Evaluating the Potential Role of Drones in Environmental Mitigation

An Interactive Qualifying Project proposal to be submitted to the faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Science

Submitted by:

Brady Jeong
Amber Lindberg
Grace Richards
Mitra Tabandeh

Submitted to:

Professor James Chairelli, Advisor
Professor Robert Kinicki, Co-Advisor
Worcester Polytechnic Institute

Sponsored By:

Mirei Endara
Association Marea Verde Panamá

Authorship

Section	Primary Author(s)	Editor(s)
Chapter 1: Introduction	Amber Lindberg	Brady Jeong
Chapter 2: Background	All	Brady Jeong
2.1 Matias Hernandez River	Amber Lindberg	Brady Jeong
2.2 River Pollution	Grace Richards	Brady Jeong
2.2.1 The Local Community	Grace Richards	Brady Jeong
2.2.2 Pollutants	Grace Richards	Brady Jeong
2.2.3 Types of Plastic	Grace Richards	Brady Jeong
2.2.4 Panamanian Waste Laws	Grace Richards	Brady Jeong
2.2.5 National Environmental Efforts	Grace Richards	Brady Jeong
2.3 Marea Verde	Brady Jeong	Grace Richards
2.3.1 Affiliations and Recognition	Brady Jeong	Grace Richards
2.3.2 Cleanup Efforts	Brady Jeong	Grace Richards
2.3.3 Utilization of Recycled Waste	Brady Jeong	Grace Richards
2.3.4 Environmental Education	Brady Jeong	Grace Richards
2.4 Potential Mitigating Technologies	Grace Richards	Brady Jeong
2.4.1 Drones	Mitra Tabandeh	Brady Jeong
2.4.2 Sensors and Cameras	Amber Lindberg	Amber Lindberg
Chapter 3: Methodology	Grace Richards	Brady Jeong
3.1 Current Environmental Drone Usage	Grace Richards	Brady Jeong
3.1.1 Remote Sensing of Coastal Algal Blooms	Grace Richards	Brady Jeong
3.1.2 Restoration Monitoring in Cut-Over Bogs	Grace Richards	Brady Jeong
3.1.3 Assessment of Microbial Water Quality in an Irrigation Pond	Grace Richards	Brady Jeong

3.1.4 Relevancy of Research	Grace Richards	Brady Jeong
3.2 Social Perception of Drones and Environmental Pollution	Grace Richards	Amber Lindberg
3.2.1 Interviews of Marea Verde Staff	Grace Richards	Amber Lindberg
3.2.2 Interviews of Panamanian Locals	Grace Richards	Amber Lindberg
3.3 Feasibility of Drones in Pollution Investigation	Grace Richards	Brady Jeong
3.4 Timeline	Amber Lindberg	Brady Jeong, Grace Richards
Appendix A: Interview Format for Marea Verde Staff	Amber Lindberg	Amber Lindberg
Appendix B: Interview Format for MHR Community Residents	Amber Lindberg	Amber Lindberg

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Pollution of waterways and rivers is an ongoing issue all over the world. Solid waste ends up in rivers, littering surrounding beaches, and flowing into the oceans. This marine pollution includes all types of manufactured products, especially plastics. Most of these products end up in rivers and other connecting bodies of water through littering, storm winds, and poor waste management. In fact, about 80 percent of the debris present in the world's waterways comes directly from land sources (National Geographic, 2019). The largest form of marine pollution in Panama is due to improper disposal of trash. Panama contributes to an estimated 100,000 plus tons of marine pollution a year (Leachman, 2020). The waste that plagues the rivers and beaches of Panama has caused several issues, specifically floods due to drainage issues after heavy rains (United Nations, 2017.). In Latin America, Panama is a leader in tackling these environmental issues with their efforts to ban plastic bags in 2019 and joining the UN's CleanSeas Campaign. Beyond these endeavors, there remains a large amount of work needed in Panama to successfully solve the ongoing pollution problem.

Due to regular improper waste disposal, the Matías Hernández River Basin's surrounding ecosystem has received irreparable damage and that will only worsen without real change. As one of the main rivers of Panama City, its pollution affects not only the immediate community, but also the entirety of the city. Marea Verde, a non-profit organization based in Panama City, is working to combat river pollution in the Matías Hernández River (MHR) through their extensive cleanup activities and efforts to educate the public on their effects on the environment (Marea Verde, n.d.). By both cleaning up the river and educating the public, Marea Verde is hoping to promote a new generation of environmentally responsible citizens. They have worked previously with the Green Classrooms program to educate the population on the environment, implemented

awareness campaigns, developed innovative cleaning initiatives in the Matías Hernández River Basin, and promoted sustainable alternatives for waste disposal.

Starting with projects to clean up rivers, Marea Verde has a vision to integrate modern technologies with their mission to reduce solid waste from all marine areas in Panama. They are considering the use of drones and remote controlled aircraft platforms in conjunction with various camera technologies for data collection purposes. The data collected by this technology is largely centered around the determination of 'hotspot' source locations of waste and identifying the types of plastic waste. With this data, Marea Verde seeks a quantitative assessment of plastic waste in the river to inform a public outreach strategy.

The essential goal of this project is to aid Marea Verde in evaluating the feasibility of drones in environmental mitigation so that Marea Verde can implement more directed initiatives in educating the local communities. We will accomplish this from a technical perspective by conducting a case study on drones collecting similar data in various environmental scenarios. From a social perspective, this project will conduct interviews of those living in the local communities surrounding the MHR basin as well as the staff of Marea Verde. Both archival research and investigative interviews are essential in identifying the technologies that will be instrumental in accomplishing our goal.

Chapter 2: Background

The issue of river pollution is on the forefront of environmentalists' minds in Panama, especially in Panama City and its surrounding communities. According to the Inter-American Development Bank and the Pan American Health Organization, Panama has the second highest production of waste per inhabitant per day in Latin America (Marea Verde, n.d). The first section of this background chapter discusses the Matías Hernández River, with a focus on its unique conditions and geography. The next section delves into the organization that is our sponsor, Marea Verde, and the measures they have already taken to reach their goals. These measures include the implementation of environmental education into the local community, as well as advancements in waste cleanup and collection. The final sections of this chapter introduce the possibility of drones for the use of data collection and situations where drones have been beneficial for environmental projects will be discussed

2.1 Matías Hernández River

The Matías Hernández River(MHR), a small river located in the San Miguelito District of Panama City, Panama, is one of the seven rivers located in Panama City. Originating at Sonsonete Hill, the entirety of the Matías Hernández Riverspans nearly 28 km (see Figure 1). The watershed of the river covers approximately 2,062 hectares, about 5,095 acres, with nearly 90% of the watershed being residential and commercial communities. Along with the other rivers of Panama City, the Matías Hernández River contributes to the estimated 480 tons of waste that flows into the Panama Bay daily (Marea Verde, n.d.).

