Hydropower Water Purification Device

Final Report

April 28th, 2024

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Introduction / Executive Summary

As students enrolled in “Bass Connections: Design & Innovation,” we formed a group to design a project that tackled an environmental issue in an energy efficient way. With backgrounds in a variety of majors that included Mechanical Engineering, Economics, Environmental Science, Computer Science, and Earth & Climate Sciences, we sought to find an issue that properly blended our academic interests properly. We were approached by a client in Columbia about an issue in the Sierra Nevada de Santa Marta National Park. With numerous visitors each year, the problem of plastic pollution, particularly from single-use plastic water bottles, is prevalent throughout the park and the local agents were hoping to ban its use but needed an alternative solution. After contemplating several ideas and doing research on previous work that had been done in the field, we believe a water filtration system, powered by the flow of rivers, would be the best solution to tackle this issue. The device would use the flow of rivers throughout the park to power a filter that would allow park goers to refill their water bottles at campsites and thus reduce the need for single-use plastic water bottles in the park. After designing the prototype, and doing a thorough social and environmental benefit analysis, we believe we can eliminate plastic water bottles in the park while also introducing an alternative system of income for locals.

Background - Small-Scale Hydropower/Plastic Control in US National Parks

Looking at the work that has already been in designing a self-sustaining water filtration system, research groups outside of the USA have made significant progress. For example, a group at Caraga State University in the Philippines published an article about work they had done where they designed a prototype for a water filtration system that is self-sustaining for the purpose of being implemented in developing regions. The moving water from the river will generate electricity which will be stored in a battery to power a filtration device (Calimpusan 2021). Work has also been done by engineering researchers at Southern University Bangladesh where in one of their articles they found that the head and available flow rate at a waterfall was able to power a mini hydropower station (Jui 2015). New engineering techniques published in an article by researchers at University of Malaya in Kuala Lumpur, Malaysia have made many of these developments in mini hydro power plants possible. This includes changes in the hydraulic turbine shape, using the pump as a turbine, and using an induction generator as a source of power generation (Laghari 2013).

Although our project focuses on implementation in the Sierra Nevada de Santa Marta National Park in Colombia, a study by Oregon State University Master's student Ashley Spoojer about the effects of reducing single use plastic bottles in national parks in the USA provides valuable insight into the implementation of our project in Colombia. For example, most park managers are unaware of how to properly handle polyethylene terephthalate (PET) plastic waste, as most PET waste is sent to landfills rather than being recycled. This is also further complicated as PET waste can no longer be sent to China as China has implemented a ban on the import of such waste (Spooner 2019). It has also been estimated in a study by the Washington Post that plastic water bottle bans eliminated 112,000 pounds of plastic from being sold and discarded each year along with 140 metric tons of carbon dioxide from being emitted (Fears 2021). It has therefore been recommended by researchers to re-establish a plastic water bottle ban, build more refill stations, increase awareness and education about plastic recycling, and possibly use a plastic eating microbe to biodegrade the PET plastic waste (Spooner 2019).

Background - Client: Sierra Nevada

While we envision our prototype being useful for a variety of national/regional parks globally, we will examine how to integrate our device in the context of the Lost City (Ciudad Pérdida), located in the Sierra Nevada de Santa Marta of northern Colombia. The Lost City, thought to have been built around 800 CE, was home to the ancient Tayrona people and was eventually abandoned during the peak of the Spanish conquest and colonization. Though known and maintained as a sacred site by the local indigenous tribes descendants of the Tayrona, specifically the Kogui and Wiwa, the "Lost City" remained hidden from public knowledge until its rediscovery in 1972 (Colbourne 2020). Following its rediscovery, The Lost City was opened to tourism, though regulated by the Colombian government as well as the local indigenous groups–the Kogui and the Wiwa. The Lost City has often been compared to Machu Picchu, as both are archaeological sites located on hillsides and buried in South American rainforests. However, the Lost City is more than 600 years older and the only way to visit is through a multiday hike, which makes the scope of tourism more feasible to implement our device.

Figure 1: The Lost City site. Source: The Trek Blog

To understand the environmental characteristics of the Lost City, it’s important to identify the geography and ecological diversity of the Sierra Nevada de Santa Marta which surrounds it. The Sierra Nevada de Santa Marta (SNSM) is a coastal mountainous system rising 5,775 meters above sea level at a distance of only 42km from the Caribbean coast (UNESCO 1999). Covering an area of 17,000 square km, it has been designated as a strategic ecosystem by the National Environmental Plan due to its special characteristics in terms of biological diversity, endemism, and hydrological resources. Thirty principal rivers run down the face of the Sierra Nevada. Additionally, nine types of life zones or vegetation biomes are found in SNSM: dry tropical forest, very dry tropical forest, semi-desert, tropical rainforest, sub-Andean woodland, Andean woodland, Alpine meadow, tundra, and permanent snow.

The Lost City is located in the upper Buritaca River basin on the northern face of SNSM at around 900-1200 meters above sea level (Mazuera 2021). The Kogui people are the main inhabitants of the area, with some Wiwa villages also established in the region. In terms of identifying nearby water sources, the path tourists embark on goes along the Buritaca River with multiple river crossings throughout. From surveying pictures of the region and river, we have identified some potential cascades along the hiking route that could exert enough force to power our device. The weather in the region is warm and wet year round, being situated in a tropical rainforest biome. Temperatures average at highs around 30℃ (upper 80s ℉) during the day and at lows around 20℃ (upper 60s ℉) at night. Because of the heat, it is critical that hikers have ample access to a clean water source in order to stay adequately hydrated.

