

Final Consultancy Report

Source Water Monitoring: Remotely Detecting the Presence of Algal Blooms

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Executive Summary

As humanity has excelled in engineering feats, the extraction of raw materials has caused global temperatures to be higher than ever. This greenhouse effect is causing blue-green algae blooms to decrease the quality of drinking water through the emission of cyanotoxins that are detrimental to human health. Currently, to monitor these algae blooms, satellite imagery is used to prompt technicians to travel to a water body and manually collect a sample for inspection. This process is both expensive and time consuming, thus Group SWM-50 has been tasked with the creation of an aerial source water monitoring system that considers all stakeholders and performs with adequate accuracy [1]. The team has also been asked to assess the feasibility of the project in detail through the PERSIED method. This report documents the development of the team's source water monitoring system and touches upon all technical components of the proposed solution. The design itself features a drone-monitoring system that obtains high resolution images that are then transferred to a ground control system. This system will identify the presence of blooms and, if a bloom is detected, sends an automatic notification to surrounding drinking water treatment plant operators so that they can take the steps required to protect human health. Specifically, the design details the use of an iMX-100 high-resolution camera that will send the images taken to an UgCS Skyhub 3 Controller. These two components were chosen over other options based on an internal analysis on accuracy and efficiency. The camera is lightweight to avoid increasing the weight of the drone, provides high resolution images and still-frames to decrease uncertainty, and features a fast shutter speed to ensure that the trip can be as short as possible. The controller can be loaded with a training set data size ranging from 5,000 to 10,000 images to increase accuracy and in turn decrease the possibility of false negatives or positives. As the client moves forward with the project, the team suggests that prototype development begins, and the manufacturing of the drone follows soon after. Additionally, testing and possible modifications may need to be made as assembly undergoes. Finally, a maintenance and repair plan will need to be developed in accordance with each area of the watershed. As the project progresses beyond the considerations made by SWM-50, the team hopes that all final recommendations are considered.

Introduction

Source Water Monitoring is crucial since recent climate changes have resulted in algal blooms lowering drinking water quality. The traditional method of collecting water samples and transporting them back to the laboratory for testing is both time-consuming and costly. Hence, alternative approaches must be explored to ensure the effective monitoring of water sources. The project objective of the SWM-50 team is to develop a system for remote monitoring of source water in the Rainy Lake of the Woods watershed; utilizing a drone monitoring device outfitted with high-resolution cameras and machine learning algorithms to detect if the harmful algal blooms are present. The main goal behind this is to limit the number of trips the technician has to make to collect the water sample for testing. A crucial part of project planning was understanding the stakeholders who will be impacted by the project, as well as their needs and expectations. The stakeholders identified included the client, government, surrounding communities, investors, and water users. Throughout the project, changes were made to accommodate the needs of our stakeholders. The scope of the project involves delivering a summary of the proposed solution, discussing how the system works alongside project constraints, and describing expected errors based on performance metrics. Group SWM-50 completed these tasks by implementing responsibilities for each member and collaborating effectively to assure the solution covers the entire scope of the project. The project exclusions, constraints, requirements, and assumptions are also taken into account. The team recognizes that algae only blooms during warm-weather months and therefore does not have to take cold-weather flight conditions into account. Additionally, the design will not purify contaminated water or reduce the number of algae blooms. Provincial and government regulations, limitations, and the surrounding environment must be considered. These also added some constraints to our design which needed to be addressed. For example, meeting all the provincial and municipal regulations, drone operation is not intrusive to wildlife and habitats, a reasonably sized drone, the flight time of the drone given downtime needed, and a drone cannot interfere with airspace drones cannot be super loud. The team assumes that photos are taken using modern lenses, battery life is reliable, and that the drone will not fly during extreme or low-visibility weather conditions. Finally, the team assumes that they are not responsible for developing the project's budget and that it will cover the components needed. The final design will feature a lightweight,

brightly colored drone and adjusted flight path to minimize noise pollution, risks to wildlife, and visual disturbance.

