ENGINEERING

McMaster University

Water-22 Final Report
Source Water Quality Monitoring Project

Engineer 2PX3: Integrated Engineering Design Project

Water-22
Design Studio Group 10

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Academic Integrity Statement

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Andrew Piotrowski, 400302825

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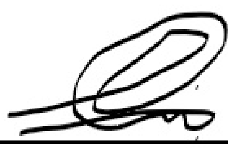
X 

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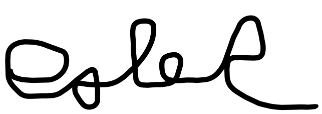
X 

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Executive Summary

Algal blooms poisoning municipal water sources is a major hazard in modern-day society. To notify local municipal authorities of such algal blooms, our team intends to use a low flying aerial surveillance drone system to tackle this problem using McMaster's PERSEID method. We have decided to use a system consisting of two drones to capture images of the lake. This system will be both effective and time efficient. The drones will include features such as pulsing light to discourage bird trikes, an hour-long battery life, and a parachute in case of a crash. Though other designs were proposed, this rose to the top as our best model overall due to its ability to effectively satisfy all stakeholder considerations. For our group the most important next step is developing and testing the design. Considerations have been made on how to implement the design, but the follow-through was outside the scope of this project.

Introduction

The threat of algal blooms has risen in recent times [1]. Climate change is bringing rising temperatures and increased rainfall, a climate that is ideal for toxic cyanobacterial algal blooms, and so they're only getting more common in time. If a water treatment plant fails to detect an algal bloom and sucks in algae, it may clog up the production line, which may require a complete shutdown of the plant to ensure a thorough cleaning, leaving the local population without water **[Appendix A].**

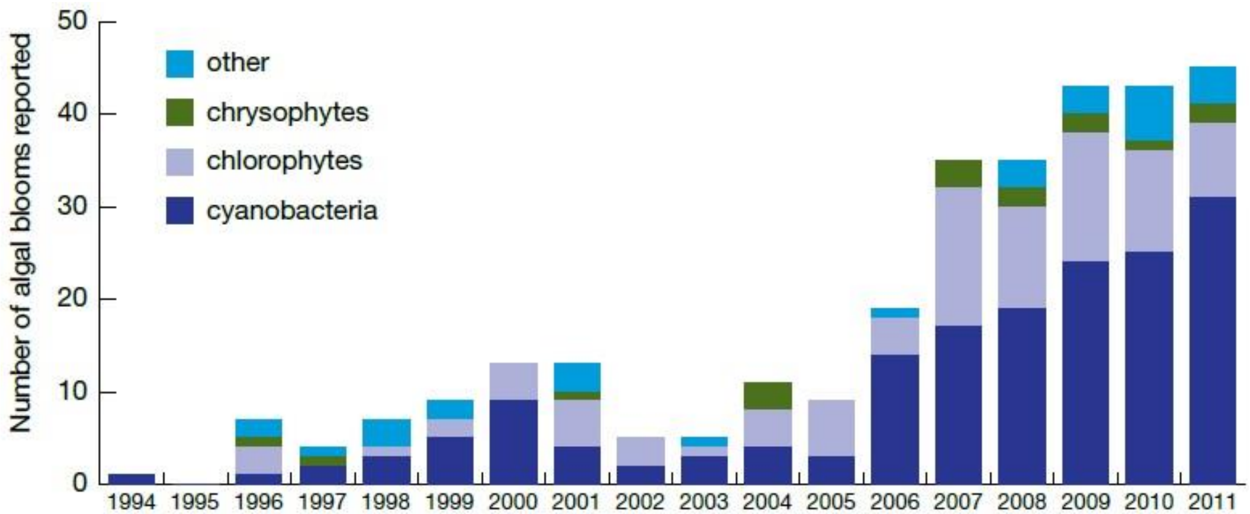


Figure 1 - Number of algal blooms reported to the Ministry of the Environment and Climate Change, 1994 to 2011.[1]

To combat this growing risk of algal contamination, this project aims to detect algal blooms in fresh water sources before they have the chance to do any harm. This group has approached this task by proposing and evaluating various drone chassis, along with the infrastructure around them, designs that were based on research that will follow the PERSEID method. Aerial photographs will be taken with these drones, and then be fed into a machine learning algorithm to determine whether the body of water is experiencing an algal bloom. This was done while adhering to local Canadian aerial legislation, taking care to keep the interests of various stakeholders in mind.

Our design should be able to accurately and punctually report when the monitored body of water is experiencing a toxic algal bloom. It must also not be disturbing to nearby people, follow aviation regulations, and operate in such a way that has little to no negative environmental impact throughout its life cycle.

These factors pull design decisions in different directions and using decision matrices we were able to arrive at an effective compromise.

While it was not a primary concern due to scope, we also pursued affordability, as this would be an important factor in real-world implementation.

Although we try to avoid it, false positive and negative rates are inevitable. However, when designing the program, we were able to choose a system that prioritized lowering false negatives, for failure to detect an algal bloom has a far worse consequence than flagging a safe lake as dangerous **(See Explanation of Machine Modelling).**

Because failure to detect an algal bloom in time may require the complete shutdown of the water filtration facility, it is paramount that we minimize the odds of a false-negative result at all reasonable costs.

Additionally, during our interview with Susan Girt of Hamilton Water, we were made aware that people's complaints regarding algal blooms come from it being "ugly and smelly" and less about its actual toxicity. The point being that people complain, highlighting the importance of socio-cultural concerns.

While the other two primary design alternatives aimed to be optimized for one specific aspect of design, our chosen final design aimed to be 'reasonable' in all metrics.

Project Scope

This project is purely an exercise in research theoretical back-end design, focusing on giving a semi-practical application of the PERSEID method. Our goal was to consider the concerns of various stakeholders, come up with a series of metrics and constraints to evaluate our designs, then filter down through the layers of PERSEID. Identifying potential technical limitations, regulatory documentation, and potential ways to test and improve the machine learning algorithm is within the scope of the report. *Following through* with this plan and ironing out the kinks that arise when we get hands-on and on-site, **is not**. Considering the financial cost of materials, though it is kept in mind, is not a primary consideration.

Though we lack the technical experience to follow through with this plan, the practice taking inspiration from various sources and filtering it through concerns outlined by our stakeholders is nevertheless valuable in and of itself.

Conceptual Design

Initial Body of Water Selection:

In the early stages of the project, we thought we would be able to have a working prototype for the final submission. During the pre-planning and team building, one of our groupmates mentioned he had access to a drone with a camera – a standard Mavic Pro. With this in mind, we initially chose Jojo Lake in Hamilton as our body of water (see **figures 2 and 3** below).

It was close to the university in which this project group based, within walking distance of our groupmate with the drone. Though it was not explicitly a water-source, we believed it would be a good place to test our proof-of-concept. Later, we expanded this to the entire Cootes Marsh to increase our project's scope, the idea being that if some issues were to arise and we had to change our location, the project would have been already built for common lake-sizes, meaning adapting to a new location would require less reconfiguring (this ended up paying off in the end, as we ended up having to change our location last-minute). With an idea of what we wanted to do and what body of water we wanted to monitor; the research portion began.