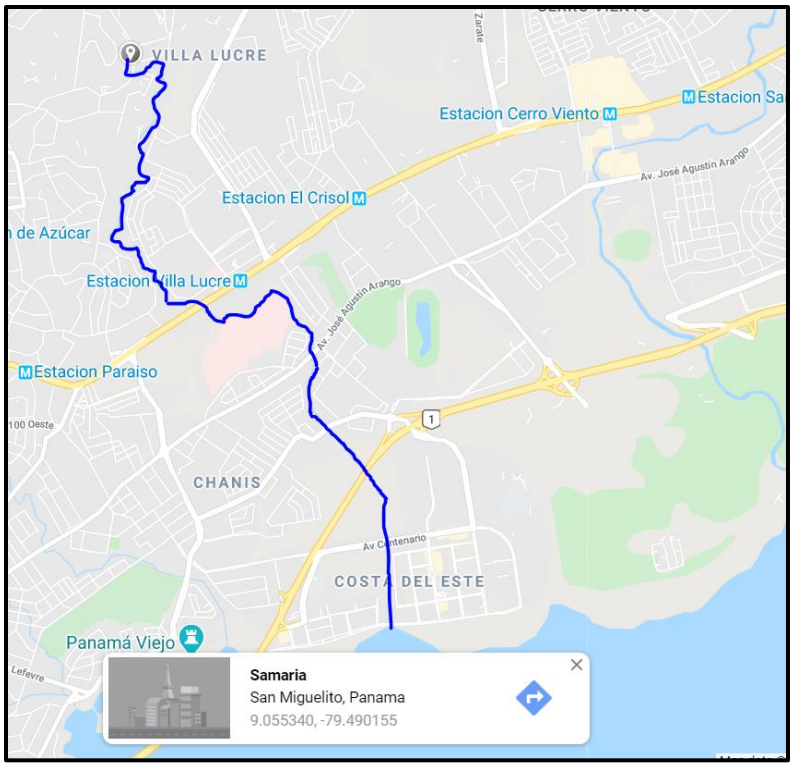

Figure 1: Map of the Matías Hernández River(Google Maps, 2020).

2.2 River Pollution

2.2.1 The Local Community

Solid waste pollution of the Matías Hernández River basin is largely due to the illegal dumping of waste by various local communities along the river bank. These local communities are mostly residential or commercial and consist of many low income residents that lack adequate waste management systems. There is no general system in place that residents can easily take advantage of to dispose of their waste in an environmentally friendly way (Marea Verde, n.d.). Consequently, these people have resorted to dumping most of their waste into the river. With approximately 356,000 people in the communities along the river, this waste accumulation has caused serious and even irreparable damage to the environment (Marea Verde, n.d.).

2.2.2 Pollutants

Because of the location of the source of dumped waste, a large mass of waste flows continuously down the river, eventually reaching the coast. Here this waste volume combines with the various other wastes brought in by the sea currents and contribute to an even larger pollution issue. Within this accumulation, many different forms of waste are present, such as toilets, refrigerators, washing machines, mattresses, car parts, tires, shoes, toys, and much more. With the mere size and volumn of these individual items, the accumulation dramatically increases the difficulty of the cleanup process. Beyond these items, the main pollutants are plastic bottles and utensils (see Figure 2). As plastics take hundreds of years to degrade, they pose the largest lasting environmental issue to the Matías Hernández River. In fact, over 55% of the trash present in the Matías Hernández River is plastic (Leachman, 2020).

Figure 2: Accumulation of solid waste, specifically plastic bottles, in the MHR basin (Marea Verde, 2018).

2.2.3 Types of Plastic

With plastics being the main pollutants of the Matías Hernández River, identifying the various types of plastic among the waste is a valuable step in controlling the pollution issue.

The Society of Plastics Industry (SPI) classifies plastics into seven different categories, each with a specific SPI code, or number, which manufactures generally mold into the bottom of the product. This makes the type of plastic easily identifiable (see Table 1). The first category of plastic is Polyethylene Terephthalate (denoted as PET), which is the most commonly recycled plastic and often used in the production of beverage bottles, medicine jars, rope, clothing, and carpet fiber. The next plastic category is High-Density Polyethylene (denoted as HDPE), which is also commonly recycled and used in many household product containers, such as for milk, motor oil, shampoo and conditioner, soap, detergent, and bleach. The next two categories, Polyvinyl Chloride (denoted as PVC) and Low-Density Polyethylene (denoted as LDPE), are only sometimes recycled. Plumbers commonly use Polyvinyl Chloride, better known as PVC, when installing pipes. Low-Density Polyethylene, a comparatively "healthy-plastic", is known for its durability and flexibility (Ryedale, n.d.).

The fifth category of plastic, Polypropylene (denoted as PP), is only occasionally recycled. Since this relatively strong plastic can withstand high temperatures, manufacturers often use PP to create plastic bottle caps. Like PET and HDPE, Polystyrene (denoted as PS) is difficult to break down and reuse. Common products containing PS include disposable coffee cups, plastic cutlery, and packing foam. The final type of plastic classified by the SPI is OTHER, a category designated for miscellaneous plastics that do not fit into the other six categories. Among these plastics are Polycarbonate and Polylactide, which are both extremely difficult to break down and recycle (Ryedale, n.d.). The identification of the SPI codes of plastics present in the river's waste is important because this information is essential in sorting plastic waste for recycling.

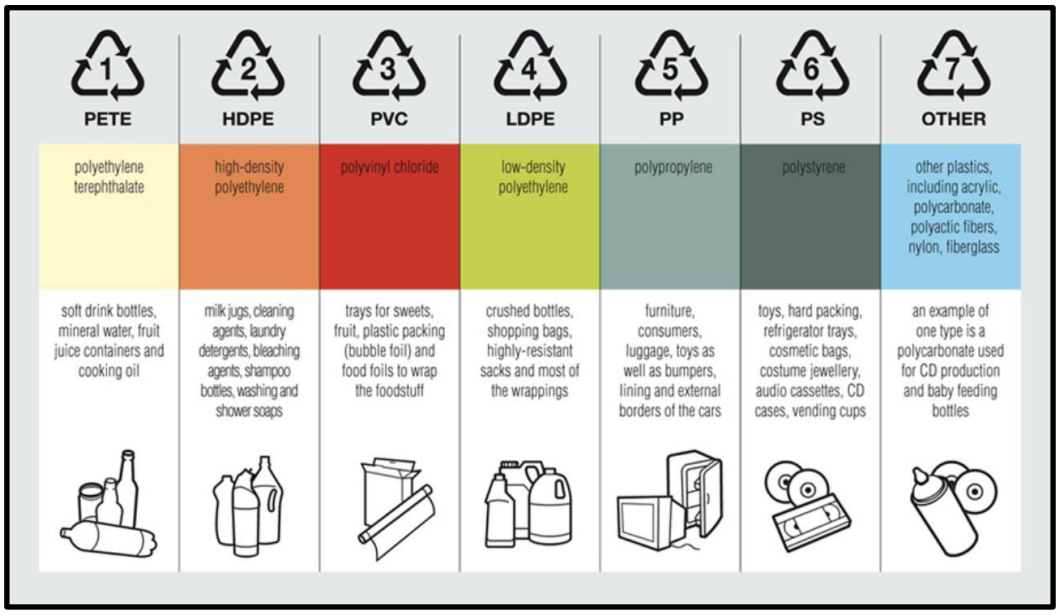

Table 1: Seven categories for plastics classified by the SPI (PolyChem, 2017).