Figure 2: The Buritaca River along the Lost City route. Source: The Trek Blog

The Lost City is tightly regulated by the Colombian government and local indigenous groups. Because of this, only five tour groups are licensed to operate the four- to five-day trek. The trip begins in the city of Santa Marta, where Tourists are picked up and then driven 3 hours away to the starting point of the trail, El Mamey. The out-and-back journey spans about 47 km (29 miles) and requires ascending and descending 4 small mountains, twice (Gillespie 2019). In order to manage and preserve the ruins, the indigenous groups have placed a limit on the number of tourists allowed to visit the final Lost City. This number falls between 100-160 people, so one might estimate between 400 and 800 tourists in the park on any given day. Additionally, the Lost City is completely closed off to tourism in September to allow for the local tribes to conduct their traditional meetings in the temples. Accounting for the daily limits and months off, it's estimated over 25,000 people visit the Lost City annually (Global Heritage Fund 2023)

Currently, the only source of water for tourists on the Lost City trek is bottled water. Considering the journey ranges from 4- to 6-days and estimating the average person consumes 4 water bottles per day, one might estimate at least 450,000 water bottles being consumed on the trek annually (with 25,000 tourists). While it's expected that all hikers pack out their plastic waste, this has not been the case in practice, and the local ecosystem remains vulnerable to plastic pollution.

Figure 3: Map of the Sierra Nevada. Source: The Amazon Conservation Team

The legal structure and administration of the Sierra Nevada de Santa Marta (and therefore the Lost City) is complex. The Kogui, Wiwa, Arhuaco, and Kankuamo are indigenous to SNSM and their *ancestral* territory, as recognized by the Colombian government, is marked by the "Línea Negra" or Black Line, which forms a rings connecting all sacred sites extending from the Caribbean coast all the way to the peaks of the mountains and across the various valleys and rivers (Duran-Izquierdo 2021). However, the Colombian government recognizes their *legal* territory within the bounds of three reserves. The Lost City falls within the Resguardo Kogui Malayo Arhuaco (RKMA), in which the indigenous groups have official authority to grant permission, coordinate, and administer all projects and initiatives (Rainforest Trust). Under this agreement, the Kogui and Wiwa have the authority to ban plastic water bottles in the Lost City; but would need an alternative solution for tourists to have access to clean and safe water. Therefore, we hope our water filtration device can be adopted to support the Kogui and Wiwa in its efforts to eliminate plastic pollution in the region.

Prototype Design

The first step in the development of our prototype was completing another Pugh Decision Matrix to narrow down the most important aspects of the prototype we would design. The team needed to decide the way this device would be powered and the way this power would be transferred to the water filtration system. The team considered three potential prototypes, the first using an electric filtration system powered by solar, the second using an electric filtration system using hydropower, and the third mechanical filtration system driven by hydropower. The criteria the team used to compare these designs were innovation, cost, feasibility, and efficiency. The innovation criterion was aimed at capturing how novel a prototype of this design would be, as we wanted to create a system that was not already readily available to the clients. The team factored in the cost of creating the prototype because having a lower cost would increase the likelihood that the system would be adopted by the client or used for other applications. The feasibility of creating a functioning prototype was weighted heavily because it was important that we created a system that could meet the requirement of providing purified water. Finally, the efficiency of the system was taken into consideration in the last criterion.

Criterion	Criterion Weight	Idea #1: Solar Power Electric Filter	Idea #2: Hydropower Electric Filter	Idea #3: Hydropower Mechanical Filter

Innovation	0.3	2	3	4
Cost	0.2	2	3	4
Feasibility	0.3	4	3	4
Efficiency	0.2	3	3	4
Total Score	1	2.8	3.0	4.0

Table 1: Pugh Decision Matrix for Prototype

The design that used a hydro-powered mechanical water filtration consistently scored the highest among the three designs, leading to its selection as the prototype we would develop. Research into the three designs showed that while small-scale hydropower systems have been designed, there were not any prototypes that integrated them with water purification systems. The simplicity of a system that does not require the conversion of mechanical energy to electrical energy allows for fewer components, lower cost, higher efficiencies, and a greater chance that the prototype will function properly, allowing this design to score higher than the other two on the rest of the categories.

This decision-making process helped the team design and build a proof of concept prototype to prove the viability of small-scale water purification through hydropower to help meet the challenge of providing clean water for those hiking to the Lost City, along with rural communities throughout the developing world. The team also hopes that by completing the process of designing, building, and testing the prototype, the group can provide valuable insights to other groups, such as park officials for the Sierra Nevada de Santa Marta, looking to design and install similar systems.

The team has completed iterative design processes on the prototype, its subsystems, and individual components. The design consists of a hydropower turbine, a pump water filter, and integrative components, however much of the design work focused on developing a design that integrates an established turbine design with a water filter product. The focus was on the integration of these systems because the novelty of our prototype lies in the fully mechanical integration of a hydro-powered water turbine with a water purification system, as there are a number of well-established hydro-powered turbine and water purification designs.