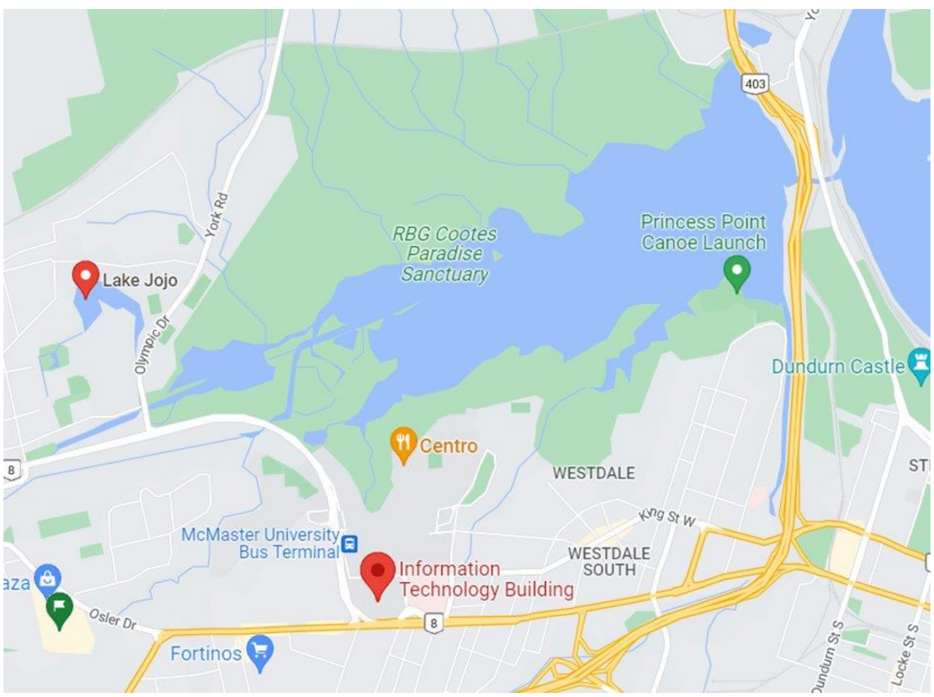


Figure 2 - Google maps representation Lake Jojo and Cootes marsh in relation to the ITB, the building in which our team meetings were held.

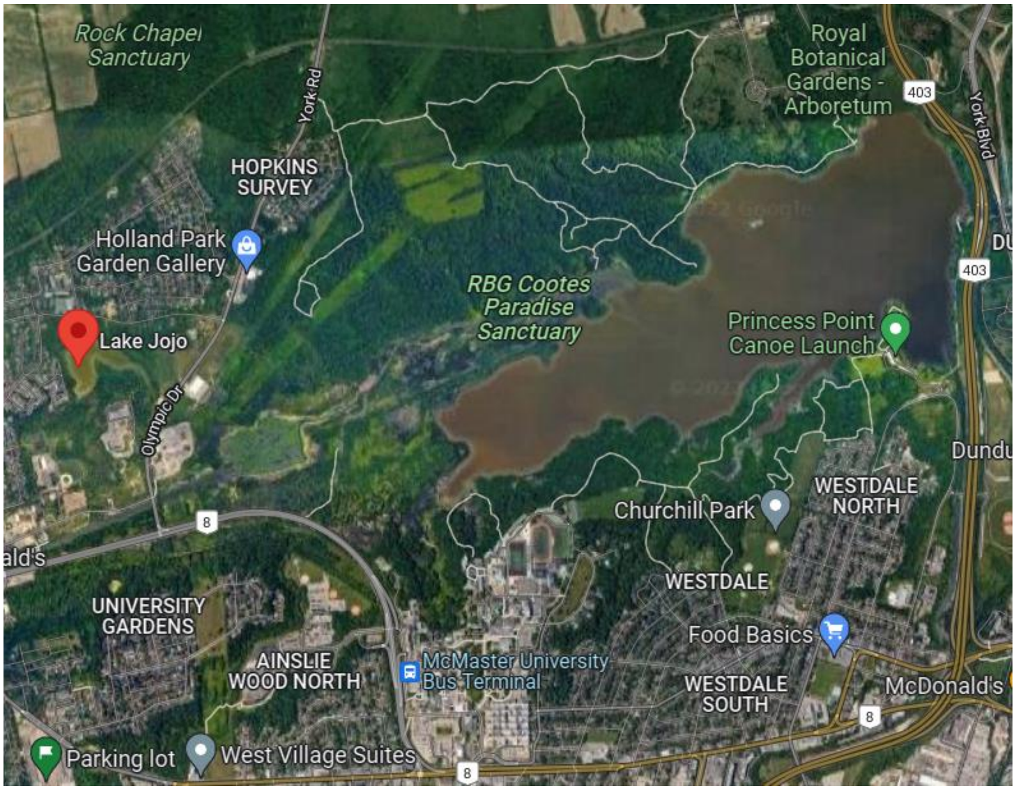


Figure 3 - Satellite view of Jojo Lake and Cootes Marsh.

Research Process

As a part of our course load, we were tasked to look at both current solutions and analyses of said solutions, generating the list of constraints we would need to consider and filter through as a part of the PERSEID method – this documentation may be seen in **Appendix B**. In addition to this, we found research publications relevant to our project, such as a lifecycle analysis on the usage of drones for package delivery [3], as well as a report documenting a team that took the same approach towards early-algae detection [4].

As our initial body of water was JoJo Lake, contacted the local authorities for comments. We *did* get **interview with a representative of Hamilton Water**, where we discussed how the water filtration process works, what would happen in the case of an algal bloom, and other general questions and feedback. We were unable to record the meeting for documentation - the notes from this meeting are in **Appendix A.**

We organized all potential design decisions or considerations that came up in our research into a table, sorted by what aspect of the PERSEID method they influence most, documenting:

- How this design element may **benefit** what layer of PERSEID
- **At the cost** of what PERSEID layer,
- And what additional **incompatibilities** would such a feature have, as well as what other features might be additionally required

This table is listed in Appendix B. From there, we came up with three different designs by amalgamating various elements from said table, trying to optimize for one aspect or another.

To use a metaphor, think of our design like a knitted blanket, where each string is a design element. We have been adding, removing, and pulling at various strings, theorizing how the blanket loosens and contracts, trying to ensure that once the blanket is fully knitted, it is large enough to cover the body, but also thick enough to provide warmth. Such was our process for coming up with these three designs.

Unfortunately, it is not possible to optimize for all criteria; different features can affect multiple aspects of design, often non-linear ways. As a result, we decided to have 2 designs that are optimized purely for one aspect of design, and a third that tries to be ‘reasonable’ in all criteria.