Decision Process

Initial Recommendations

Based on the project objectives, requirements and constraints, Group SWM-50's initial recommendation is to design a drone-based monitoring system that should collect accurate information using remote sensing technology and machine learning algorithms to detect and identify harmful algal blooms in Ontario lakes. And the system should function in accordance with all provincial and municipal laws and without endangering wildlife or their habitats. Aerial monitoring can provide a productive approach to collect a great deal of information over large areas. Large portions of the lake can be covered by drones, which can also capture high-resolution photographs and send the information to ground-based devices. Drone-collected data may be automatically analyzed with machine learning algorithms to spot problem areas. These algorithms could be trained to recognize patterns linked to dangerous algal blooms and indicate regions for further investigation. Initially, the Group SWM-50 considered that the design of the water monitoring system should prioritize accuracy, as well as ensuring that the system is efficient in detecting and identifying harmful algal blooms, while complying with all regulations and restrictions.

Decision Matrix

Through our initial research, we were able to determine 3 competitive drones in the commercial data collection and mapping industry, as well as three viable camera options for aerial video and photography. The following weighted decision matrices are based on the most important considerations made for the SWM-50 project.

The following matrices are made using a 1-5 scale, where 1 is least important in terms of weighting and 1 is the lowest score for criteria, and 5 is the highest for both weight and score.

<i>Criteria, Weight</i>	DJI Matrice 300 RTK [2]	WingtraOne GEN II [3]	XAG V40 [4]
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Weight, 3	3	3	2
Camera and processing capability, 4 *	3	2	4
Flight time, 4	2	3	1
Additional capability, 2 **	4	2	2
Cost, 2	5	3	1
TOTAL	47	39	36

[Table 1, Drone Weighted Decision Matrix]

**Camera and processing capability refers to the drone's camera quality and onboard/supported information processing ability.*

***Additional capability refers to the drone's ability to support third-party attachments and accessories and have a payload (for example, water sample collection hardware).*

Criteria, Weight	iXM-100 [5]	Trillium HD25-XV [6]	Sierra-Olympia VAYU HD-1 [7]
Weight, 3	3	4	1
Image quality, 4	4	2	4
Power consumption, 4	5	2	3
View angle, 2	4	2	3
Capture rate, 2	5	3	4
Cost, 2	2	4	3
Data storage ability, 2	3	2	2
TOTAL	73	50	55

[Table 2, Camera Weighted Decision Matrix]

Design Evaluation

When evaluating the decisions made throughout the design process, SWM-50 heavily focused on using the four layers of PERSIED to evaluate all possible considerations and

constraints. The PERSIED method includes using performance, regulatory, socio-cultural, and environmental screening to analyze the feasibility of an engineering design [8]. Within the performance layer, SWM-50 began by analyzing the accuracy and efficiency of both the physical and the algorithmic components of the system. The team fixated on ensuring that photos taken were of high quality, the drone was lightweight, and a comprehensive data training set could be utilized. Also, within this layer, the team performed an error analysis and examined the possibility of false positives and false negatives. The team agreed that the possibility of a false positive was more favourable, as while it would require money and resources being spent, it would pose less of a threat to human health. Therefore, it was decided that the performance of three algorithms would be evaluated alongside physical water samples taken from key areas within the watershed. These samples would then be used to test the ongoing accuracy of the algorithms, where two of the three would need to report a negative reading for the result to be considered negative. This would ultimately reduce the rate of false negatives by approximately 20% according to the equations $FP = \frac{(1-2 \cdot FN)}{4 \cdot FN + 2}$ and $FN = 1 - (1 - FN_1)(1 - FN_2)$, where FP and FN represent false positive and false negative rates respectively. In addition to the technical performance of the system, the regulatory requirements that had to be taken into consideration also played a large role in evaluating the final design. The team focused on ensuring that the drone met Ontario regulatory requirements by keeping within the province's 90-meter altitude limit, remaining 5.5 kilometers from all light zones and 75 meters from any moving vehicles [9]. Additionally, as SWM-50 is predicting that the drone will be greater than 250 grams, a licensed pilot must be always within visible distance of the drone during flight [10]. The team also focused on ensuring that the project aligned with Canada's privacy act. To do so, the team recognizes that all collected information must be accessible by governing bodies and that any images taken from public spaces must be available to the public upon request [11]. To ensure this is a possibility, the team will create an archive which stores all photographs taken by the drone and encrypt all other data for sake of the client's privacy.