2.2.4 Panamanian Waste Laws

In May 2018, the National Congress of Panama passed *Law No. 33 on Integrated Waste Management and Zero Waste Policy* which establishes a policy and active framework working towards a successfully integrated solid waste management system. The Zero Waste Policy centers around a closed-cycle waste system where communities recycle and utilize waste products as resources “to achieve the greatest economic, environmental and social use of waste materials, as well as to generate employment and reduce pollution” (Verisk 3E, 2018). Some fundamental principles of this policy include recognizing a shared waste management responsibility, the establishment of a hierarchy of waste management, and the internalization of waste based on disposal costs. With these guidelines, Panama put the Zero Waste policy into effect in November 2018 (Verisk 3E, 2018).

2.2.5 National Environmental Efforts

In addition to plastic water bottles, plastic bags are a huge contributor to the solid waste in the Matías Hernández River basin and other areas in the country. To combat the accumulation of plastic bag waste, Panama became the first Central American country to ban the use of plastic bags in 2019 (Moreno, 2019). Additionally, Panama became the first Latin American country to join the UN Environmental CleanSeas Campaign, which centers around fighting marine plastic pollution (Clean Seas, n.d.). Furthermore, the Panamanian government and community has explored a variety of initiatives and pilot programs concerning solid waste cleanup efforts, sparking the establishment of environmental organizations, like Marea Verde.

2.3 Marea Verde

Marea Verde started in 2017 as a non-profit organization and a "concern of citizens of a community in which, despite the cleaning campaigns carried out each year, they continued seeing a lot of garbage and a problem that was not resolved" (Marea Verde, n.d.). Their core mission is to take action and raise awareness of potential strategies to mitigate solid waste pollution in the rivers and coasts of Panama, especially the Matías Hernández River. Marea Verde's efforts involve not only the clean up of solid waste but also the education of the local community on the environmental effects of pollution. Additionally, they look to strengthen alliances with civic groups as well as public and private institutions, to promote actions for change.

2.3.1 Affiliations and Recognition

Current affiliates of Marea Verde include Morgan & Morgan, Panama Waste Management, and the Panama Trucking Corporation. The work of Marea Verde is recognized nationally with numerous awards including the "Positive Environmental Sustainability" award (Marea Verde, n.d.). In January 2020, the Benioff Ocean Initiative selected Marea Verde as one of the nine river clean-up programs across the world "to receive a total of $11 million [US dollars] over the next three years as part of a unique partnership between The Coca-Cola Foundation and the Benioff Ocean Initiative" (Coca Cola, 2020). Marea Verde intends to expand upon their cleaning initiative and develop innovative strategies to collect and analyze the pollution in the rivers of Panama with this generous funding. They plan to "integrate technology and artificial intelligence into [their] project", helping them more effectively collect trash, generating "pertinent data and [developing] the capacity to work with communities" (Leachman, 2020).

2.3.2 Cleanup Efforts: Barrera o Basura

Marea Verde's first project in the physical cleanup of accumulated waste in the Matías Hernández River basin was the installation of the Barrera o Basura (BoB), a single barrier on the MHR that traps the waste that the riverbed brings (see Figure 4). This is a system tested in other countries by various organizations tasked with similar river pollution issues. The BoB has been effective for the Matías Hernández River so far and Marea Verde hopes to install more in the future (Marea Verde, n.d.). The BoB experienced its first heavy rain in April of 2019, and was successful in collecting the unusually high volume of waste. Approximately 470 bags of waste were filled by Marea Verde staff (Marea Verde, n.d.). The heavy rains experienced in the spring

facilitate the flow of waste down the river and make the combination of this waste with the waste at the coast a much larger issue. Hence, it is during these times that technology like the BoB is the most effective. In total, Marea Verde collected approximately 966.4 tons of waste and continues to increase that number as they explore more efficient methods of garbage removal in the future (Marea Verde, n.d.).

Figure 3: Marea Verde's "Barrera o Basura" trapping waste on the Matías Hernández River (Marea Verde, 2018).

2.3.3 Utilization of Recycled Waste

With a large portion of the collected waste being various types of plastic, one of Marea Verde's long-term objectives is to develop efficient techniques for recycling and reusing this plastic waste. Marea Verde has explored different mechanisms to achieve this and successfully reuse the collected garbage instead of just relocating it. They have explored the possibility of

crushing the plastic collected from the mangrove swamp and treating them in co-processing furnaces to fuel cement manufacturing (Marea Verde, n.d.).

Additionally, Marea Verde has investigated the option to construct roads using a mixture of typical asphalt and recycled plastic. The goal of this study was to help build from the recycled materials something productive and functioning for the local community. The first pilot project was in Vacamonte, Arraiján, where using the asphalt and plastic mixture of 1 to 2% recycled plastic, the construction team hired by Marea Verde paved about 500m of road (see Figure 4). Subsequently, in the second pilot project conducted in Carlos, Chiriquí, Marea Verde tested a larger concentration of recycled plastic between 1.5 and 3% to pave 600m of road. To put in perspective how much plastic they are using in the pavement, 1% of the pavement mixture intended for paving 500 meters is the equivalent of about 13,000 plastic water bottles (Marea Verde, n.d.). By creating a circular environmental economy that effectively repurposes used materials, Marea Verde is able to tackle and mitigate the problem.

Figure 4: This image displays the first pilot project for paving roads (Marea Verde, 2018).

2.3.4 Environmental Education

In February of 2017, Marea Verde initiated a multi-pronged plan that included cleaning and restoring activities in the mangroves of Costa del Este, a small coastal region in the San Miguelito district (see Figure 1), as well as promoting the Panama Audubon Society's environmental education program. In collaboration with the Audubon Society and its Aulas Verdes program, Marea Verde has implemented environmental education programs at two schools: the State of Israel primary school and the Carlos A. Mendoza primary school, located right in the San Miguelito district of Panama City. Environmental educators lecture once or twice a week, raising awareness to the children about their environment and the importance of maintaining a healthy ecosystem for their own personal well-being. Marea Verde believes that this will motivate the children to become "actors of change" (Marea Verde, n.d.). In 2018 alone, 426 middle school children received this education and beyond this, the program continues to educate new children each year. To complete their mission Marea Verde must combine this educational aspect with necessary technologies to improve their efficiency in cleanup efforts.

2.4 Potential Mitigating Technologies

Marea Verde determined that about 43.2% of the garbage captured by the BoB, currently their sole cleanup strategy on the MHR, are plastic bottles (PET) and disposable plastic containers (HDPE or LDPE) (Marea Verde, n.d.). To come to this conclusion, Marea Verde staff and volunteers manually collected, analyzed, and sorted the waste. Manually sorting the waste is very time consuming and inefficient. At this point, there is no efficient technique to sort the waste other than manually sifting through the waste. By quantifying the amount of each type of plastic in the river basin, Marea Verde hopes to reform their educational programs in the local

communities. The addition of drones to their mission would increase the efficiency of their process because particular drones have the technology to scan the waste from a relatively low distance and determine the exact polymers present in the plastics. Additionally, Marea Verde wishes to collect data on the 'hotspots' of waste dumping along the MHR basin. Identifying these hotspots would be beneficial for Marea Verde to identify the communities in the district to target with educational programs and implement other environmental strategies in the area. Analyzing these hotspots without the aid of additional technology is also an inefficient and tedious process. Thus, Marea Verde is turning to various modern technologies to enhance their data collecting capabilities. The next section provides a brief background on drones.