Turbine and Water Filter Selection

The group considered several turbine designs for our prototype. Given the application of the system to rural communities near relatively small rivers, the turbine had to be able to be installed without a significant amount of additional infrastructure. This meant that the turbine should be able to function in a run of the river system and without a great head. These constraints, along with the fact that the group wanted to be able to 3D print the components of the turbine to allow for quick, iterative design, led the group to select a Pelton wheel design.. Important considerations for the design of our Pelton wheel included ease of construction, minimizing weight, and maximizing torque.

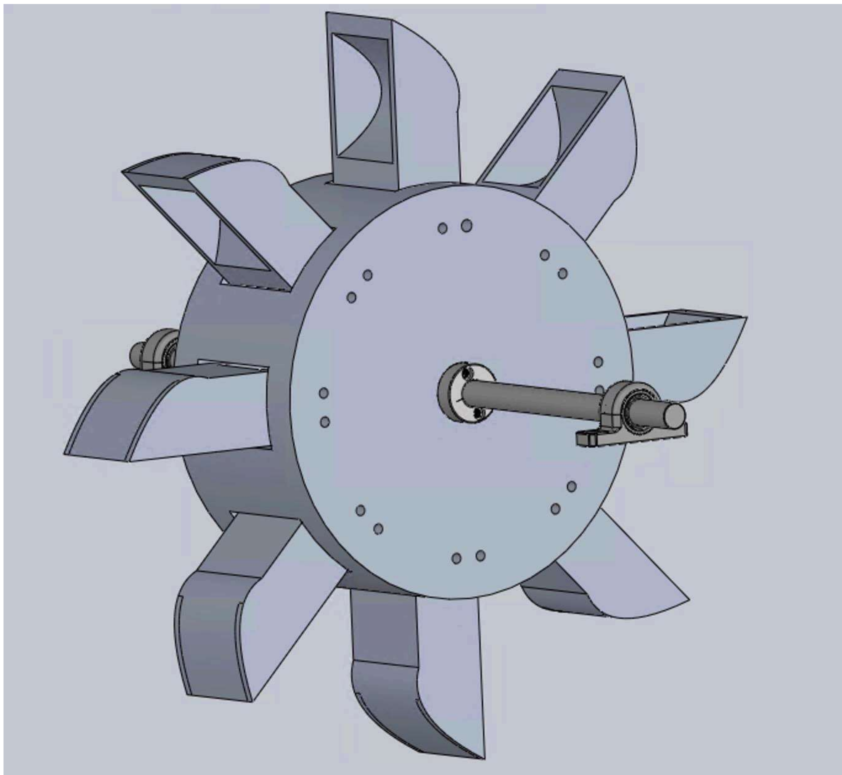

Figure 4: CAD rendition of our Pelton wheel design.

The team considered several factors when it was time to select the method of water filtration. First, the group completed research and conducted water tests to determine the contaminants that the purification system would have to filter out. The team also researched established designs and available products that could effectively pump and filter water for our application. In addition, our team considered the design of our integration components in conjunction with the purification selection in order to ensure that an effective integration between the turbine and water purification system would be possible. Through this process, we came to the conclusion that our system should be completely mechanical to eliminate the losses that would come from the conversion of the mechanical energy from the turbine to electrical energy to power a purification process. This decision added the additional constraint of selecting a pump and purification system that was entirely mechanical. Taking all of this into consideration, we elected to purchase the MSR MiniWorks EX Backpacking Water Purifier System, a product commonly used by backpackers to pump and filter water. The pump is powered mechanically through the displacement of a crank arm to suction water into a piston before it is forced through a water filter. The presence of both the crank arm and piston allowed multiple options to integrate the power from the hydro-powered turbine with the filtration system completely mechanically. This, along with the fact that the water filter in the system met the specifications necessary for our system and the cost of the product was well within the amount the team budgeted for a filtration system, led us to select to use this product in our prototype.

Integration Design

In the design of our integrated system, our team first considered the most important functions of the system, which are increasing the torque of the turbine, and thus the pressure used to pump and filter the water, and the conversion of the rotational motion of the turbine to the linear motion necessary to power the filtration system. In order to increase the torque produced from the water turbine our team decided to use the well established method of meshing two gears before the motion is translated to linear motion. Our design includes meshing a twenty tooth gear on an axle that is connected to the turbine with a sixty tooth gear, increasing the torque available by a factor of three. Our team considered a number of methods for the conversion of rotational motion to linear motion, but ultimately selected to use a slider-crank mechanism. This decision was made primarily on the efficiency of slider- crank mechanisms and our confidence in constructing it effectively.