Alongside performance and regulatory layers, the socio-cultural considerations played a very critical role in shaping the team's design. These elements involved contemplating how the design would be perceived by the public and to what level it would be accepted. Thus, to guarantee that the final product is feasible within the watershed, the team aimed for the drone to

limit invasive practices as much as possible. Specifically, this included reducing the visual and audio disturbance effects the drone might have. To do so, the team evaluated the type of drone used and decided it should be of neutral color, contain no large propellers, and run entirely off battery power. It was also concluded that, to ensure residents felt safe and secure, nearby communities would inform their members of the project and all privacy protocols being put in place. Finally, the team evaluated environmental impacts the drone may have, including adding to noise pollution, releasing carbon emissions, and the possibility of wildlife interference. Thus, the design was evaluated once again and it was determined that the drone would seek to fly high above residential areas to reduce possible noise, only dropping to take photos at critical locations within the watershed. While at this point the drone was already deemed to be fully battery powered, thus cutting the possibility of fuel emissions, the team also wanted to consider the full lifecycle of the product. In this way, the design would be as environmentally friendly as possible, not just while in use but when being constructed as well. Lastly, it was decided that to prevent wildlife interference the drone would contain a small blinking light to warn birds in flight as it approaches. The flight path will also avoid crossing through any natural habitats to take as much precaution as possible. These evaluations made using the PERSIED method will ultimately ensure that the final design is feasible within all aspects of the project.

Implementation of Client Requests

When working on a project, client satisfaction is crucial to its success. One way to achieve this is by listening to their needs and adjusting accordingly. This includes making modifications to the project design and schedule to accommodate their requests. Throughout the project our team had several meetings with the client. During these meetings our team was tasked with various specific requests by clients due to which we had to modify our design throughout the process. We will discuss all these requests individually and reflect on the changes we made to implement. Firstly, our client asked us to set aside maintenance day. This was an easy request to include in the project because no modification to the hardware was necessary to implement it. When making a schedule for flight times and locations, we considered that one day was now unavailable to use and is solely for maintenance. This ended up working in our favor as we used that day for data transfer, updates and charging our drones.

Next request was implementing hardware and software that ensures collected data is kept private and confidential. For this request we had to change both the hardware and software of our design to protect the data. We planned to use encryption software that will ensure that the data is not accessible to anyone without the proper decryption keys. We also included measures that will allow for remote data wipes in case the drone is stolen or compromised, which will help prevent unauthorized access to the data. In addition to software measures, we implemented physical protection measures that will limit access to the data if the drone is stolen or compromised. This included measures like locked compartments or tamper-evident seals that would make it difficult for anyone to gain access to the data without being detected. Another request was if water is to be collected by the drone, what regulations and issues could arise and what can be done to amend this. We increased security and sanitization on the drone, so danger from contact with hazardous waste is minimized, as well as sealing and properly containing hazardous waste. Our client requested to consider flight paths and how each path impacts a different PERSID layer and find the most optimum path that aligns with our project goals. We designed our flight paths weighing the pros and cons of the various flight paths and then we selected the ones which respected the PERSID layers and had the least conflicts with any of the layers. All these various requests throughout the project helped us shape the final design solution.

Final Proposed Design

Final Design and Deliverables

After careful consideration, Group SWM-50 decided to design a water source water monitoring system that uses drones and remote sensing technology to collect and classify data. Data will be delivered to drinking water treatment plants through the system using effective flight paths and techniques. Several significant aspects will be taken into consideration when designing the flight path [Figure 1]. For instance, the green lines represent the main highways, the yellow regions represent the first nation reserves, and the red circles represent the municipalities and communities that need to be considered.