Design Alternatives

Design 1

Two Drone Crew, prioritizing reasonable efficiency

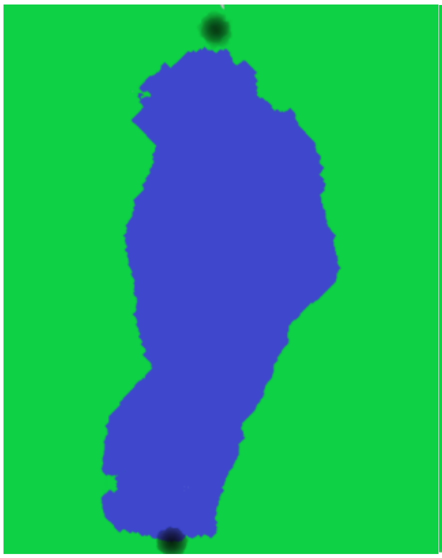


Figure 4 - Two drone crew docking station

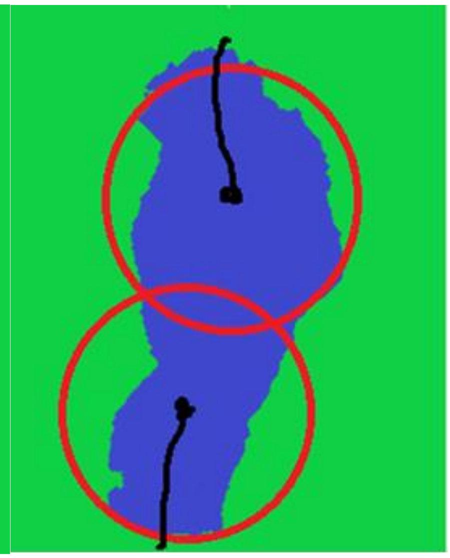


Figure 5-The scanning area of the drones

For our first design, we wanted to choose something feasible and suitable for a variety of different bodies of water. The design philosophy for this design was to maximize efficiency, within reason, by being ‘reasonable’ in every criterion. We wanted a design that checks every box but does not stand out in any negative ways.

Two drones start at opposite sides of the lake. They will fly towards the center of the lake and stop once they reach a distance that is ¼ of the lake. Each drone will capture images of their side of the lake. The idea is that the images taken by both drones combined will end up making a complete scan. Each docking station will be powered by solar panels so that the energy used is renewable.

The machine learning model would be false-negative biased, meaning it minimizes the odds of a false-negative result, this is because we are to ensure the safety of our clients with a reasonable cost-effective solution.

Figure 6- DJI m200 [5]

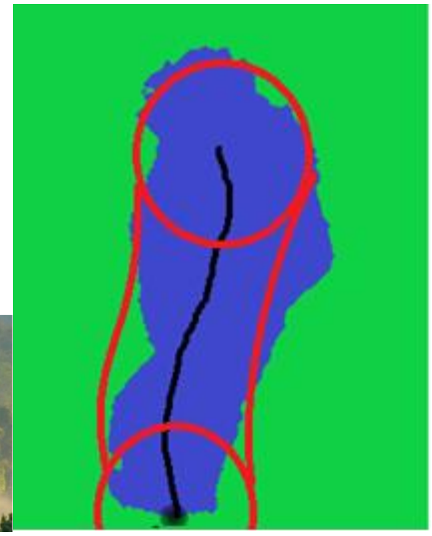
The Drone that we chose to use in this design is a preexisting drone called DJI M200 with AVSS Parachute Recovery System. This is an ideal drone for this design for many reasons.

Strengths:	Weaknesses:
Already exists, approved my transport Canada Allowed to: • **Fly near and over people** [6] • **Fly in controlled airspaces** [6] According to the Canadian Aviation Regulation, because the drone is allowed to fly over and near people, we do not have to wait for the lake to be empty when taking pictures of it [6]. **Water resistant** – Able to handle the water vapor and mist, which would reduce maintenance costs in the long run [7]. **Level 7 wind resistance** (52 – 61 kph) this means that the drone will be stable in wind and will be able to operate as normal at high wind speeds [7]. **55 min battery life [7**], meaning that we can cover large distances. If one drone has a problem and can't do its job, then the other drone likely can still capture the entire lake itself **Simple and effective** - System requires only two drones and has a very basic flight path, but can still cover the whole lake	**Already exists –** due to this design using an already existing technology, we are bound to repeating what has already been done. This limits our scope. **Not waterproof -** If it crashes, it is likely that it will fall in the water and will not be able to be recovered, possibly contaminating the water source we are supposed to monitor [7]. **Noise factor** – Loud, wide, few anti-noise measures. **Wildlife concern** – If the drone crashes, then it's likely to fall into the water. This is very bad because if the chemicals in the battery leak out into the water it can be toxic to the wildlife.

Fast - Has a max speed of 54 kph [7]. This will help improve with scanning time. Can operate at cold and hot temperatures [7]. **Modifiable –** meaning we can incorporate a small pulsating light to discourage bird strikes.	

Design 2

Blimp, prioritizing performance and carrying capacity



Fi*gure 7 – Blimp base station* *Figure 8 – Example Blimp* [8]
Figure 9 - The scanning path and area

Design Two is a hypothetical blimp-based design. Unlike the other two designs, there is not an exact analog of this design in the real world. However, there is an example that is similar that shows such a design can be feasible and what it could look like [8]. The principle behind this design is to examine the pros and cons of focusing entirely on performance for the main task while putting little thought into the impact this may have on the other layers of PERSEID.

The blimp design would perform its function via single large sweeps of the water source, thanks to its ability to stay in flight longer than a conventional drone. On calm days, it could even maintain additional surveillance throughout rather than performing separate day and evening sweeps.

The onboard image processing would allow it to send warnings without landing, reducing the complexity of the base station.

Such a design may have the potential to succeed in the field if its impressive performance leads people to "shrug off" its potential negatives, and the blimp technology in theory could be applied to other applications as well. The idea is that the small airship will have a set carrying capacity that can be modularly fit with a variety of equipment – simply use the tonnage used for photography and analysis for other applications.

Such a design is most optimal for larger bodies of water where it may be able to make use of its extreme range to get a full thorough scan – as a result, if we were to implement such a design, we would change our body of water to one of the Great Lakes, for example.

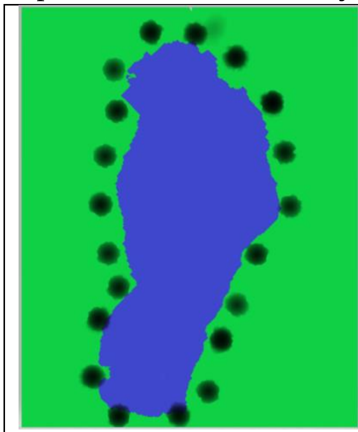
With a large enough carrying capacity, we may even be able to attach solar panels to give its electrical motors and other systems nearly unlimited range, in addition to pulsating lights to discourage bird strikes.