2.4.1 Drones

A drone is defined as an unmanned aircraft or ship that navigates either autonomously by an onboard computer or under remote-control by a human operator. Commonly, the term drone is used interchangeably with the phrase Unmanned Aerial Vehicle (UAV). Among those in the scientific community, determining whether a difference between the two exists is an ongoing debate. Generally speaking, drones are smaller and compact than UAVs (see Figure 5). Private individuals and media companies typically utilize drones for their attractive prices and relative ease of use. Research organizations and companies that deal with large stretches of area use UAVs for their ability to fly higher and longer (Forbes, 2017). For simplicity, we will refer to any type of unmanned aircraft as a drone in this paper.

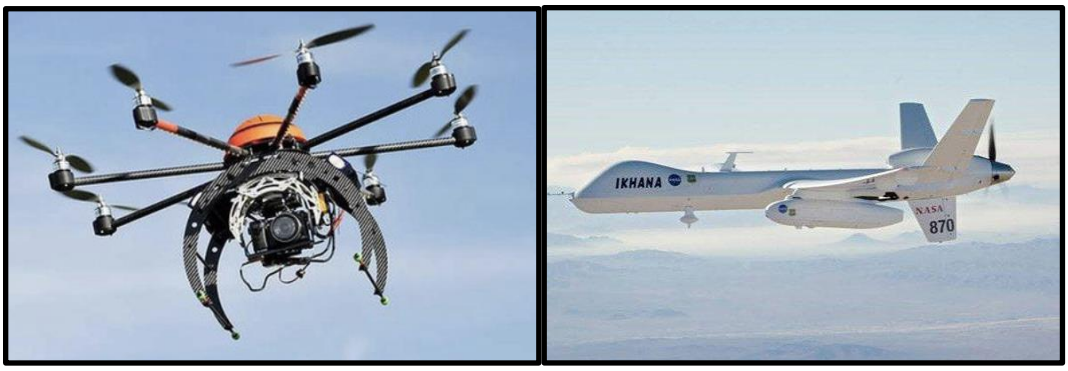

Figure 5**A**: Multicopter drone Figure 5B: UAV operated by NASA (Identified Technologies, 2017).

Both autonomous and remote-controlled drone models are currently on the market. Most autonomous aircrafts operate with a pre-programmed flight path specified by the operator. Some even have the capability of adapting their flight path in real time. Unlike autonomous aircrafts, remote-controlled drones require human control during the entirety of the flight. Often, the operator guides these drones using joysticks or similar mechanisms to control the height and direction of the drone. Our recommendation for Marea Verde's drone selection will depend on the drone's functionality and its applicability to the needs discussed earlier in this section.

2.4.2 Sensors and Cameras

In tackling this project, various sensors attached to the drone will play a key role in collecting data on the types of plastic in the river and the waste 'hotspots' along the river. Recycling plants have explored the use of infrared (IR) sensors to identify plastic waste (Association, 2018). Because of this, we will explore the use of IR sensors to evaluate their feasibility for identifying the various plastics in the MHR basin.

An IR sensor emits and detects infrared radiation to sense its surroundings. IR sensors work in the "near infrared region" of the electromagnetic spectrum, sensing waves between 700nm and 1400nm (Electronics Hub, 2017). These waves work in a wavelength range not

visible by the human eye. Three different laws govern the workings of an IR sensor: Planck's Radiation law, Stephen-Boltzmann law and Wiens's Displacement law.

- **Planck's Law:** Every object at a temperature T not equal to 0 K emits radiation.
- **Stephen-Boltzmann Law:** The total energy emitted at all wavelengths by a black body is related to the absolute temperature.
- **Wien's Law:** Objects of different temperatures emit spectra that peak at different wavelengths. (Chilton, 2014)

We can use these three laws to create many different applications for IR sensors. These applications range from simple operations like changing the channel on your TV to more complex operations like heat detection and thermal imaging. The principles of all IR sensors are the same. The IR sensor has both a transmitter and a receiver. The transmitter sends out an IR signal which reflects off of an object and the reflected signal is received by the IR receiver (see Figure 6).

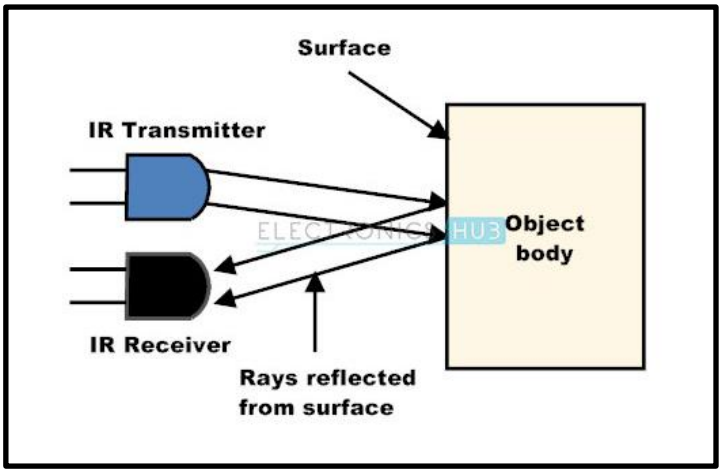

Figure 6: The workings of an IR Sensor (Electronics Hub, 2017)

Depending on the type and quality of the IR sensor, there can be different advantages to using one IR sensor over another. Different circuitry in the IR sensors can increase the range of

the IR signal sent and received. When dealing with range on any type of sensor that sends and receives a signal, one thing to keep in mind is that the signal will make a round-trip traversal regardless of the distance of the object from the sensor. If the sensor moves too far away from the object, the transmitted signal will never reach the receiver. This results in the sensor interpreting false or incorrect data.

Recycling plants utilize IR sensors along with machine learning concepts to sort various plastics (Clancy, 2019). This helps categorize the types of plastics and aids in streamlining the recycling process. Theoretically, Marea Verdes' plan to uncover what types of plastic are disposed of in the river can be determined using similar techniques. Marea Verde wants to implement a type of technology similar to this for future use of plastic separation. This process would also enable our sponsor to determine the types of education plans to install into the community in order to help prevent the harmful dumping of plastic waste. The conditions that the IR sensors work in at the recycling plants are much different than the conditions at the Matías Hernández River. The climate along the river is very humid, meaning there is a large amount of water vapor present in the air. The water particles in the air can actually absorb the IR waves and prevent them from reaching their intended target of the plastics in the river (Naval, 2005). We expect this to be one of the challenges that we will face while we evaluate the use of infrared sensors for data collection at the MHR basin.

A multispectral camera houses multiple sensors ranging in different wavelength bands (see Figure 7) (Corrigan, 2020). One of these sensors is the visible light sensor that we could use to determine the hotspots of waste along the river. These sensors will collect images of the waste along the banks of the river and within the river. By using a multispectral camera, our sponsor will save time by collecting multiple data of interest in parallel. The camera must be sufficiently

small and lightweight for easy attachment to a drone. The imaging parameters of the camera is another important factor to consider. These parameters include the size of the sensor and the focal length of the lens which help define the ground sample distance or GSD (O'Connor, n.d.). The GSD relates the size of the pixel size to a measurement in the real world. This relationship allows for the determination of the size of objects through computer imagining. It is important to consider the pixel pitch, or the width of each pixel, when determining which cameras to use. The bending of light also known as diffraction can distort the image. Using a camera with a higher pixel pitch can mitigate the effects of diffraction on an image.