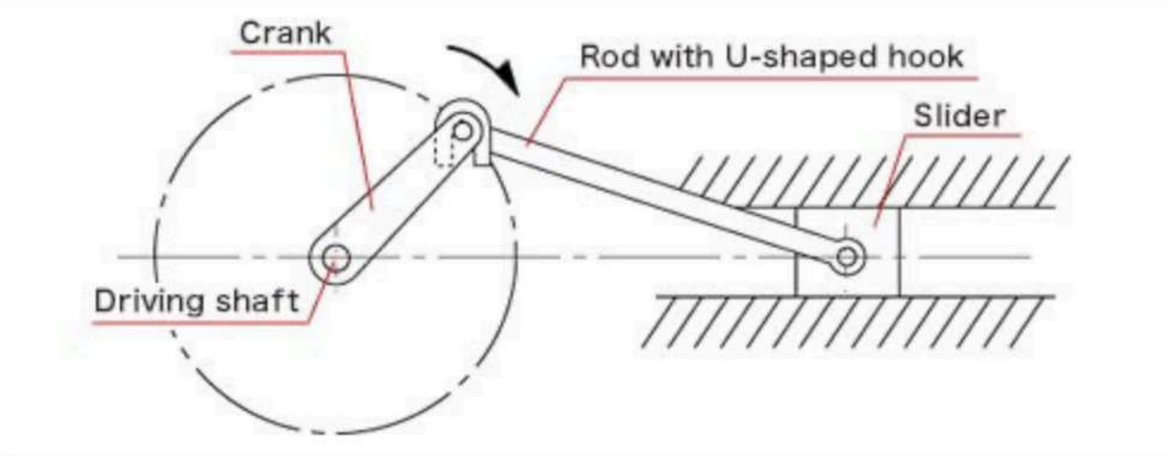

Figure 5: The slider-crank mechanism our integration subsystem is modeled after.

In order to apply this mechanism to our prototype designs were necessary a rod and its attachment to a rotating gear on one end and the water filter crank on the other. Our team selected to use an 18 inch long aluminum rod because it would be lightweight, its length would fit within the proposed structure of the system, and we could tap the ends of it using the machines available to us. These tapped ends allowed us to use rotating rod ends on both sides of the rod that would allow for a secure connection a bolt while allowing for the slight deflections that the motion of these parts would create. The rod-ends were selected based on the ability to fit within the tapped rod and to allow for bolts to fit tightly within the crank of the water filter and a hole designed into the gear. The spacing of the bolt on the gear was also designed for a full rotation of the gear, or twice the distance from the bolt to the center of the gear, to result in a full stroke length of the water filter crank. Testing integration design confirmed that these integration techniques were secure and allowed for the water filter and pump system to function as desired with the rotation of the gear.

Structural Design

The final step of the prototype design involved developing a structure that supported all of the components of the system and allowed them to function together properly. We designed and constructed a frame of one-inch 8020 aluminum based on the specifications of each of the components. We also designed and 3D printed a housing that supported the water filter and pump in a way that would allow for the crank to be displaced in a linear motion.

Figure 6: Water Filter Housing

In addition to the static structure, axles, housings, and collars were used to support the rotating components of the design and secure them to the framing. Two stainless steel half-inch axles were each connected to the framing with a set of lube-impregnated bronze bushings. Collars that clamped onto the axles allowed for components to be connected to them; bolts were used to connect the turbine and twenty-tooth gear on one axle and the sixty-tooth gear on another axle. These components were chosen based on their function, cost, and efficiency. The team tried to use stainless steel components as much as possible, due to the durability and corrosion-resistant properties of this material. Aluminum, a slightly softer metal, was used in some places because of its affordability and corrosion-resistant properties. Uncoated steel was avoided because of its tendency to rust in wet environments.