Strengths:	**Weaknesses:**
• **Long flight duration** (battery life) due to not relying on motors to stay aloft. • **High Image quality** due to its ability to carry a high quality, heavy camera. • **Able to fly in harsh weather conditions** (will not crash easily, even if conditions can push it off course) • Can cover the whole lake in one sweep • Onboard image processing to allow **faster reporting** • Will not crash immediately if propulsion motors fail. Enough weight capacity to carry redundant systems. • Waterproof in intended conditions • Only needs one base station • Sufficient carrying capacity to include a **black box** for data collection and recovery. • Modular equipment application can be modified for other uses.	• Larger drone means more frequent bird collisions, though the blimp can be outfitted with the bird avoidance mechanisms described prior. • More electricity would be needed to power it • The contents of the balloon would be a fire/explosion hazard • A crash of this design would be much more problematic than a small drone • It would be loud. *Far* less inconspicuous than a normal drone • Requires a mechanism of heat in addition to propulsion (more complex) • We will need to apply for a Special Flight Operations Certificate if we intend to have a total weight higher than 25kg.

Design 3

Drone swarm, prioritizing speed

The design philosophy for this idea was to ignore monetary efficiency and sacrifice materials to prioritize time efficiency.



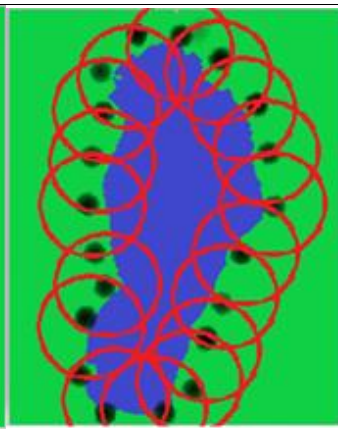


Figure 10 - starting position of drones *Figure 11- Flight path and scanning area*

Figure 12 - ASTM Compliant DJI Mavic 3 Cine with AVSS Parachute Recovery System (PRS-MAVIC) [9]

This design is based on having multiple drones and docking stations along the perimeter of the lake **[Fig 7,8].** The drones themselves will be little more than 4 propellers attached to a camera, as cheap as feasible. The drones will fly directly upwards and take a picture, never directly over the lake. They will have a parachute in case of crash landings, which will minimize the possibility of losing the entire system due to damage.

For this design no complicated flight path is needed because all the drones need to do is go up. This allows our design to be transferred between different bodies of water very easily.

Due to the low battery life required, we may even be able to use a less environmentally toxic battery than the standard Lithium-ion/Lithium-polymer battery. One may notice that the centre of the lake is not being monitored by this design. This is considered an acceptable risk, as algae most often blooms closer to the shoreline **[10]**.

The drone we decided to use for this design is the DJI Mavic 3, because it is small, affordable, and uses a smaller than average battery, making it more environmentally friendly. It is a **drone that was already approved for this purpose by Transport Canada.**

Strengths:	**Weaknesses:**
- **Very quick to scan**. The total scan time would be close to around 2-4 mins, - **Fast (max speed of 15m/s)** [11]. This speed is important because it improves the speed of the scan - **Low Disturbance.** Will not cause as much as a disturbance because the drones are in the air for such a small amount of time. **- Low chance** to crash because there will be no obstacles the drone has to move around. If a crash landing occurs, the drones have a built-in parachute that will allow it to be recovered - **Already exists, approved my transport Canada** **Allowed to:** • Fly near and over people [6] • Fly in controlled airspaces [6] According to the Canadian Aviation Regulation [11]. Because the drone is allowed to fly over and near people, we do not have to wait for the lake to be empty when taking pictures of it.	- **High monetary cost**, even though the drones are cheap due to the amount of drones used - **Only Level 3 wind resistance [13-20 km/h]**. Because the drones are so light weight the wind might cause the drone to not stabilize and take bad pictures. - **Low Environmental Durability:** Cannot be operated in less-than-ideal conditions. This is because the drone is not water resistant and bad in wind. - **Socio cultural concerns:** Might surprise people that are by the lake when they see many drones rise into the sky at once. - **Low battery life:** Max flight time of drones is 20 mins (though this is less of a concern due to the lack of a flight path required). - **Regulatory concerns:** We would need to apply for a Special Flight Operations Certificate as this system flies more than 5 drones at the same time.

Decision Matrices and Design Evaluation:

As a group, we discussed what factors should be included to decide between our three drone designs from Milestone 2. This was somewhat difficult since we had to come up with factors that only represented a single element of our design's requirements. The list we ended up deciding on was:

1. Carrying capacity
2. (Lack of) Noise Pollution
3. Visual appeal
4. (Lack of) Regulatory Risk
5. Simplicity
6. Environmental friendliness factor
7. Scanning time

We made a point to word these in such a way that more of each is good, making it easier to decide on scores. It was also noted that:

- Coverage of the body of water was considered as a criterion, but we ended up not using it since we have been assuming all our designs could cover the whole thing.
- "Range" is not a valid factor, because the (lack of) individual range of a drone can be mitigated via drone amount/orientation and other factors.
- "Weight/Size" is not a valid criterion, because bigger is not always better. Being bigger and heavier may give us more carrying capacity, at a cost of speed/noise/etc. "Carrying capacity" is a more valid measurement to consider.

Using the chosen metrics, we worked together to make a weighted decision matrix. As we developed our weights and decisions, we were able to refine and add some of the above criteria we had in our final version and spent some time discussing our weights and how each design is worse or better than the others in each category.

For example, as we thought about the way each system operated, we lowered the simplicity factor of the blimp due to the complexity of having to deal with heating gasses and the mechanisms that that entails.

	Weights (1-10)	Two Drone Crew	High-Capacity Blimp	Drone swarm
Carrying Capacity	7	5	10	9
(Lack of) Noise	4	5	8	4
Visual appeal	3	5	3	3
(Lack of) Regulatory risk	9	8	5	5
Simplicity	4	6	4	4
Environmental friendlyness factor	5	8	5	4
Scanning Time	5	5	3	9
Grade		231	212	214

Figure 13 - Initial decision matrix evaluating the three designs.

Following a lecture that emphasized the importance of socio-cultural factors in a design's success, we re-weighted the factors in green and red, leading to a greater spread in scores. This further solidified our final decision to pick **Two Drone Crew**, as this more decisive matrix outcome agreed with our collective intuition.

	Weights (1-10)	Two Drone Crew	High-Capacity Blimp	Drone swarm
Carrying Capacity	7	5	10	9
(Lack of) Noise	**5**	5	8	3
Visual appeal	**5**	5	3	3
(Lack of) Regulatory risk	**10**	8	5	5
Simplicity	4	6	4	4
Environmental friendlyness factor	5	8	5	4
Scanning Time	**4**	5	3	9
Grade		249	228	215

Figure 14 - Re-weighted decision matrix

Explanation of the Machine Modelling:

To have some experience with the machine learning model and the python code on which it is built, we were provided two sample python codes and machine learning algorithms to classify different terrain types and identify algal blooms. These are **Terrain.ipynb** and **Algae.ipynb** respectively, with a dataset for each **[Appendix C].**

While it is ideal to maximize detection accuracy as much as possible, we acknowledge that **false-negatives in our algorithm are far more dangerous than false-positives.** If we fail to detect an algal bloom in time, the worst-case scenario is the total shutdown of the water filtration facility. The worst-case scenario of a *false-positive* result is the water filtration facility sending a technician out to the lake to refute our detection, and then operation as usual, a *far* less dangerous result. Therefore, we aim to train the machine learning algorithm to minimize the odds of a false-negative detection.