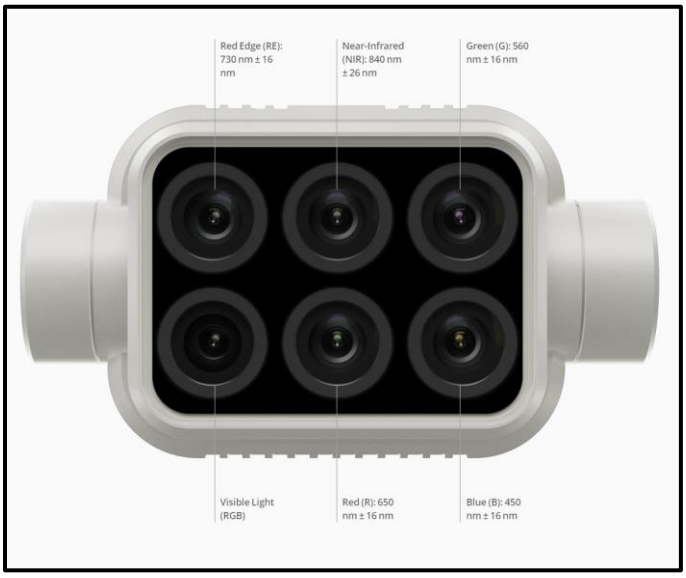

Figure 7: DJI P4 Multispectral RTK (DJI, n.d.)

Chapter 3: Methodology

The goal of this project is to aid Marea Verde in evaluating the feasibility of drones in environmental mitigation so that Marea Verde can implement more directed initiatives in educating the local communities. The addition of this technology will assist our sponsor in targeting their environmental education program to the various communities that are contributing the most to the pollution problem.

To successfully implement the best-suited technology to achieve their mission, we must account for both the technical and social factors that contribute to our evaluation. On the technical side, our research looks into similar applications of drones in various environments to gain understanding on the technical feasibility of our project. On the social side, we will investigate the communities surrounding the Matías Hernández River to gauge their familiarity with drones as well as gaining insight into how these communities view the pollution problem and their role in the issue. This social investigation will help us determine the appropriateness of utilizing drones in these areas. Additionally, it will allow us to get a better grasp on the background of the local communities and provide Marea Verde with more information to form their educational program. With these considerations, our methodology will determine the feasibility of using drones to complete our project. Our approach, including our project goals, objectives, methods, and end product is shown below in Figure 8:

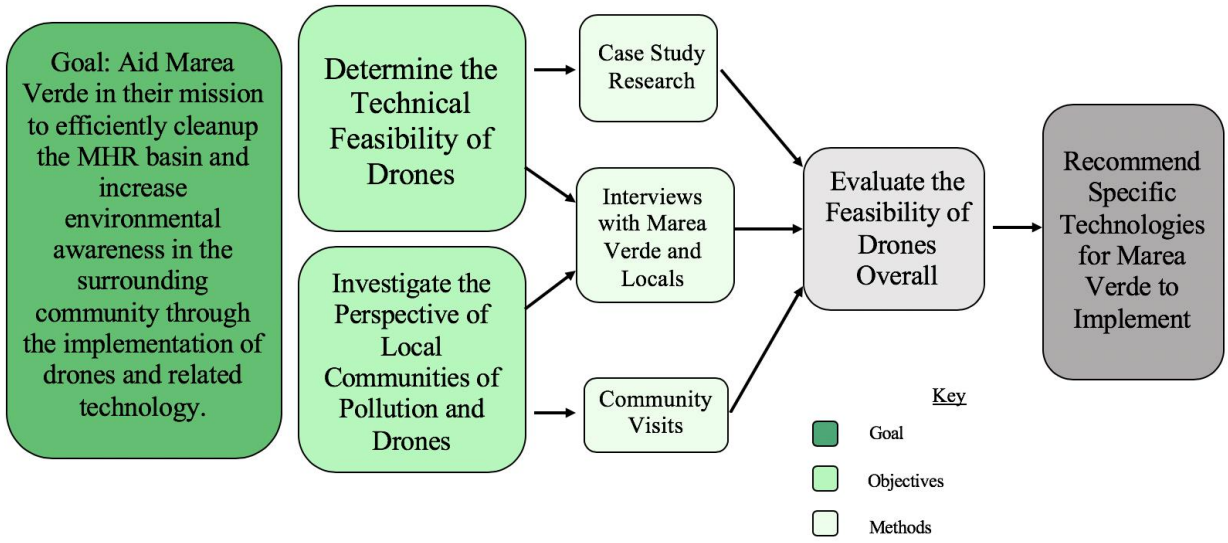

Figure 8: Methodology Overview Flowchart

3.1 Current Environmental Drone Usage

To recommend the correct technology to aid in Marea Verde's goal, investigation of previous work with drones in similar environmental scenarios is necessary for our technical analysis. This research is useful in determining which drones operate best under similar conditions to that of Panama and specifically the humidity aspects of capturing images while flying over the Matías Hernández River basin. Not only is the type of drone important to consider when determining the best option, the consideration of additional technology attached to the drone is necessary regardless of the sensor we use. To complete this investigation, the project team will conduct a case study centering around these concerns. Case studies are defined as "research [that] can be single or multiple case studies, includes quantitative evidence, relies on multiple sources of evidence and benefits from the prior development of theoretical propositions" (Press Academia, 2018). This research will focus on the capability of drones and the feasibility of drones in collecting the data of interest. Below is a discussion of a few drone projects that serve as a preview of our case study research.

3.1.1 Remote Sensing of Coastal Algal Blooms (Cheng, 2020)

This project, conducted by the Department of Civil and Environmental Engineering at The Hong Kong University of Science and Technology in Kowloon, Hong Kong, China, centers around the monitoring of the growth of phytoplankton in their subtropical coastal waters. This monitoring is necessary because an over population of phytoplankton causes water discoloration and kills large numbers of fish. Because a significant portion, about 20 percent, of the Asian diet depends upon fish, the extreme decrease in fish population due to the phytoplankton is a pressing issue. Prior to this project, environmentalists conducted water quality monitoring through manual field sampling and then tested the samples in a laboratory to obtain the current chlorophyll-*a* (Chl-*a*) concentration. This process requires many steps and proved to be extremely time consuming, leading to the need for this project.

To improve the efficiency of the monitoring process, this project team decided to utilize unmanned aerial vehicles (UAVs) at a low altitude to map the surface of the water and the Chl-*a* distribution. The specific model UAV used was the DJI Phantom 4, equipped with a Global Positioning System (GPS), a Global Navigation Satellite System (GNSS), and a Vision Positioning System. The vehicle also contained an autopilot system that can hover at a position with an accuracy of 0.1m vertically and 0.3m horizontally. The maximum transmission distance between the UAV and its controlling source was 5 km. The project team faced challenges when utilizing the technology in a marine environment. Weather conditions were important in the resulting quality of the images gathered of the water surface. Sun glint proved to be an obstacle; in many of the images collected from sunny days, a bright zone appeared on the pictures. This bright zone lowered the clarity of the water and compromised the quality of the images. To resolve this issue, they decided to fly the drones and conduct imaging at a calculated angle in

which the sun glint would no longer be visible. In terms of our case study, this project is important because it illustrates the ability of UAVs to successfully collect data in marine climates.