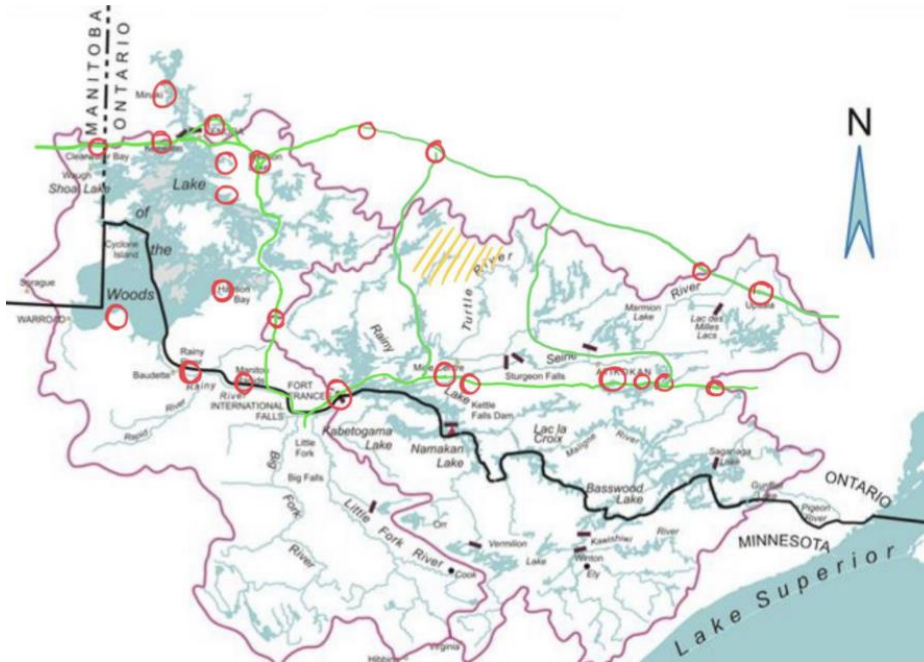


Figure 1. Flight path consideration

The client had a choice of two drone types [Figure 2], a multi-rotor drone and a fixed-wing drone, each with its own advantages. Multi-rotor drones are easy to operate and can hover in place, with shorter flight times but more agile and flexible flight paths. Fixed-wing drones, on the other hand, can fly longer distances and have longer flight times, but require a larger landing area and have a more expensive price. Clients can choose the type of drone that best suits their requirements.



Multi-rotor drone



Fixed-wing drone

Figure 2. Drone types

To control the drone and collect data, the Group SWM-50 will use the UgCS Skyhub 3 controller [Figure 3] as the ground control software. The software provides real-time telemetry data and a user-friendly interface for controlling the drone's flight path. The telemetry data can be used to ensure that the drone flies within the prescribed and restricted range and to optimize its flight path. The iXM-100 and iXM-50z high-resolution camera [Figure 4] will be used by the Group SWM-50 to take high-quality pictures. Algal blooms could be correctly identified and categorized using the camera's precise photos, which can be captured at a quality of up to 100 megapixels.



Figure 3. UgCS Skyhub 3 controller



Figure 4. High-resolution camera

Objectives and Constraints

In the initial stages of the project and its development, we brainstormed a number of requirements and constraints that would be necessary to complete the project in a feasible and realistic manner. Throughout the design process and eventually leading to our final design, we met a lot of the requirements and constraints put in place. First, the physical aspects of the drone in terms of requirements and constraints were size (later specified to be under 25kg), and photo/video quality, which we met by using the UGcS SkyHub 3 and the iXM-50/iXM-100 high-resolution aerial photography cameras, as mentioned earlier. Next, the operation of the drone is needed to avoid airspace, access remote areas, and meet local regulations. By creating a flight path [Figure 1] that avoids airspace and other sensitive areas (First Nations reserves, dense municipal areas), the drone flight path is not only optimized but meets regulatory requirements. Additional regulatory requirements are met by having licensed pilots operating the drones at all times, as well as getting Special Flight Operations certificates where needed for drones that will be collecting water samples [12]. Further design requirements included having an appropriate downtime, which was also later a request that was made by the client. This was addressed by creating a 4-weekday data collection flight plan, where the drone flies from sunrise to sunset consistently, stopping only to charge and offload data, where the 5th and final weekday will be used as a maintenance and repair day. The drone not being intrusive to wildlife and natural habitat was also an important consideration highlighted early on that also falls under the environmental layer of the PERSEID method. This was addressed by making the drones bright colours and LED lights to allow them to be easily seen by wildlife so that they can be avoided. Additional constraints were introduced later in the project through requests that were made by the client. These requirements lead us to implement a variety of changes that have been mentioned. This included, for example, hardware and software to protect data on the drone by introducing a locked system that cannot be tampered with and introducing a remote wipe feature that can be triggered from a control system to prevent a data leak. By meeting these objectives and constraints, layers of the PERSEID method were addressed. For example, by making the drone bright and adding flashing lights, people are less likely to feel that an inconspicuous drone is 'spying' on their community. First identifying constraints and requirements, and then developing the design to address them proves to be a difficult task but is a vital part of the engineering design process. Through these steps, we have been able to develop an effective and