Performance on validation tests:

The Algae dataset contained images of various lakes in varying conditions, resulting in overall poor accuracy as the machine learning algorithm struggled to even reach the accuracy of the validation data, plateauing around 58% accuracy as compared to the input data's accuracy of 66% **[Appendix D].**

As expected, increasing the number of epochs does increase the accuracy of the final iteration, but it is subject to asymptotically diminishing returns. Past some number of epochs, improvements in accuracy are negligible at best. In relation to training database size, we are also seeing that same asymptotic behavior. Past some point it is no longer worthwhile, especially on the testing data side where human labeling is required.

Performance Regarding Various Datasheet Changes:

Through testing on our own time, we concluded our initial assumptions. More training data as well as more epochs, leads to greater model accuracy, though epochs have greater diminishing returns when compared to database size. Halving the training database size had only a minor effect on accuracy. Decreasing it by factors of five significantly affected accuracy, and the algorithm is a coin flip in terms of accuracy when it is trained off a single image.

Database Type & Number:

Model Name	Database Size	FP	FN
DNN	~10000 images	1%	3%
DNN	~ 1000 images	3%	7%
DNN	~ 100 images	29%	41%
RNN	~ 10000 images	5%	2%
RNN	~ 1000 images	10%	6%
RNN	~ 100 images	21%	20%
CNN	~10000 images	4%	1%
CNN	~1000 images	9%	12%
CNN	~100 images	39%	41%

Table – Database

Chosen method: RNN, ~1000 images, 10%, 6%.

This following table shows the three types of models that detect false positives and false negatives, at different number of images taken. The method that was chosen was: RNN, ~1000 images, 10%, 6%. Though at every scale of images, there is an objective best algorithm, 10,000 is a lot of images and we are concerned about the viability of getting a dataset of that size. As a good balance, we think ~1000 is viable, and from there we chose to minimize the number of false non-detects. False positives are much less concerning compared to false negatives since having a false negative means that the water is contaminated with algae is undetected, which can be harmful, causing logistics issues at the filtration plant and potentially getting people sick. In contrast, a false positive should simply be a minor inconvenience.

Real-World Example:

These sample models were purely conducted as a learning exercise. However, in the field, the machine learning algorithm would be trained for the specific body of water we have chosen. Performance would heavily depend on which lake we are modelling and the atmospheric conditions at the time, the details of which would only become apparent once we begin testing the algorithm on the lake itself.

Maximizing the accuracy of the training data is vital. The training data provided is only 2/3rds accurate; it acts as a hard cap on the accuracy of the algorithm – this is because performance heavily depends on which lake we are modelling. The algorithm would work best if it were trained for this ONE LAKE we are working on. Ideally, we would be able to contact the local authorities, see if a database of aerial photographs of the lake ranging from June 1st to October 31st already exists, using that as a baseline for our training dataset. From there, the first few hundred images taken would have to be hand-confirmed algae/no algae, up until the algorithm is reasonably accurate on its own. Ideally, every image we take would be hand-confirmed, then refed into the algorithm, and so that the algorithm improves over time.

Naturally, having to repeat this process anytime we want to apply this system to another body of water is not ideal, but it is a reasonable sacrifice to make for detection accuracy.

Design Evaluation:

Our final design checks every box, but within reason. It is time efficient, effective, and not a huge distraction. Naturally, there are optimizations to be made from the base-model of the drone: Camera quality can be improved, flight stability can be optimized, as well as a more selective choice of scanning times. We could ensure we scan the lake at ideal conditions so there would be no camera shaking due to wind, or blurry pictures due to rain.

There was **one major flaw** we discovered in our research: Lake Jojo and Cootes Marsh are in **two separate no-fly zones [2]**.

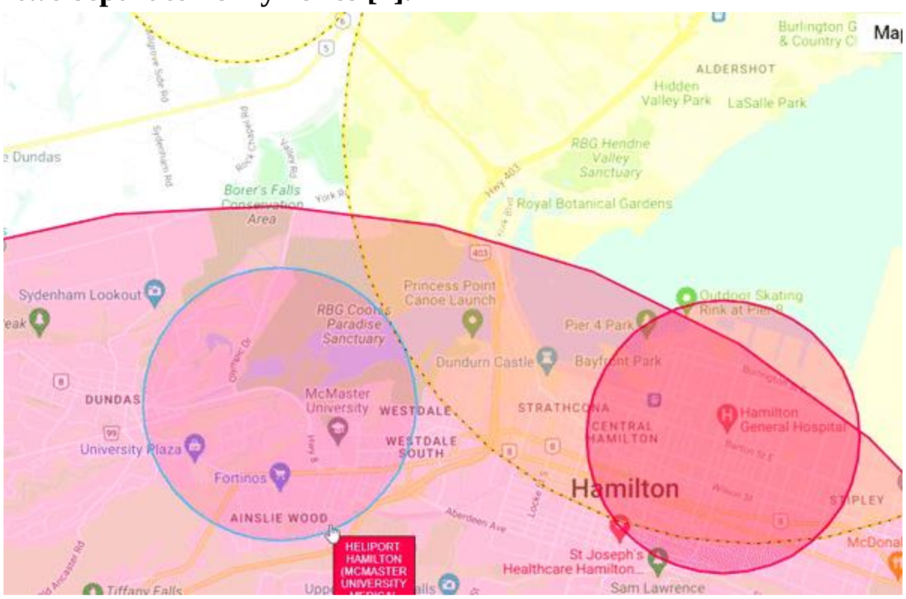


Figure 15 - No fly zones around Hamilton [12]

Despite these discrepancies, we **did** manage to find another body of water to scan, that being Moose Lake, Alberta. Although it's located in Alberta, the total surface area is comparable to that of Lake Jojo and Cootes Marsh combined, in addition to being a source of water, it's within a "safe" fly-zone area. Due to it having a similar profile, we would be able to implement and adapt Design 1 for Lake Jojo and Cootes Marsh onto Moose Lake, with minimal effort. Naturally, if the system were to detect algae blooms, we would be contacting the local authorities such as the Moose Lake Watershed Society and Alberta Health Services, instead of Hamilton Water.