3.1.2 Restoration Monitoring in Cut-Over Bogs (Knoth, 2013)

A research team at the University of Münster in Münster, Germany, investigated whether "UAV-based Near-Infrared (NIR) remote sensing supports restoration monitoring of over-cut bogs by providing valid information on species distribution and surface structure". In Europe, companies drained and mined peat bogs, transforming the agricultural area from a slight sink to a large reservoir with extreme carbon emissions that create a greenhouse gas crisis. Environmentalists quickly recognized this issue and the restoration of peat bogs became a pressing matter. Monitoring of the peat bogs focused on the characteristics of the vegetation present in the bogs because they indicate the health of the bogs. Because of the harsh conditions of the peat bogs, the restoration of peat vegetation is slow. This makes it challenging to determine if restoration efforts are effective or not. Under these circumstances, the only practical technique to successfully monitor the bogs and determine if the restoration process was effective was to compile multi-spectral images from commercial satellites passing over the area. With this method, small spectral differences are difficult to detect and there was limited spatial and temporal resolution. To improve upon their process, these researchers turned to UAVs as an autonomous and low-cost alternative.

To monitor the bogs, the team used two radio-controlled, four airscrew-powered quadcopters. Both UAVs had an autonomous flight controller and a GPS flight control. In addition to these base navigation technologies, the first UAV carried a Canon IXUS 400 digital camera modified with an internal infrared filter that blocks visible light. This served to collect

the desired panchromatic NIR images. The second UAV had onboard a modified Panasonic Lumix LX-3 digital camera with a neutral glass filter in place of a hot mirror to enable the camera to read radiation in both the visible and NIR regions. With these modifications, the project team flew the UAVs over the peat bogs in question and collected multispectral images. The team then analyzed these images with the necessary technologies and discovered that the high spatial resolution of the images revealed the definition of plant-related features, which meant this approach could determine if the restoration methods were successful. This research proves that UAVs can be successful in collecting multispectral images, including the NIR region.

3.1.3 Assessment of Microbial Water Quality in an Irrigation Pond (Morgan, 2020)

The USDA-ARS Environmental Microbial and Food Safety Laboratory in Beltsville, Maryland in collaboration with the Department of Civil Engineering at the University of Alicante in Alicante, Spain investigated the capability of drone-based imaging to assess the microbial water quality in an irrigation pond.This was a pilot study to determine if including drones in the remote monitoring process of irrigated agricultural practices would increase the efficiency of a difficult process. These microbial water quality datasets are “essential to detect and inform measures to prevent the contamination of produce”. This is because the pond in question is the sole source of irrigation for the surrounding farmland. The team used *Escherichia coli (E.coli)* concentrations to successfully evaluate the quality of the microbial water. Prior to this pilot study, testing of the microbial water quality required field sampling which proved to be inefficient. Therefore, the researchers turned to considering technological advancement, namely the use of UAVs.

In this pilot study, the project team utilized UAVs to better estimate the microbial water quality through imagery. They concurrently imaged the surface of the pond in question, located

in central Maryland, using three GoPro cameras with modifications and a multispectral MicaSense RedEdge camera with five spectral bands mounted on a 3DRSolo drone. The five spectral bands of the MicaSense RedEdge camera used were blue, green, red, red edge, and near-infrared, which is typical for a multispectral camera. The drone collected images in 23 different sampling locations across the pond. At each sampling location, the multispectral camera collected five images, one for each spectral band. The team modified all of the GoPro cameras to capture images within specific ranges. The first of these cameras captured both visible and infrared bands. The second camera captured the visible band. and the third camera captured the infrared band.

Flying at about 400 ft, the UAV collected essential spatial and temporal information through the images taken and their corresponding GPS coordinates. The team then compiled all collected information and conducted their analysis of the pond concerning the microbial water quality. This project employed several technologies that are possibly applicable to our project. Their work with both multispectral and GoPro cameras is similar to our project goals and exhibits the potential success that we anticipate with similar technologies.

3.1.4 Relevancy of Research

This research serves as a sufficient stepping stone for the additional research concerning drone usage that our team will conduct during our time working with Marea Verde in Panama. From this preliminary research, our student team will bring knowledge about related technologies and work with Marea Verde's technical team on more directed research. Our team will compare our research with theirs to develop a cohesive conclusion approach concerning the feasibility of drones in their environmental cleanup efforts by the end of our time in Panama. These combined efforts will bring Marea Verde one step closer to determining how to

successfully advance their technologies and further their environmental mission with increased efficiency.

3.2 Social Perception of Drones and Environmental Pollution

The entirety of the social portion of our project depends upon determining the perception of the local communities on the subject of drones and environmental pollution. This investigation must conduct a social analysis which involves recognizing the existing role of drones and how they could make a difference in the MSR basin. This analysis will involve directly gaining the perspective of both stakeholders in our project and the Matías Hernández River area, through the conduction of interviews. During these interviews, our team will divide into pairs and conduct interviews concurrently.

3.2.1 Interviews of Marea Verde Staff

The volunteers and engineers that devote their time to Marea Verde are the first stakeholder that we will interview. While our team established contact with the co-founder of Marea Verde, Mirei Endara, as well as project manager, Sandy Watemberg, prior to conducting our project, a deeper analysis into the organization and those that conduct the cleanup work and technical research will provide valuable information. Marea Verde's technical team likely has minimal background knowledge on drones, since they have enlisted us to aid in their technological efforts. Interviewing their team members to gain more insight on specific topics is important. These topics mainly center around understanding their motivation for joining the organization and why they think drones would be a positive addition to their efforts. The main topics we will explore are:

- ➔ Why did you join Marea Verde's cleanup initiative?
- ➔ Do you think drones are a necessary addition to complete Marea Verde's mission?

Below is a list of the specific questions we intend to address in these interviews:

1. How long have you worked for Marea Verde?
2. What made you want to be more involved in Marea Verde?
3. What are you hoping to gain from working for Marea Verde?
4. What benefits do you think integrating technology into the current project will bring?
5. What do you think the general consensus of the communities surrounding the Matías Hernández River is regarding waste in the river?
6. Do you think that stricter legal guidelines will help prevent this issue?
7. The mouth of the river passes through Coste Del Este which is known to be a nicer, fancier setting. How do you think those locals feel about the waste passing through their community?
8. Why do you think locals end up dumping their waste in the river as opposed to disposing of it properly?
9. What has been your favorite part about working on this project?
10. Do you think that drones are a feasible option for this community and project?

The full format for these interviews is available in Appendix A.

3.2.2 Interviews of Panamanian Locals

Since the MHR pollution problem stems directly from the residential and commercial communities surrounding the Matías Hernández River, whether that be intentional dumping of waste or mere runoff, our second stakeholder group in this social analysis includes those who

live in the communities that surround the Matías Hernández River. An investigation into these communities and their perspectives on drones and the issue of waste pollution is essential information to better target any proposal for an environmental education initiative.

Through the coordinators at Marea Verde, we will arrange interviews with locals that live in all communities that surround the river. With their work in the past through community cleanup and environmental education, Marea Verde has established a relationship with these communities, which will facilitate the arrangement of these interviews. To conduct these interviews, the interviewees will either have to come to Marea Verde or we will enter into their communities and bring the interviews to them. One anticipated obstacle with conducting these interviews is the language barrier that exists between our team and the locals. Panama is a predominantly Spanish-speaking country and none of our team members are fluent in Spanish. Therefore, a representative from Marea Verde will accompany our team in the interviews. We will choose what communities to interview by consulting with Marea Verde to determine what communities will serve as the best representation of the area.