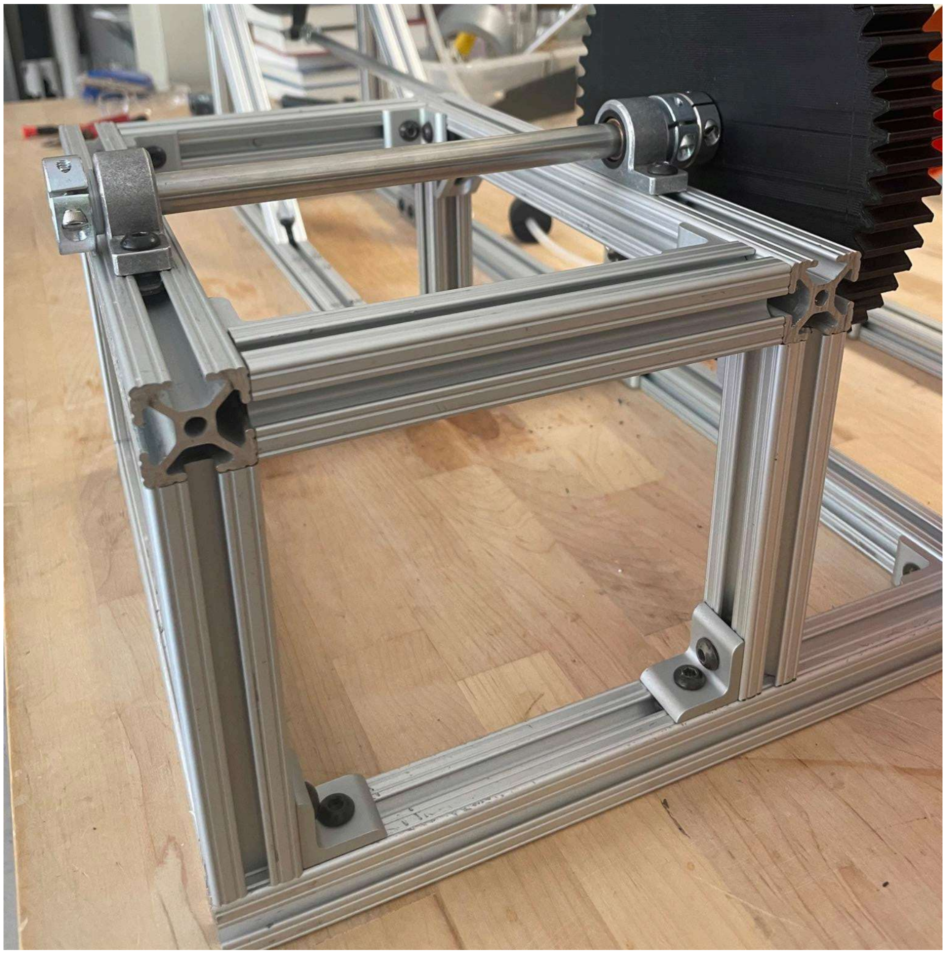

Figure 7: Framing, Collars, and Axle

Final Prototype and Testing Results

Figure 8: Final Prototype

Our final prototype, pictured above in Figure 8, was able to function as desired during testing. Our team conducted both manual testing where the turbine was rotated by hand, and more robust testing that included a “simulated head” setup; this allowed us to confirm its ability to function using hydropower, verifying that the system could function in an environment with water, and quantify the head used to power the system. When manually spinning the turbine, it was demonstrated that our system could purify up to 580 ml of water a minute when the turbine was rotating at a speed of 120 revolutions per minute. These results show that if our prototype functioned continuously over the course of a year, it would be able to produce over 300,000 liters of potable water, the equivalent of over 600,000 standard sized water bottles. Ideally, the translational speed of the pelton wheel would be half of the translational speed of the water that is moving the wheel. If we are assuming this phenomena, the head height to produce this 120

RPM of the pelton wheel would be 1.9 meters. This is assuming no loss of energy due to non-conservative forces.

The group then wanted to test the prototype with running water to see how efficient the pelton wheel is and to see how energy could get transferred through the device to the pump. PVC pipe was used to create 10 ft (3.05 m) of simulated head. A 90 degree connector was attached to the bottom to direct the waterflow horizontally, and a 0.5 inch outlet was attached to the end of the 90 degree coupling. The group attached a running hose to the top of the PVC pipe to ensure that the water was replaced in the pipe as water came out of the outlet at the bottom. The testing apparatus is shown in Figure 9 below:

Figure 9: Testing Rig

Using this testing setup, the team found that 3.05 meters of head would spin the pelton wheel at 150 RPM. Using energy balancing, 3.05 meters of head would create a theoretical translational water speed of 7.73 m/s at the bottom outlet. Based on the pelton wheel spinning at

150 RPM, the experimental translatoinal speed of the pelton wheel was 2.99 m/s. The ratio of pelton wheel speed to water speed was ideally assumed above to be 0.5. However, the actual experimental ratio turned out to be 0.387. This was a pleasing result to the team - the pelton wheel could definitely be designed to extract more evergy from the flowing water, but the current setup was still able to extract significant amounts of energy from the flowing water. Taking the data collected from manually spinning the pelton wheel, the group was able to interpolate the number of water bottles the device could purify over the course of a year based on actual head height. It was assumed that the rate of purified water per rotation of the peloton wheel was constant. This lead the group to find that with 1 meter of head, the data could be extrapolated to purify 444,000 standard water bottles (0.5L) annually. With 2 meters of head, the data could be extrapolated to purify 628,000 standard water bottles (0.5L) annually. With 3.05 meters of head, the device could purify 775,000 standard water bottles (0.5L) annually. With more head, even more water bottles could be purified.

The team would like to make some improvements to the prototype, if given more time. A more efficient pelton wheel could be designed with a comprehensive CFD analysis - this would allow the wheel to extract more energy from the flowing water. The team would also like to look into solutions for increased filtration capabilities, such as being able to filter viruses form the river water. Finally, the team would like to explore a welded metal structure as opposed to extruded aluminum - this will create a more robust design that is not susceptible to connectors loosening over time.

These results were encouraging, as the rivers along the trail to La Ciudad Perdida in Santa Marta de Sierra Nevada National Park, along with most water sources where we could apply our prototype, certainly contain rapid elevation changes of 1-3 meters.

Cost Analysis

The total cost of the prototype design is shown in Figure 10 below:

Item	Cost	Units	Total Cost
Bronze Bushings	$15.41	4	$61.64
Stainless Steel Round	$53.52	1	$53.52
Face mount collars	$16.00	3	$48.00
Collars	$9.60	4	$38.40
PTFE shims	$8.81	1	$8.81
Aluminum link	$4.77	1	$4.77
Rod Ends	$5.43	2	$10.86
Pump	$129.95	1	$129.95
Extruded Aluminum (8 ft)	$44.32	2	$88.64
Extrusion Connectors	$4.01	38	$152.38
Misc hardware	$50.00	1	$50.00
2000 g PLA	$0.05	2000	$100.00
		Total Cost:	**$746.97**

Figure 10: Final Prototype

The total build cost for our initial prototype was less than the $746.97 listed above. Extruded aluminum, extrusion connectors, and the Aluminum link were already available in the teams' lab space; therefore, the total build cost for the initial prototype that the team fabricated was closer to $501.18. If this product were to enter mass production, the team believes the cost to produce each unit would decrease significantly. By implementing strategic design changes to enhance the product's manufacturability and durability and leveraging economies of scale through bulk material procurement, the team believes it can significantly reduce the per-unit cost of each product without compromising on quality.

Environmental Benefit Analysis

Colombia is highly vulnerable to the impacts of climate change and environmental degradation, despite being a relatively low greenhouse gas emitter globally. Protecting its rich biodiversity and ecosystems like the Sierra Nevada de Santa Marta is crucial for mitigating climate risks, maintaining vital environmental services, and achieving sustainable development goals. As outlined in Colombia's National Determined Contributions, top priorities include combating deforestation, restoring ecosystems, transitioning to renewable energy, and implementing climate-smart agriculture practices. However, a productive step towards all of these goals is ensuring that clean drinking water is readily and sustainably available.

