0.25t +5.95

Tub B: P_{OH} = 0.05t + 6.47

Figure 28. Graphical depiction of pOH trends between Tub A and B.

The trendline gradient of Tub A was |0.25|, whereas Tub B was |0.05|, reflective of the ecological change caused by cyanobacteria's proliferation within the water and the lack thereof caused by my design. Cyanobacteria grow best in more alkaline conditions between pOH 4 and 6. In the control, these conditions were satisfied, ranging from pOH 5 to pOH 6, and the negative gradient insinuated the continual decline in pOH. This can be explained by the principle that as cyanobacteria proliferates, alkalinity and hydrogen concentration decreases. However, Tub B maintained water quality, with a negligible decline to a more neutral pH (by 0.2). *See Figure 28.* Overall, it is an explication of the maintenance of neutral acidity and alkalinity in the water.



Trendline Formulas:

Tub A: P = -0.1734t + 1.2936

Tub B: P = -0.1724t + 0.7564

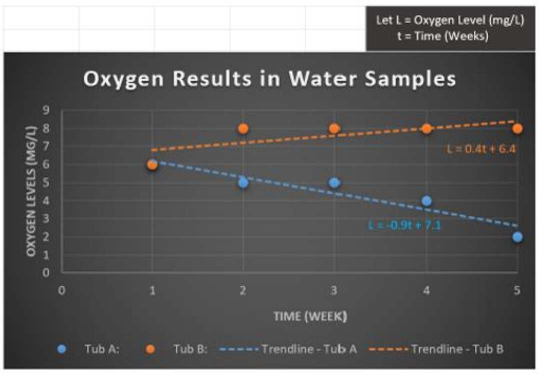
Figure 29. Graphical depiction of phosphate trends between Tub A and B.

The photometer also provided phosphate levels. Phosphate content originated at a level of 0.8ppm. In Tub A, a rapid increase in phosphates occurred between weeks 1 to 3, nutrient enrichment which can be explained by the rainfall present during testing. Contrarily, after week 3 as the cyanobacteria proliferated, a decrease in phosphates was observed, but the concentration is still considered to be high. *See Figure 29.* This is because the nutrients were utilised as a food source for the organism and upon further research, I learnt of the process by which the bacterium stores nutrients in their vegetative cells when in abundance, to prepare for a shortage. The vegetative cells create endospores to ensure the survival of a bacterium through periods of adverse conditions or environmental stress. Thus, this decline in phosphate is reflective of its utilisation by the bacterium and not a marker for healthy water. Alternatively, in Tub B the phosphates decreased rapidly, indicating the success of the bio-foam filter. Ultimately, these results prove that the SolarCyanoSlayer has the capacity to amend eutrophication, by removing phosphates from water. (Braun et al, 2018).

I undertook the O_2 tests, by using a colour chart indicator, which decreased accuracy as it did not provide numerical data. Validity was decreased through individual human eye colour perception. I conducted testing 3 times for each water sample, using a buffer solution to filter and ensure accurate results. However, the accuracy of this test was hindered as dissolved oxygen levels can range from less than 1 mg/L to more than 20 mg/L, whilst the reagent testing only produced results between 1-8mg/L. To improve accuracy and validity, a digital reader can be utilised in the future.

Cyanobacteria create anoxic and hypoxic environments to preserve nitrogenase. Higher oxygen content prevents the proliferation of nitrogenase, which is an enzyme allowing for nitrogen fixation in waterbodies. The resulting products of nitrogen fixation detrimentally impact ecosystems as they produce nitrites, nitrates, and ammonia, which are extremely toxic to marine life. To protect this O_2-sensitive enzyme, cyanobacteria will create anoxic and hypoxic environments in water. As oxygen is removed from selective areas, many species will suffocate.

6mg/L is a suitable level of oxygen for all marine species and other micro-organisms inhabiting the waterbody. (GNT, nd). Alternatively, when levels reach ≥4mg/L there is insufficient oxygen for many species, and any less highlights a serious deficiency. In Tub A the gradient outlines a continual decrease of 0.9mg/L per week, whereas Tub B displays the success of the oxygenation system, through a continual increase to 8mg/L, abundant to support all marine life. Expectedly, Tub A, lacked these preferable conditions, by the end of the testing period decreasing to 2mg/L. *See Figure 30.* Unbeknownst to me when I collected the water samples, there were fish eggs in the waterway, and the fish did survive the course of testing, reflective of the sufficient O_2 concentrations capable of supporting aquatic life.