After doing qualitative analysis on the interview responses, the resulting trends will help us discover which communities will benefit the most from the education initiatives. This will also assist us in gaining insight into the communities' familiarity with drones and how comfortable they are with this technology, especially the use of cameras collecting images within the confines of their communities. In this interview process we will ask questions to gain insight on the knowledge and attitudes of this stakeholder group while giving the interviewee direction to tell their story. The main topics we plan on exploring are:

- ➔ How familiar are you with the pollution issue of the Matías Hernández River?

- ➔ How comfortable are you with use of drones in your community and using this technology to collect images of the area?

Below is a list of the topics that we intend to address in these interviews:

1. Interviewee's Background (occupation, education, location,age).
2. Interviewee's knowledge on their waste management system.
3. Interviewee's knowledge on pollution issues at the MHR.
4. Interviewee's familiarity with Marea Verde and their cleanup efforts.
5. Interviewee's attitude toward the use of drones over the MHR.

The full format for these interviews is available in Appendix B.

The answers to these questions are instrumental in uncovering the root of the pollution issue and why it actually exists. Marea Verde staff indicated a large part of the reasoning behind the dumping of waste into the river is due to the inadequate waste management system in these communities, but communicating with the residents directly will hopefully uncover other unknown factors as to why their communities are not controlling the issue. Ideally, we will also gauge the communities' view of drones and plan accordingly.

3.3 Feasibility of Drones in Pollution Investigation

The entirety of our project centers around evaluating the feasibility of drones as an addition to Marea Verde's cleanup efforts by taking into account both the technical and societal implications of this possible implementation. This evaluation will stem from two main sources of information, our case study and the investigative interviews in the MHR basin. Our steps to address this objective include presenting the information gathered from our research of previous drone usage in environmental pilot projects to the technical team at Marea Verde as well as the

analyzed results extracted from the interviews of the communities surrounding the Matías Hernández River.

To conclude our work with Marea Verde while in Panama, our team will present our recommendation and other relevant findings to Marea Verde's technical team and gain their input on our decision. With this mass of information compiled, our student team combined with Marea Verde's technical team will come to a recommendation concerning the use of drones in this particular situation. In this discussion, we must also address any potential shortcomings that Marea Verde may encounter in using drones to complete their desired tasks. In our research conducted thus far, it is evident that the humid climate of Panama may pose an issue in relation to the use of IR sensors. The water droplets present in the air may disrupt the accuracy of the sensor and lead to inaccurate readings and object detection. One possible scheme to overcome this issue would be to operate the drones at a lower altitude, decreasing the distance between the sensor and the waste, allowing for less interference. IR sensors are a possible technology for the classification of plastics amongst the waste accumulation, which makes them an important addition to the technology we intend to recommend.

Beyond the technical feasibility of the drones, a consideration of the technology's feasibility within these specific communities along the river may also reveal challenges. If the people of these communities are not comfortable with the operation of these technologies in their communities, that poses a large issue for our team and the Marea Verde staff working on this project. A possible way to prevent this issue would be for Marea Verde to include drones as one of the topics they cover in their environmental education program. Inclusion of this information would familiarize the public and likely ease any stress or discomfort that the technology might

produce. As our project progresses, more shortcomings and challenges may arise, which we will then discuss with the technical team to determine our best course of action.

During our time in Panama with Marea Verde, our evaluation of the feasibility of drones will be an educated and in-depth decision that encompasses many factors involving implementing this technology including their advantages or disadvantages. Beyond this evaluation, our team will then return to our research to recommend which technologies we believe Marea Verde should include in their efforts. The technologies selected will ideally cover all needs of Marea Verde and effectively assist them in determining the best locations to implement their environmental education programs.

3.4 Timeline

Since we will conduct our project during the entire duration of A term of 2020, we will have seven weeks in Panama to complete our project. Because of this limited amount of time, all project operations will be carefully planned. Table 2 represents our predicted timeline without the inclusion of any unforeseen circumstances or factors that we may encounter.

Task	Week 1					Week 2					Week 3					Week 4					Week 5					Week 6					Week 7				
	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F
Meet With Sponsor and Aquire Agenda																																		
Contact Locals Through Marea Verde to Plan Interviews																																		
Present Case Study Research and Combine with Marea Verde Research																																		
Interview Marea Verde Staff																																		
Visit the Matias Hernandez River																																		
Interview Locals in the Communities Surrounding the MHR																																		
Compile Case Study Research and Interview Findings																																		
Work Alonside Marea Verde to Evaluate the Feasibility of Drones																																		
Look Into Best-Suited Drone Models and Camera Equipment																																		
Recommend Specific Technology for Marea Verde to Implement																																		
Finish Final Report and Presentation																																		

Table 2: Proposed timeline of work in Panama.

Works Cited

Association of Plastic Recycling (2018, July 20) “Near Infrared (NIR) Sorting in the Plastics Recycling Process”. Retrieved May 05, 2020 from https://plasticsrecycling.org/images/pdf/design-guide/Resources/NIR_Sorting_Resource.pdf.

Cheng, K., Chan, S., & Lee, J. (2020). “Remote sensing of coastal algal blooms using unmanned aerial vehicles (UAVs)”. *Marine Pollution Bulletin, 152*.

Chilton, A. (2014, October 15). The Working Principle and Key Applications of Infrared Sensors. Retrieved April 22, 2020 from https://www.azosensors.com/article.aspx?ArticleID=339.

Clancy, H. (2019, June 18). “How artificial intelligence helps recycling become more circular”. Green Biz. Retrieved on May 5, 2020 from https://www.greenbiz.com/article/how-artificial-intelligence-helps-recycling-become-more-circular.

Clean Seas. “Impact”. (n.d.). Retrieved April 29, 2020, from https://www.cleanseas.org/impact/un-environment-supports-massive-beach-clean-ups-panamas-coasts

Coca Cola. “Benioff Ocean Initiative and The Coca-Cola Foundation Announce $11 Million in Funding to Clean Up Rivers and Stem Flow of Waste to Oceans.” (2020, January 15). Retrieved April 13, 2020, from https://www.coca-colacompany.com/press-releases/benioff-ocean-initiative-and-the-coca-cola-foundation-announcement.

Corrigan, F. (2020, April 14). 10 Thermal Vision Cameras For Drones And How Thermal Imaging Works. Retrieved May 5, 2020, from https://www.dronezon.com/learn-about-drones-quadcopters/9-heat-vision-cameras-for-drones-and-how-thermal-imaging-works/

DJI Phantom 4 Multispectral RTK. (n.d.). Retrieved May 5, 2020, from https://www.rmus.com/products/dji-phantom-4-multispectral-rtk

Electronics Hub. “IR (Infrared) Obstacle Detection Sensor Circuit”. (24 Dec. 2017). Retrieved April 30, 2020, from www.electronicshub.org/ir-sensor/

Forbes. (2017, August 15). “What Are The Differences Between Drones, UAVs, And RPVs?” Retrieved April 29, 2020, from https://www.forbes.com/sites/quora/2017/08/15/what-are-the-differences-between-drones-uavs-and-rpvs/#515a3d3f7b21

Google Maps Satellite View, 2020. Retrieved April 15, 2020.