well-rounded design that efficiently collects high-quality data from a variety of locations while meeting legal requirements.

Implementation of the Final Client Request

A number of potential changes could be implemented in the design as a result of the week 10 client request, where the option of outsourcing data collection to local residents was presented either as a supplement to the drone collection system or as an alternative to using the drones. Our group came up with two major ideas. First, a mobile app that residents who complete data security and effective collection training are able to download, where they may be prompted to take images of their local water bodies. The second is that these trained and trusted individuals will be sent sample collection kits similar to those used for COVID-19 testing, which they will then send to the closest lab via a trusted courier. Major considerations that immediately presented themselves as a result of this request were the impact on data quality, data and information privacy, and the size of the collected data set. With people manually collecting data, the quantity will undoubtedly be less, whether that is physical samples they are collecting and sending out, or images that they are taking. Outsourcing collection to community members also requires changes to how data is protected and processed, and finally, if machine learning algorithms like the CIFAR-10 training data set, thousands of images are needed to teach the algorithm and allow it to make effective decisions. Given the idea presented and the considerations that arise, the design will be entirely different from the initially presented drone data collection idea. The machine algorithm will have to be trained using preexisting imagery and adapted to images taken on mobile phones, the data encryption and protection system will have an additional step for training and screening for people prompted to collect data, and the quality of the data will be assessed through an additional algorithm that will initial accept or reject photos and re-prompt collection to ensure high-quality data.

Conclusion

Group SWM-50 conducted a comprehensive feasibility study of the source water monitoring project, focusing on important factors such as technical performance, socio-cultural, policy and regulatory, and environmental impacts. Performance challenges include ensuring the reliability and safety of drone flights, the accuracy of computer vision models, and the collection of high-quality training data sets. Socio-cultural considerations include addressing privacy issues, minimizing noise pollution, and promoting social acceptance of the technology. Policy and regulatory challenges involve designing drone flight plans within strict regulatory constraints and balancing client requirements with accessibility regulations. Environmental impact challenges include minimizing disturbance to the public and wildlife, noise and emissions pollution while maintaining performance efficiency. Group SWM-50 also proposes solutions to these challenges. To ensure accuracy and efficiency, the team prioritizes the use of cost-effective and easily integrated sensors and technologies, such as single-sensor imaging systems with multispectral filters, to reduce complexity while still enabling high-quality data collection and image processing. As well as selecting appropriate flight paths to minimize battery consumption to improve drone performance. In terms of sociocultural aspects, data security precautions will be taken to ensure that data is encrypted in both transmission and storage. And publicly communicating the goals of the project and the intended use of the drones to increase social acceptance. To comply with regulations, the SWM-50 was designed to meet regulatory constraints on flight plans while balancing the client's requirements for data security. To minimize visual and wildlife disturbance, drones will be designed to limit visual disturbance to the public and avoid noise and emissions pollution, as well as avoid flying drones near wildlife habitat and consider flying drones at higher altitudes to reduce ground noise levels.

After reviewing the project requirements and considering the available solutions, the next steps for the client involved the implementation phase. The first step is to acquire the necessary components, such as the drone frame, motors, sensors, and batteries. Once all components have been procured, the prototype development phase can begin. This will involve assembling the drone and testing it to ensure that all components are functioning as expected. If any issues arise during the testing process, the client will need to make the necessary adjustments and retest the drone until it successfully passes all tests. Once the drone is operational, the client will begin using it for performance testing. During flight, the drone will capture images that will be sent

back to the ground station for analysis and comparison with real values to test accuracy. The client will also need to create a maintenance and repair plan to guarantee the drone's durability and efficacy. To keep the drone in peak functioning condition, frequent inspections, maintenance, and repairs will be required.