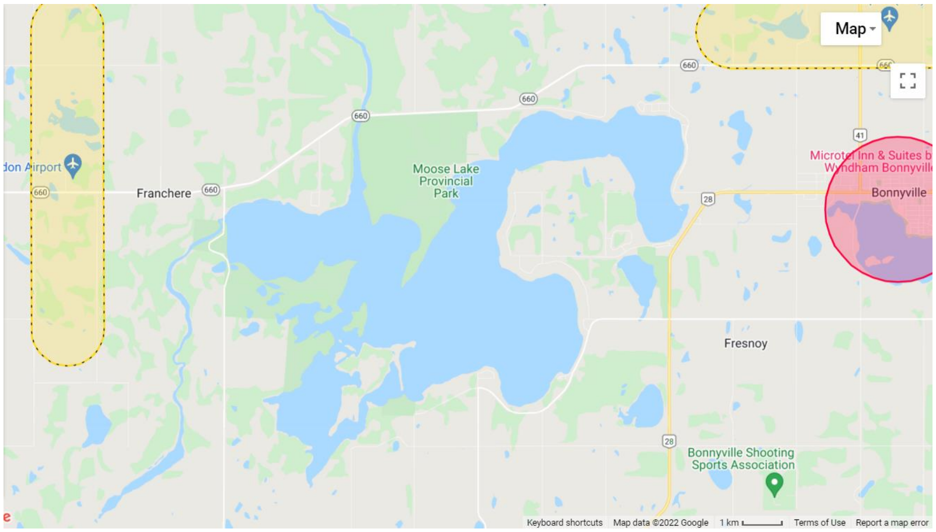


Figure 16 – No flying and surveillance restrictions over Moose Lake

Final Proposed Design

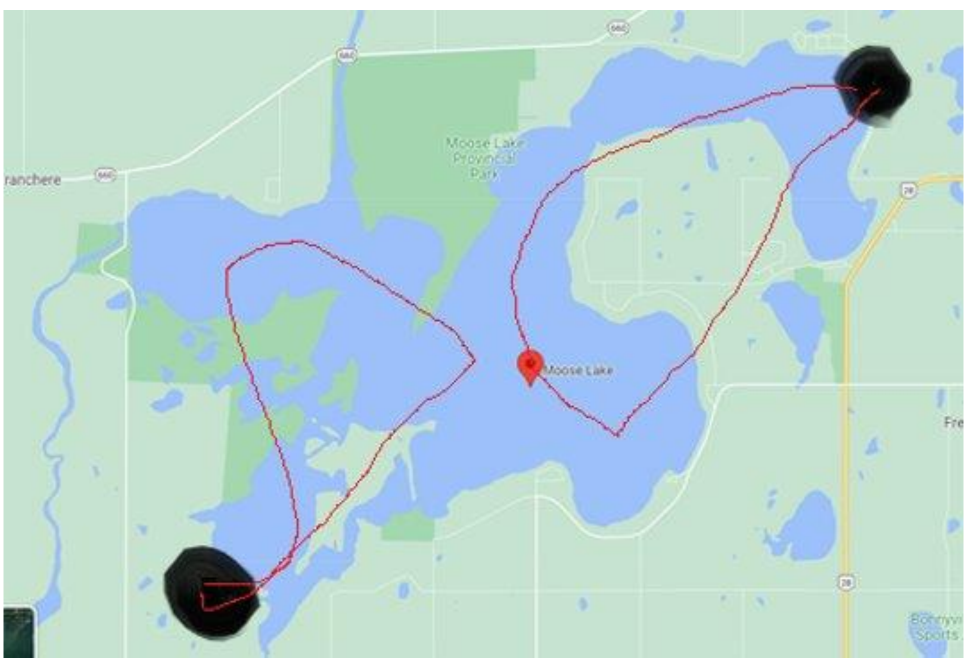


Figure 17 – Approximate flight paths (red) and docking areas (black) over Moose Lake, Alberta.

Our final design will be based on the Two-drone Crew design. We concluded that this was the superior design in the decision matrix above, both due to its high score and the intuitive understanding that it is a good overall choice for our needs. As you can see from the image above, we will be setting up our docking station at opposite ends of the lake. The drones will each have a unique flight path to cover the most distance and capture the whole lake.

Some important technical specs are: Carrying capacity of 2.34 kg, relatively fast scanning time, environmentally friendly, Simple, and easy to implement, not too noisy or distracting, wind resistance level of 7, water resistance, battery life of 55 mins, travels at 13 m/s, Modifiable - can add a small pulsating light to discourage bird strikes.

This design meets our objectives and constraints quite effectively, as it a good “all rounder” design. It has the performance to survey the lake quickly and reliability, while easily complying with regulations and being inconspicuous enough to avoid disturbing the nearby area. Given our assessment of its technical capabilities, it would be an accurate source water monitoring system when equipped with an effective machine learning algorithm.

When implementing this in a physical location, this applies to the updated chosen body of water, Moose Lake. Though the average surface temperature is lower than that of Hamilton’s Lake Jojo, and overall flight range required is slightly higher, the difference is not sufficiently major such that a redesign is required. As mentioned before, this lake is optimal for monitoring algal blooms, as it has the major benefit of not having any monitoring or flying restrictions.

Conclusions

The threat of toxic cyanobacterial algal blooms has risen in recent times, spurred on by rising global temperatures. This proposes a way to detect algal blooms before they have the chance to do any harm.

Though our initial goal of having a proof-of-concept prototype was outside the scope of the project, this team has done its due diligence to ensure the work done could be applied elsewhere. This project acts as a thorough plan on how to approach this issue – unfortunately, no plan survives contact with the enemy. Moving forward, we intend to ‘make contact the enemy’ and follow through our plan, ironing out any issues that arise along the way. Future steps would include:

- **Follow Up with Relevant Authorities:** Contacting both Hamilton Water and Moose Lake Watershed Society with our proposal, asking if such a system is of use to them, asking for feedback and comments, establishing a formal line of communication.
- **Further Testing of the Machine Learning Algorithm:** We would generate or acquire a database of images and train the algorithm to detect algae specifically on our body of water. Experimentation would be required to identify the optimal false-negative/positive rates.
- **Ironing out Technical Details:** Much like building a PC, putting drone parts together requires thorough research of the technical specifications, ensuring compatibility. Though we intend to use a pre-existing drone, the exact make, model, and software installed is up to debate, along with any discussion on what modifications are required.

- **Regulatory Details:** Our research identified common regulatory constraints, making note of various documentation listing what is required. If we were to follow up with this project, we would need to properly file all paperwork, notify all stakeholders involved, acquire a drone license, etc.
- **Proof of Concept Test:** Once we get all the kinks ironed out, all that is left is to fly it over our body of water, taking an image, and feeding it into the algorithm.

Taking a moment to look back, we learned the importance of social cultural concerns, and the importance of looking at the design through the eyes of the stakeholders. As a team we learned the importance of communication and time management. We realized that clear communication is key. If we were to work together again, we would change how we handled work outside of the in-person design studio.

Ultimately, though our development was troubled, our final proposal was well researched, documented, and feasible. This project was emblematic of engineering projects, and a valuable learning experience for all.