The Sierra Nevada de Santa Marta region in particular faces immense pressure from drivers like illegal mining, deforestation for agricultural expansion, tourism development, and the compounding effects of climate change. According to ecosystem assessment studies, these interlinked human activities generate pollution, habitat loss, and disruptions to the area's delicate mountain, forest, and wetland ecosystems. In addition, plastic waste is a pervasive threat in both the Sierra Nevada de Santa Marta and the wider world, with freshwater ecosystems worldwide contaminated by microplastics and associated toxins that bioaccumulate up the food chain.

There are certainly incentives for plastic usage in the Sierra Nevada Park: plastic is a cheap and accessible option to make drinking water easier. But the downsides far outweigh the benefits: once the plastic ends up in the rainforest, it takes over one thousand years to decompose. There are several issues that plastic contributes to before it completely decomposes. The first of these is microplastics: microplastics are small pieces of plastic measuring less than five millimeters. Researchers in Germany have warned about the long-term negative effects of them in soil, sediments, and freshwater. “Earthworms, for example, make their burrows differently when microplastics are present in the soil, affecting the earthworm’s fitness and the soil condition." (UN Environment). This will further impact the flora and fauna in the area, which are dependent on earthworms as a vital contributor to a number of important ecosystem services. Microplastics also release additives such as phthalates and Bisphenol A (widely known as BPA). This can lead to disturbances in the hormone systems of both vertebrates and invertebrates. In elevated temperatures, as observed in Sierra Nevada, it emits an increased quantity of substances such as fire-retardants, parabens, artificial dyes, and various other compounds into soil and water systems. These substances then stick to different particles, resulting in their persistence and long-term presence within those ecosystems.

In Sierra Nevada, there is not only a physical change in the environment due to increased plastic pollution happening, but also a cultural change regarding the environment and the indigenous population. Taking the Kogui tribe as an example, originally Kogui priests believe that between man and nature exists an equilibrium that can easily be disturbed by human action. Although this equilibrium refers to a spiritual and moral balance of the individual, it also refers to irresponsible resources, water management and forest conservation. They are very aware of their environment. Their ecological awareness has heightened as indigenous groups were forced higher into the mountains by settlers. It is still important to note that plastic pollution is not the first environmental change in the region. After colonization there was an agricultural change from an intensive maize cultivation to planting many other crops such as plantains, bananas, yams, potatoes, pigeon peas, sugar-cane, mango, and others. Still, this has a significantly lower impact on the environment than plastic pollution.

Our modular water purification device directly tackles this issue of plastic pollution while supporting Colombia's adaptation efforts. Our testing results show that we can significantly filter for particulate matter (PM), such as soil and detritus particles.