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Appendix

Appendix I: Decision Matrices

<i>Criteria, Weight</i>	DJI Matrice 300 RTK [2]	WingtraOne GEN II [3]	XAG V40 [4]
Weight, 3	3	3	2
Camera and processing capability, 4 *	3	2	4
Flight time, 4	2	3	1
Additional capability, 2 **	4	2	2
Cost, 2	5	3	1
TOTAL	47	39	36

Table 1. Drone Weighted Decision Matrix

<i>Criteria, Weight</i>	iXM-100 [5]	Trillium HD25-XV [6]	Sierra-Olympia VAYU HD-1 [7]
Weight, 3	3	4	1
Image quality, 4	4	2	4
Power consumption, 4	5	2	3
View angle, 2	4	2	3
Capture rate, 2	5	3	4
Cost, 2	2	4	3
Data storage ability, 2	3	2	2
TOTAL	73	50	55

Table 2. Camera Weighted Decision Matrix

Appendix II: Important Figures

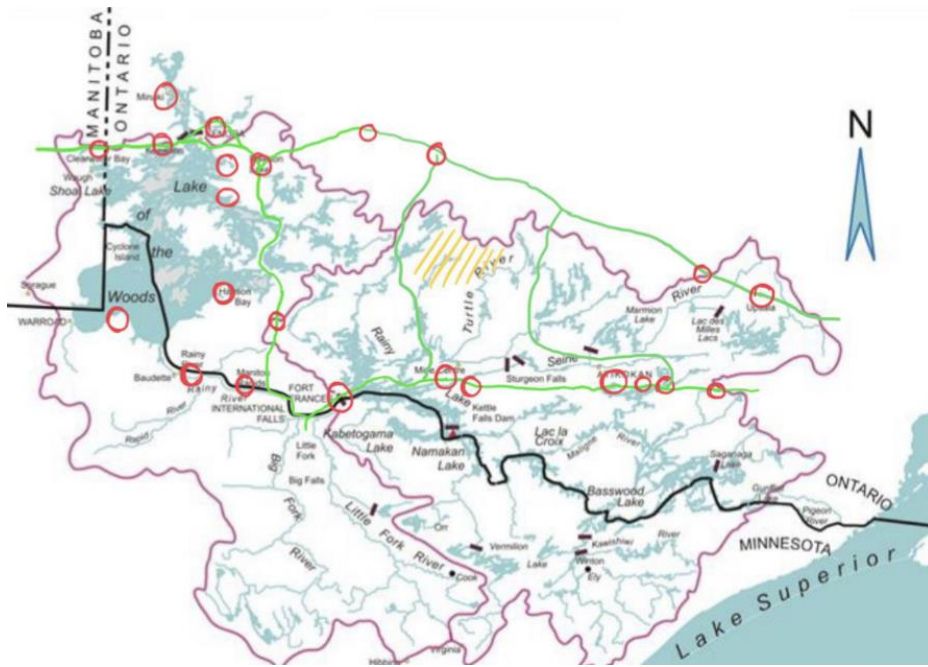


Figure 1. Flight path consideration

Appendix III: Worksheets and Meeting Minutes

[Synchronous Design Studio Week 2](#)

[Synchronous Design Studio Week 3](#)

[Synchronous Design Studio Week 4](#)

[Synchronous Design Studio Week 5](#)

[Synchronous Design Studio Week 6](#)

[Synchronous Design Studio Week 7](#)

[Synchronous Design Studio Week 8](#)

[Synchronous Design Studio Week 9](#)

[Synchronous Design Studio Week 10](#)

[Milestone 1](#)

[Milestone 2](#)

[Week 3 - Agenda and Meeting Minutes](#)

[Week 4 – Agenda and Meeting Minutes](#)

[Week 5 - Agenda and Meeting Minutes](#)

[Week 6 - Agenda and Meeting Minutes](#)

[Week 7 - Agenda and Meeting Minutes](#)

[Week 8 - Agenda and Meeting Minutes](#)

[Week 9 - Agenda and Meeting Minutes](#)

[Week 10 - Agenda and Meeting Minutes](#)