Lessons to take from this endeavor:

- **Iterative Design is messy:** It involves tons of considerations, conditions and constraints may change wildly as more information comes to light, and it may be hard to wrap your head around all of it at once. I
- **No plan survives contact with the enemy:** As mentioned previously, we were initially set to scan Jojo Lake. Once further information came to light that made this no longer feasible, we were forced to improvise, adapt, and overcome.
- **Team Dynamics:** While it is possible for a team like this to improve and accomplish tasks more effectively over time, scheduling and productivity conflicts caused by differing schedules provided by our different disciplines appear often and are hard to avoid. This is a disadvantage that comes along with the advantages of having a multidisciplinary team in university.

Overall, this project was a successful journey into the PERSEID method and how it applies to a diverse system that has many technical areas and impacts a variety of stakeholders. Throughout, we conceptualized various system concepts, refining as we went based on the relevant goals and constraints, and eventually arrived at the best of three unique systems with the help of a decision matrix. Our final design, Two-drone Crew, would be able to effectively monitor most landlocked bodies of water effectively and accurately, equipped with an algorithm combination suited to its capabilities.

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Appendices

- *Supporting Documents:*
    - data
    - graphs not needed in the body of the report, but that support decisions you have made
    - code
    - code output
    - design studio worksheets (group synchronous)

any other supporting material that a reader may be interested in

Appendix A: Hamilton Water Notes

As a part of our research, Andrew had an interview with Susan Girt, Compliance & Regulations manager at Hamilton Water to ask various questions about the water filtration system and their experience with algal blooms, as well as asking for general feedback. Though the meeting could not be recorded, it acted as a valuable source of insight on which various design decisions have been made. The following are the unedited notes and commentary from the meeting, along with some follow-up research we did.

Color code:

Yellow were fundamental questions, things to follow up on.

Bold were important tidbits for the incoming milestone.

Spoke with Girt, Susan <Susan.Girt@hamilton.ca>

Do we still want to just Jojo Lake? Or can we expand to Cootes Marsh, or even Lake Ontario as a whole?

We are to report and algae blooms to both Hamilton Water or Hamilton Public Health – though reporting it to the city of Hamilton is often good enough.

905-546-2489 – city of Hamilton hotline.

1-866-MOETIPS or 1-866-663-8477 – Spills Action Centre

Algae is caused by climate change in a variety of ways
Hamilton and Carlyle's municipalities are of our interest, though Carlyle is not likely to be hit by algae

Extra monitoring is most useful from **June 1st to October 31st**
Lake Ontario is where Hamilton water pulls water from, so monitoring that would be a good idea - see document, find where exactly it pulls from. Extra monitoring would be required in a **radius around the intake - define this radius. See document attached.**

Visual inspections are done near the intake and along beaches, aerial would be good as well. There is a lot of intercommunication between water municipalities so that people downriver have advanced warnings.
Hamilton water does water to drink, Hamilton public health does algal blooms covering beaches - both are notified when we message Hamilton (what is the name here)

Beach Water Quality in Hamilton -
To report safety hazards at the beach please call 905-546-2489.
This is for beach water, not Hamilton total but might be good enough.

Lake Jojo would fall under Hamilton Public Health
Most complaints regarding algal blooms come from it being ugly and smelly and less about the actual "not being able to go to the beach" issue. **Point is, people complain, meaning our drone cannot be loud, annoying, or ugly.**

If algae bloom is detected, notify all municipalities that may be affected.

Look at other municipalities, where they intake, what those bodies of water are, and identify other possibilities.
Example: For Barrie, it is Lake Symco.

If algae are visible, it is assumed toxic.

Sewer overflow areas are also monitored for algae, but not applicable to this project.

Environment Canada handles the fallout in case a drone was to crash in a sensitive area - **someone needs to follow up with this.**

Contacted Environment Canada regarding this, waiting for a response.

Algae blooms will continue to grow, so regular checks are required.

Regarding Indigenous peoples:
First and foremost, it is something we need to consider and account for.
They do not like to be considered Stakeholders; they like to be considered as keepers of the land.
Ask for *advice*, not approval, and see if they approve from there. Be respectful
We need to see if we are working on indigenous land.

Find out who the spokesperson is, but do not assume they speak on behalf of all indigenous communities. The spokesperson may initially say yes but be sure to wait for him to notify the chief and for him to go up the chain of command and confirm.

Series of sensors as discussed before are unavailable and come with a whole new set of problems.

Some discussion regards to how the water itself is filtered, there is documentation on specifics (insert here)
https://www.hamilton.ca/home-property-and-development/water-sewer/water-quality
This is the top of the page; I am not going down the rabbit hole.

Various programs in Hamilton Water that help with this by preventing pollution prevention and encouraging farmers to use environmentally safe fertilizers. Find what these projects are

Got a response. Literally just scroll down.
https://www.hamilton.ca/source-water-protection

How are our sources of water threatened?
Both the quality of our water and the amount available can be threatened by different activities. Some of the threats to our water include:

- Natural contaminants
- Irresponsible land use activities which contaminate our water or take too much out.

- Urban development can make it difficult for water to filter into the ground to replenish groundwater sources. When this happens, water just flows across the surface of land rather than percolating down to aquifers.
- Air pollution from vehicles, coal plants, industries and other sources fall directly on surface waters or enter water sources through surface runoff.
- As a result of climate change, there is also concern that the warming of the Earth's atmosphere will reduce the amount of water available in lakes, rivers, and streams due to reduced precipitation and increased evaporation.

Under the Clean Water Act, 2006, additional protection of our drinking water sources from potential contamination is provided through the mandatory implementation of approved Source Protection Plans.

Lists who are affected by source water protection plans.

Also, risk management plans.

Potential causes of contamination

- Application, handling, and storage of Agricultural Source Material (i.e., manure produced by farm animals, runoff from farmyards and manure storages, or wash water from milking centre waste, or compost, or source materials produced from the cultivation of fish or other aquatic organisms in a controlled environment)
- Application and storage of Non-Agricultural Source Material (i.e., sewage bio-solids and other wastes such as pulp and paper biosolids)
- Livestock grazing, pasturing and outdoor confinement areas
- Application and storage of commercial fertilizers
- Application and storage of pesticides

How to reduce fertilizer runoff

- Plant vegetation along watercourses to prevent erosion and runoff
- Conduct regular soil testing to determine nutrient requirements
- Maintain setbacks from watercourses when applying nutrients or pesticides
- Maintain private water well(s) and decommission unused wells.
- Dispose household hazardous waste through the City of Hamilton's community recycling program.

This if we need to recycle hazardous drone parts:

https://www.hamilton.ca/garbage-recycling/waste-recycling-facilities

Report blue-green algal blooms
If you spot blue-green algal blooms, call the:

Spills Action Centre
1-866-MOETIPS (6638477)
TTY: 1-855-889-5775

Search a location to see if it is in a vulnerable area – that is, close to a municipal drinking water well or other drinking water intake, by viewing the provincial scale map.
Intentional sabotage of water supplies has never happened, but unintentional is a concern, it might be within our interest to catch people illegally dumping stuff.

https://www.ontario.ca/laws/statute/06c22
Law that would be a good idea to reference.