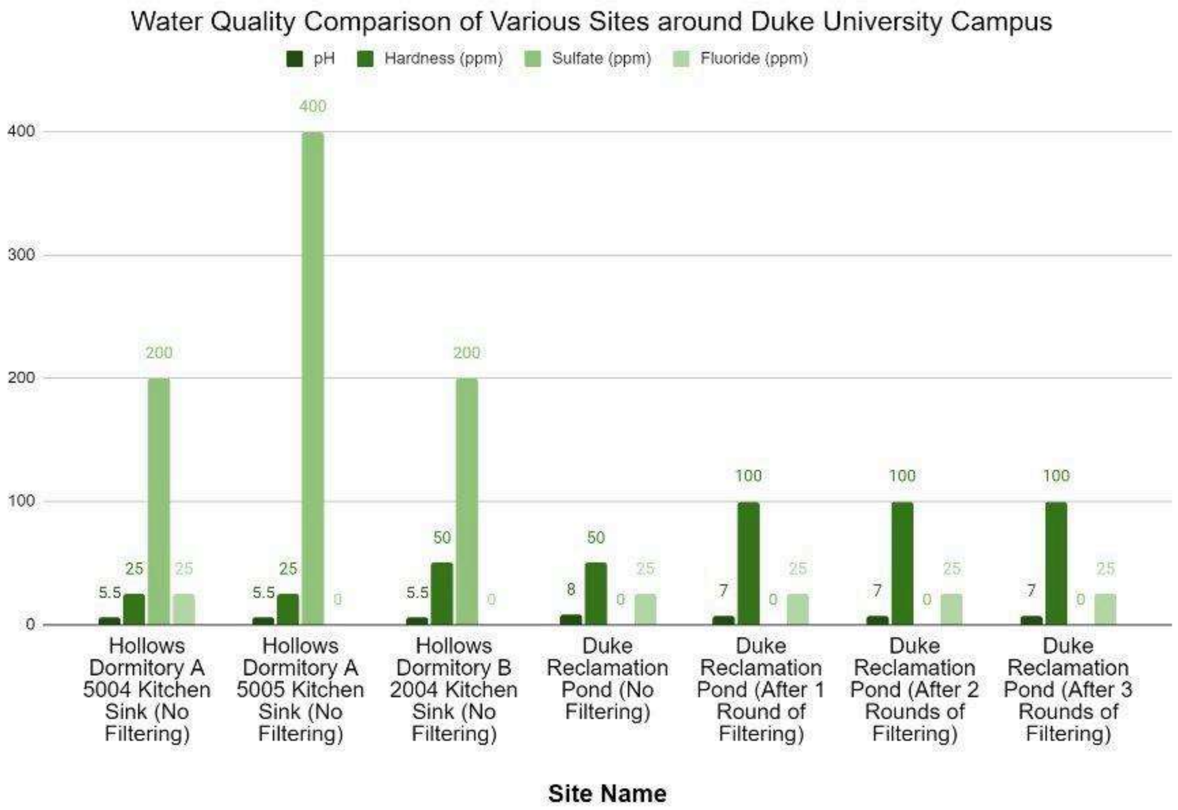

Figure 10: Water Quality Comparison of Various Sites around Duke University Campus. Parameters include pH, hardness (ppm), sulfate (ppm), and fluoride (ppm). Duke Reclamation Pond results demonstrate water quality after increasing the number of rounds of filtering with the device.

Using the Bomsit Drinking Water Testing Kit, we tested for the following water quality parameters: metals (copper, lead, zinc, mercury, manganese, and iron), physical properties (pH, hardness, total alkalinity), and inorganic substances (fluoride, sulfate, sodium chloride, total chlorine, hydrogen sulfide, nitrate/nitrite). At sites tested on Duke University's campus, we discovered several violations of the EPA Primary and Secondary Drinking Water Standards, such as low pH, high sulfate concentrations, and high fluoride concentrations. Though the filter cannot effectively alter pH or remove fluoride and sulfates, these contaminants are not commonly found in biomes like the Sierra Nevada and will not be considered in the scope of this study.

Qualitative visual comparisons between water samples were also utilized to test the filter's effectiveness in removing PM. The filter was particularly successful in removing PM from Duke Reclamation Pond water samples. Qualitative comparisons note that, without filtering, water samples were "brown, cloudy, and translucent" and by the third round of filtering, water samples were "clear, transparent, and showed no visible signs of PM presence." In high energy riparian biomes like the Sierra Nevada, PM may be commonly found in river water samples, particularly in the aftermath of fluvial flooding events. Hence, the filter may prove to be helpful in removing those substances from drinking water sourced from riparian environments.

By providing a renewable, decentralized clean water source, our prototype eliminates the need for thousands of single-use plastic bottles annually in indigenous and rural communities as well as from tourists and trekkers visiting the Sierra Nevada de Santa Marta's protected areas. Reducing tons of plastic waste each year translates to preventing the equivalent of millions of microplastic particles from entering sensitive terrestrial and aquatic habitats. Furthermore, the device is designed to have a near-zero carbon footprint and minimal resource use. This aligns with Colombia's goal of developing sustainable infrastructure solutions, especially in vulnerable regions impacted by climate change.

Social Benefit Analysis

Our device would aid with Colombia's goals of reducing plastic waste. Recently, Colombia has specifically sought to curb the amount of urban plastic waste that is making its way into marine ecosystems. For example, in 2023 Colombia, Jamaica, and Panama approved a

$42 million project designed to reduce the amount of plastic that enters our oceans by introducing a circularity to the way we design, make, use, and discard plastic products. This is estimated to reduce the number of plastics in the oceans by 80%, save governments $70 billion in less than 20 years, and create an additional 700,000 jobs by 2040 (UN Environment 2023). Colombia also passed a law in 2023 that has placed a ban on 14 different types of single use plastics. Other goals included in this law include having at least 25% of plastic packaging containers and eating utensils be recycled, having 100% of single use plastics be either be reusable, recyclable, or compostable by 2030, and having all single-use plastics should have a minimum average content of 30% recycled material by 2030 as well (Zero Waste Europe 2024). By integrating this device within the Lost City as well as potentially expanding its integration into other areas of SNSM and parks in Colombia, Colombia is better able to tackle the widespread issue of plastic pollution. Plastic that accumulates in the rivers of SNSM can eventually make its way to the nearby ocean, not only threatening the biodiversity within SNSM but also the vulnerable marine ecosystems.

Importantly, this device allows the Kogui to exert more autonomy on their land and align the practices of tourists more toward their cultural values of environmental preservation and sustainability. From our discussions with Duke University Professor Dalia Patino Echeverri, we learned that the Kogui and other tribes had the authority and desire to ban all plastic water bottles from the Lost City in order to protect their land from pollution and microplastic accumulation. However, at the time, they needed an alternative which would provide tourists with clean and safe water. Because our device is modular and relatively small for the amount of water it filters, we anticipate placing it along the Buritaca River will present little ecological disruption while eliminating a much more prescient threat to biodiversity–plastic pollution.

Additionally, there are health benefits to eliminating plastic water bottle consumption. Recent studies have highlighted the threats of accumulation of microplastics within humans, linking these plastic compounds which contain endocrine disrupting and carcinogenic chemicals to a higher risk of cancer, reproductive issues, metabolic disorders, asthma, neurodevelopmental disorders, blood disorders, and nervous system damage (Campanale et al. 2020). While plastic water bottles are not the only source of plastic which ends up in human systems, working towards eliminating this source is especially impactful, considering its prevalence of usage globally. If our prototype can provide clean and safe water and eliminate further exposure to microplastics, it becomes an obvious choice to not only protect the natural environment but also the person's long-term health. While we anticipate there may be some hesitation amongst tourists to let go of their filtered plastic water bottle for the filtered river water, we hope that by educating those about the dangers of microplastics in human systems and the safety of our filters that adoption will be widespread. For the Lost City, this becomes less of an issue since the Kogui have the authority to ban, giving tourists no choice but to consume the filtered water.