Trendline Formulas:

Tub A: *L = 0.4t + 6.4*

Tub B: *L = -0.9t + 7.1*

Time (Weeks):	Tub A (mg/L)	Tub B (mg/L)
1	6	6
2	5	8
3	5	8
4	4	8
5	2	8

Figure 30. Graphical and tabulation comparison of O_2 levels in water sample A and B

I additionally tested for nitrates, nitrates, and ammonia composition. *See Figure 31.* The limiting factor of this experimentation was the use of reagents, as facilitated skewed data due to the subjectivity of the human eye. This testing was completed primarily to assess the filter's uptake of the harmful impacts of the products of N_2 fixation. Le Chatelier's principle applies to the functioning of my filter. As the filter effectively removed ammonia from the water sample (a reactant), the equilibrium will shift to the left, converting products back into reactants. The equation will continue to shift until the macroscopic quantities of the aqueous solutions are balanced. *See Figure 32.* Hence, this means that the overall quantities of each compound will decrease until a ratio equilibrium is achieved, thus decreasing overall water contamination. (OrganicChemistryTutor, 2021).

	Nitrogenous Compounds (products of N_2 fixation)		
Time (Week)	NH_3 (mg/L)	NO_3^- (mg/L)	NO_2^- (mg/L)
1	10	40	4
2	6	15	1
3	4	10	0.5
4	1	5	0.25
5	1	5	0.25

Figure 31. Tabulation of nitrogenous compounds, as per reagent results.

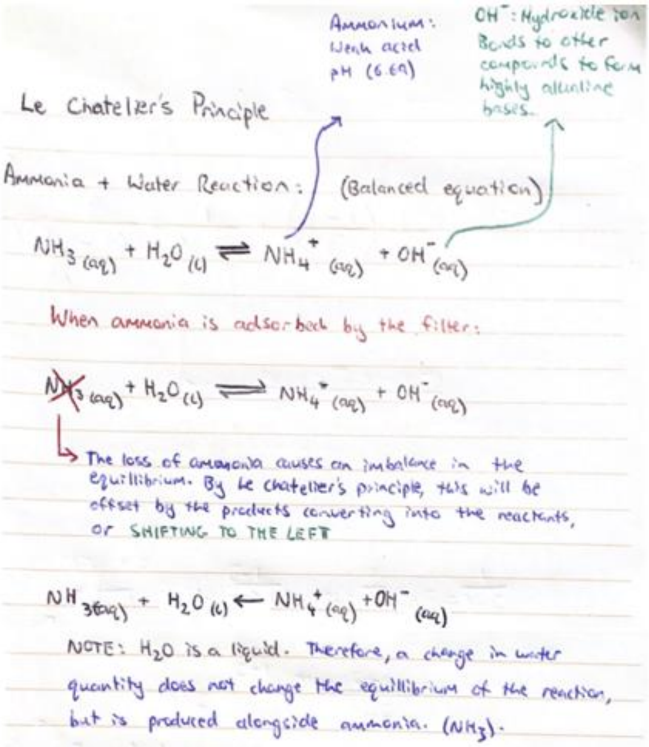


Figure 32. The application of La Chatelier's Principle to the filters functioning.

Qualitatively, I observed the appearance of each water sample. In Tub A there is an evident presence of cyanobacteria growth. The air bubbles depict trapped oxygen which is withheld from the waterbody. *See Figure 34.* Tub B did not visually demonstrate potable water for human consumption, however, the water was clean enough for animal consumption, to support any aquatic life, or to be passed through current water-testing to produce potable water for human consumption. *See Figure 35.*