Identified Technologies. “Ending the Drone vs UAV debate: Drone basics 101”. (2017, May 9). Retrieved April 30, 2020, from https://www.identifiedtech.com/blog/uav-surveying/drone-technology-ending-the-drone-vs-uav-debate-drone-basics-101/

Knoth, C., Klein, B., Prinz, T., Kleinebecker, T., & Goslee, S. (2013). “Unmanned aerial vehicles as innovative remote sensing platforms for high-resolution infrared imagery to support restoration monitoring in cut-over bogs”. *Applied Vegetation Science*, *16*(3), 509–517.

Leachman, S. (2020, January 15). “River Recovery”. Retrieved April 13, 2020, from https://www.news.ucsb.edu/2020/019758/river-recovery.

Marea Verde Panama. “Marea Verde Panama: Limpieza de Manglares en Cosa del Este”. (n.d.). Retrieved April 13, 2020, from http://www.mareaverdepanama.org/.

Marea Verde Panama. (MareaVerde_PA). “Ayer les mostramos las adecuaciones que se le hicieron al #BOB, y hoy amanece así ¡Lo que hace una lluvia! ¡Panamá, tomemos conciencia! #mareaverde #únetealamareaverde #somoslamareaverde #porunpanamamaslimpio” 24 June 2016, 10:00 p.m. Twitter.

Moreno, E. (2019, July 21). “Panama Becomes First Central American Nation To Ban Plastic Bags”. Retrieved April 29, 2020, from https://www.huffpost.com/entry/panama-bans-plastic-bags_n_5d3465cee4b0419fd32e4246

Morgan, B., Stocker, M., Valdes-Abellan, J., Kim, M., & Pachepsky, Y. (2020). “Drone-based imaging to assess the microbial water quality in an irrigation pond: A pilot study”. *Science of the Total Environment*, *716*, 135757.

National Geographic Society. (2019, June 27). “Marine Pollution”. Retrieved April 29, 2020, from https://www.nationalgeographic.org/encyclopedia/marine-pollution/

Naval Meteorology and Oceanography Professional Development Detachment Atlantic (2005, June). “Atmospheric Effects on EO Sensors and Systems”. Retrieved May 2, 2020, from http://www.deltagearinc.com/library/OpticsFacts/EO.pdf

O’Connor J., Smith M. “UAV Camera Review for Surveying”. (n.d.). Geo-Matching. Retrieved May 4, 2020, from https://geo-matching.com/content/uav-camera-review-for-surveying

PolyChem. “Plastic Coding System Guide For Resin Types”. (2017, August 2). Retrieved April 29, 2020, from https://polychem-usa.com/plastic-coding-system/

Press Academia. “Definition of Case Study”. (2018, July 9). Retrieved April 30, 2020, from https://www.pressacademia.org/definition-of-case-study/

Ryedale. “Different Types of Plastics and Their Classification”. (n.d.). Retrieved April 29, 2020, from https://www.ryedale.gov.uk/attachments/article/690/Different_plastic_polymer_types.pdf

United Nations. “Panama National Action Plan on Marine Litter and Stakeholder Round Table on Marine Debris” (2017). Retrieved April 29, 2020, from https://oceanconference.un.org/commitments/?id=16802.

Verisk 3E Regulatory Research Team. “Panama Issues Law on Integrated Waste Management and Zero Waste Policy”. (2018, July 2). Retrieved April 28, 2020, from https://www.verisk3e.com/resource-center/blog/panama-issues-law-integrated-waste-management-and-zero-waste-policy

Appendix A: Interview Format for Marea Verde Staff

Introduction:

Hello!

Thank you for meeting with us. We are a team of WPI university students from the United States that are in Panama to work alongside Marea Verde to investigate the potential role that drones and related technologies could have in controlling and reducing river pollution due to local waste. For our project, we would like to interview you to gain insight into how you came to work at Marea Verde and learn your thoughts about the uses of drone technology in Panama. Your answers will be very valuable to us to identify opportunities to use this technology and associated mechanisms to lessen the pollution issue that plagues the Matías Hernández River and to evaluate the conditions in which drones would be a feasible approach.

Before beginning the question portion of the interview, we would like to remind you that this interview is anonymous and completely voluntary. We would like to record this interview with the use of one of our phones to ensure that we catch all important topics covered in this interview. Are you okay with this recording? If not, that is completely understandable and we will proceed by taking handwritten notes. Do you have any questions before we begin?

Questions:

1. How long have you worked for Marea Verde?
2. What made you want to be involved in Marea Verde?
3. What are you hoping to gain from working for Marea Verde?
4. What benefits do you think integrating technology into the current project will bring?
5. What do you think the general consensus of the communities surrounding the Matías Hernández River is regarding waste in the river?

6. Do you think that stricter legal guidelines will help prevent this issue?
7. The mouth of the river passes through Coste Del Este which is known to be a nicer, fancier setting. How do you think those locals feel about the waste passing through their community?
8. Why do you think locals end up dumping their waste in the river as opposed to disposing of it properly?
9. What has been your favorite part about working on this project?
10. Do you think that drones are a feasible option for this community and project?

Interview Closing Remarks:

With that we conclude the question portion of our interview. Do you have any questions or comments for us? Is there any more information that you would like us to provide you about our project? If you would like to contact us in the future we are available via email through gr-Marea-Verde20@wpi.edu. Thank you for your time.

Appendix B: Interview Format for MHR Community Residents

Introduction:

Hello!

Thank you for meeting with us. We are a team of WPI university students from the United States that are in Panama to work alongside the environmental organization, Marea Verde to investigate the potential role that drones and related technologies could have in controlling and reducing local river pollution at the Matías Hernández River. For our project, we would like to interview you to gain insight into the community in which we will be working and the local knowledge of these environmental issues. Because the entirety of our project centers around incorporating advanced technology into the cleanup efforts of Marea Verde, we would also like to learn more about the perception of drones in the local community. Your answers will be very valuable to us and will bring us one step closer to completing our goal and helping the community.

Before beginning the question portion of the interview, we would like to remind you that this interview is anonymous and completely voluntary. We would like to record this interview with the use of one of our phones to ensure that we catch all important topics covered in this interview. Are you okay with this recording? If not, that is completely understandable and we will proceed by taking handwritten notes. Do you have any questions before we begin?

Questions:

1. How old are you?
2. What is your occupation?
3. What is your highest level of education?

4. Where do you live? (i.e. which community do you live in?)
5. Are the waste methods currently available to you adequate?
    a. What types of methods are available?
6. Are you aware of the pollution issue of the Matías Hernández River?
    a. If so, how much waste have you seen in the river?
    b. What do you think about this pollution?
    c. Do you think the waste is an issue?
    d. Have you seen the MHR during a storm?
7. Are you familiar with Marea Verde and their cleanup efforts?
8. Our project is to help Marea Verde incorporate new technologies, like drones, into their cleanup efforts. How familiar are you with drones?
9. Are you comfortable with drones being flown near your community?
10. These drones will likely carry cameras to capture images of the waste to analyze. Do you have any issues with this imaging?

Interview Closing Remarks:

With that we conclude the question portion of our interview. Do you have any questions or comments for us? Is there any more information that you would like us to provide you about our project? If you would like to contact us in the future we are available via email through gr-Marea-Verde20@wpi.edu. Thank you for your time.