Further, we anticipate that the locals can utilize the filtered water for their own consumption needs. The cleaner water produced from our device may lower the risk of contracting a waterborne disease as well as provide them with higher quality water free of particulate matter, bacteria, sulfates, and with a better pH.

A final consideration of our device are the economic benefits. One issue we learned about in our primary diligence on the Lost City was that plastic water bottle sales currently serve as a source of income for some locals. Because of the isolated nature of the journey, locals who transport supplies up the mountain are able to charge a premium for water bottles for as much as 6 times what it would cost in town at the start of the journey. For example, a water bottle can be purchased at 1000 pesos in Santa Marta, but upon visiting the villages further up the mountain, water bottles are often sold at 6000 pesos. Eliminating all plastic packaging and water bottles from the park would result in a loss of financial benefit for many individuals who reside in the various villages along the journey. Thus, implementing this solution would require an alternative source of profit that can benefit the locals. While there are many possible solutions, we envision laying out a framework in which the rights to the purified water produced by our device would fall with the Kogui and Wiwa. They would either 1) sell this purified water directly to tourists or 2) require all tour companies to add a mandatory water fee to the overall trip cost, where 100% of the water proceeds return to the indigenous groups. These proceeds can then be distributed among the locals or used to improve facilities and services within the villages. Another solution which would place income on individual economic agents would be to provide locals with reusable water bottles which they can sell in place of the plastic water bottles at the start of the journey. The water bottles can be branded with a Lost City logo, so it holds some sentimental value and serves as a souvenir for trekkers. Additionally, these water bottles showcase the park's commitment to ecological preservation and sustainability, as well as advertise the Lost City once taken home. Our team would work with the Kogui and Wiwa to help procure and design these bottles.

Business Plan/Device Integration Plan

The first phase of our business plan is to integrate the prototype within the Lost City. This first requires our team to visit the Lost City and survey points along the Buritaca River that would best hold our device. Once we've identified where to install the device, we will work to design adequate mounts/infrastructure to secure our device in the river and ensure its resistance to rising water levels and natural events.

Once we have a specific plan of integration, we will apply for funding through a government grant or collaborate with a NGO to fund the project. A potential grant could be sourced from Roots RFA Colombia, an affiliate of the U.S. Agency for International Development (USAID) that provides funding for projects which support self-determined development of indigenous and Afro-Colombian populations and encourage their participation in peacebuilding and sustainable development (USAID 2024). We believe this project hits all the objectives of Roots RFA Colombia, including cultural preservation through biodiversity conservation (via eliminating plastic pollution); environmentally sustainable and socio-economic opportunities fostered and created (via purified water ownership and reusable bottle sales); territorial governance advanced (via Kogui autonomy in banning plastic water bottles); and cultural appreciation (via sustainable ecotourism to the Lost City site). We will work toward securing enough funding so that there is zero out-of-pocket expense for the Kogui and Wiwa tribes.

Once a grant is secured, we will work closely with the Kogui and Wiwa tribes to install the device. Additionally, we will ensure that local agents are adequately trained to maintain and service the device with new filters so that it continues to function smoothly without the need for an outside party.

After successful implementation of the device within the Lost City, we would seek to expand its integration and market to other tourist areas of the Sierra Nevada de Santa Marta. For this second phase of our business plan, we would work more closely with the Colombian government and other indigenous groups as our client. Whether we seek further NGO or USAID funding or turn to a more for-profit model would depend on the Colombian government's willingness to purchase the device. We would also work to market the device globally to other national or local parks which receive annual tourism in the 10,000's of visitors (which our device is designed toward). By having its already successful implementation in the Lost City as a case study/trial run, we believe our device will be more marketable to other parks. With more clients and customers, we anticipate our ability to reach greater economies of scale and lower our supplies and production costs to make our device more affordable for customers.

Conclusions and Recommendations

The development and testing of our prototype proved the potential for a small-scale hydro-powered water filtration system with our design to eliminate single-use plastic water bottle waste in national parks (such as the Sierra Nevada de Santa Marta) and other remote areas, providing clean water for tourists and locals. While the results are promising though, moving forward there are further technical improvements that would be necessary for a practical application of our prototype. For instance, incorporating a more robust filter for rivers with higher sediment loads as well as viruses would be beneficial to the utility of our product. Furthermore, conducting longer-duration field testing in the target environment would be optimal as a final test before implementation in the park; these tests would provide insight into the system's resilience against extreme weather events, fluvial flooding, and interferences from the tourism industry.

Before deployment, it is recommended to reach out to form inroads and collaborate with local partners like indigenous communities and tour operators, as well as complete a more comprehensive assessment of life cycle costs. Deployment of the device would also require training these groups on proper use and maintenance (ex. changing the filters) of the device. Additionally, it is suggested that these groups are equipped with the resources necessary for long-term maintenance (ex. sourcing the filters) so that the device can successfully provide safe drinking water for years to come.

Overall, our findings indicated that our device has the potential to provide a renewable, low-cost solution for safe drinking water access that eliminates plastic waste in ecologically sensitive areas globally, and that its successful implementation would yield environmental, social, and economic benefits.

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