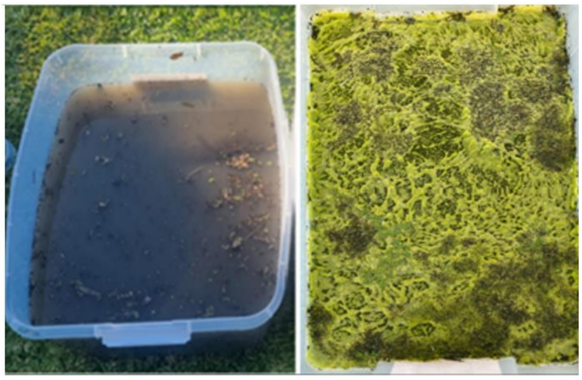



Figure 33: Qualitative comparison of water quality between Week 1 and 5 in Tub B (as a result of SolarCyanoSlayer)
Figure 34: Qualitative comparison of water quality between Week 1 and 5 in Tub A (which acted as a control for baseline assessment)

PRELIMINARY MODIFICATIONS – BIOFILTER

Blackwater occurs naturally when "floods sweep organic debris from riverbanks and floodplains into streams making water appear darker." (MDA, 2022). Following a bushfire event burnt matter is swept via winds or rain into waterways, creating damaging blackwater. The bacterial breakdown of organic matter subsequent to bushfires utilises much of the waterbodies dissolved oxygen to do so. Hypoxic blackwater occurs under these conditions when oxygen levels are <3mg/L. Thus, the warm waters following a bushfire, high organic matter composition, and hypoxic conditions create the ideal breeding ground for cyanobacteria.

Hence, I have experimented with the development of a biofilter utilising principles of compost filtrations, mycofiltration, and natural organism with water purification properties. However, research in these areas is minimal especially in that involving nitrogenous compounds produced through N_2 fixation. Alarmingly, is estimated that each year 33% of all food produced globally is wasted. (Foodprint, 2023). Thus, over the past few months I have experimented with a filter attachment to the pre-existing SCS allowing people who use the system (especially farmers) to repurpose the vast array of wasted compost matter. As the SCS would prevent cyanobacteria blooms, cyanotoxins would not enter the filter medium that pose a health risk through oral consumption. The filter is also completely biologically derived so could be utilised as a soil enrichment fertiliser for crops alongside naturally decomposition processes. This is because phosphorous, nitrogen, and ammonia which cause eutrophication, are essential nutrients required for crop growth. The need for physical replacement of the filter and impact on circulation is something that I am still considering but will be able to share my findings with the judges in Stockholm.

FUTURE IMPROVEMENT

The modifications I would employ are as follows:

1. Solar Battery - The system could be enhanced by having a solar battery to allow the design to function efficiently during all hours of the day. Since photosynthesis is an endothermic reaction dependent on the solar radiation, no oxygen is added to the waterbody during an overcast day or the night. Hypoxic, and anoxic conditions will result, and harmful nitrogenous compounds will be produced via nitrogen fixation. Thus, a solar battery is significant in storing excess energy to maintain oxygen levels and circulation across all times of the day.
2. Additionally, the size of the design should be increased to house 4 tubing systems, oxygenators and pumps as would be more suitable for implementation in a farming dam. These alterations will increase the effectiveness of the design, as it is only currently a small-scale prototype with great potential for use.

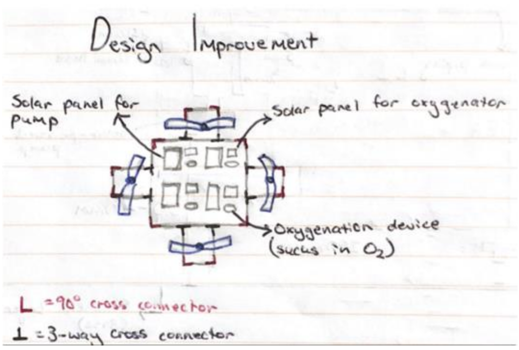


Figure 35: Diagram demonstrating the expansion and improvement which will be applied to the SolarCyanoSlayer in the future.

After these modifications are made a large-scale field testing in a real dam would be effective in determining the real-world effectiveness of the system.

However, the successful results demonstrate the SolarCyanoSlayer's ability eliminate the uncontrolled proliferation of cyanobacteria within standing, anoxic or hypoxic and eutrophicated waterbodies. As a result, the SCS removes the barrier to water being utilised for human consumption. Thus, these results can be extrapolated to determine that the innovative design has a very applicable real-world utilisation which can combat cyanobacteria blooms before they initiate. This novel and innovative design has the potential to improve water quality around the world, to mitigate one of the greatest ecological threats to our waterways.

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