Local watershed management agencies, mandated to ensure the conservation, restoration and responsible management of Ontario's water, land and natural habitats through programs that balance human, environmental and economic needs. Not sure how this helps but okay cool Hamilton falls under:

Conservation Authority	Name of Source Protection Area
Ganaraska Region Conservation Authority	Ganaraska Region Source Protection Area
Halton Region Conservation Authority	Halton Region Source Protection Area
Hamilton Region Conservation Authority	Hamilton Region Source Protection Area
Niagara Peninsula Conservation Authority	Niagara Peninsula Source Protection Area

Finding a lifecycle analysis of the drone is a good idea.

Fish intake is rare but a concern.

She would love to see the final report.

Excerpt from Hamilton Water documentation:

6.0 Studies Required

Harmful Algal Blooms

6.1 The owner shall develop and keep up to date a Harmful Algal Bloom monitoring, reporting and sampling plan, herein known as the "Plan", to be implemented when a potential harmful algal bloom is suspected or present. The owner shall have the Plan in place on or before November 30, 2019.

6.1.1 The owner must have a copy of the Plan available onsite at the drinking water system, for inspection upon request by Ministry staff.

6.1.2 The owner must implement the Plan annually during the harmful algal bloom season, during but not limited to the warm seasonal period between June 1 and October 31 each year, or as otherwise directed by the Ministry or the Medical Officer of Health.

6.1.3 The owner must train all relevant drinking water system staff on the Plan prior to the beginning of each warm season, as described in Condition 6.1.2.

6.2 For clarity, a Harmful Algal Bloom is considered suspected or occurring when:

6.2.1 the owner or operating authority has observed an algal bloom:

6.2.1.1 near the shoreline at or near the source water intake(s) described in drinking water works permit # 005-201, or

6.2.1.2 where the intake has an Intake Protection Zone in a source protection plan, within IPZ-1, or

6.2.1.3 within a circle that has a radius, measured from the intake, equal to the distance from the intake to the farthest edge of IPZ-2.

6.2.2 microcystin has been detected in a raw or treated water sample; and/or,

6.2.3 the owner has received any form of notification related to an algal bloom from the Ministry, a Medical Officer of Health, or the public; or,

6.2.4 the presence of or identification of cyanobacteria has been determined though optical probes or other analytic techniques used by the drinking water system.

6.3 The Plan described in condition 6.1 must include, at a minimum:

6.3.1 details relating to visual monitoring for harmful algal blooms at or near the drinking water system intake(s),

6.3.1.1 as described in drinking water works permit # 005-201, or

6.3.1.2 where the intake has an Intake Protection Zone in a source protection plan, within IPZ-1, or

6.3.1.3 within a circle that has a radius, measured from the intake, equal to the distance from the intake to the farthest edge of IPZ-2.

6.3.2 details relating to visual monitoring of shoreline; this is applicable to drinking water systems where the proximity of the intake(s) may be of concern.

6.3.3 details relating to reporting the observed or suspected harmful algal bloom, as described in section 6.2:

6.3.3.1 to the Overall Responsible Operator(s) and/or Operator(s)-in-Charge if the blooms have been observed or suspected by a duty operator; the Plan shall include wording that directs relevant drinking water staff to follow the instructions provided by the Overall Responsible Operator(s) or the Operator(s)-in-Charge;

6.3.3.2 to the medical officer of health; and

6.3.3.3 to the local MECP representative and the Ministry's Spills Action Centre.,

6.3.4 a sampling plan, including the identification of sample location(s) and frequencies that at a minimum match those described in condition 6.4.

6.3.5 triggers that may increase the required sampling frequency;

6.3.6 up-to-date records that document staff training on the harmful algal bloom monitoring, reporting, and sampling procedures.

6.4 Any water samples collected under Condition 6.3.4 must be:

6.4.1 collected, at a minimum, once per week, or as otherwise directed by the Ministry or the medical officer of health;

6.4.2 collected prior to any treatment, if the sample is taken from raw water;

6.4.3 collected at the point of entry into the distribution system, if the sample is taken from treated water;

6.4.4 collected from the shoreline by the drinking water system, if applicable based on Condition 6.3.1;

6.4.5 submitted to a laboratory licensed to perform ELISA testing for total microcystin;

6.4.6 repeatedly collected until 3 consecutive samples have shown non-detection of microcystin and the algal bloom is no longer suspected or visually observed.

Here is a link to the MECP's site: https://www.ontario.ca/page/blue-green-algae

City of Hamilton website (beaches): https://www.hamilton.ca/parks-recreation/parks-trails-and-beaches/beach-water-quality-in-hamilton?WT.hamilton_redirect_friendly=1&force=yes&pedisable=false

City of Hamilton website: https://www.hamilton.ca/city-initiatives/our-harbour/watershed-nutrient-sediment-management-advisory-group

Appendix B: Design Element Table

The following table documents all considerations and the design elements they inspire:

Constraints to filter through	**Description of constraints**	**Design Configuration/Iteration/Element**
Technical Performance	Resilience and redundancy	**High redundancy** would be ideal but having multiple redundant parts would mean carrying a lot of weight that is most often not necessary. It is assumed that conditions will never be ideal, but nevertheless, the amount of redundancy we could include is a wide spectrum and depending on where on that spectrum we end up, the drone's fuselage may have to be built to accommodate. Being **watertight** would against water and water vapor, but may increase the drone's weight, as well as limit our choice of components to those that can be made watertight. **Black box for recovery –** one much like civilian jet aircraft which documents the drone's flight path and operational statistics (height, location, propeller output, etc.). The idea is that in the case of an unexpected water landing, this black box would send out "pings" so that recovery teams may be able to recover the data. **Material selection for the body – C**arbon fiber is often considered the prime material of choice for a drone frame. However, Carbon Fiber is very toxic to the environment to produce. A green composite material made of natural fibers could be a more environmentally friendly choice, at the cost of structural integrity.

	Resilience and redundancy continued	**Wind Resistance Rating –** Though we will not be flying in extreme winds, there is some amount of wind we expect our drones to be able to handle. Drone wind resistance levels describe the ability of any drone to maintain its position against blowing wind [12]. What wind resistant level we choose to aim for is a consideration to make.
	Frequency of flight – How many flights would be required to make a single "scan" of a lake? How often do these scans happen?	**Daily scans –** Scanning the body of water for potential algae blooms daily would be optimal, for algae blooms can often appear overnight [13]. **Twice daily scans –** Scanning once in the morning then once again later in the day would mean we could catch blooms in the case they start forming in the mid-day. **Number of flights required –** Due to battery life and range concerns, it might be worth considering that the design will not get a full scan of the water source in a single flight before it needs to recharge. How many of these flights would be acceptable, if more than one?
	Database size and image quality – Affects the accuracy of the machine learning algorithm.	**Image quality prioritization –** We can adjust our design to prioritize image quality, which will in turn increase detection accuracy, and minimize the possibility of false detects and false non-detects. **Camera quality -** Doing the above may require a larger and heavier and more power-intensive camera, which in turn may require a larger drone which in turn affects other factors. **On-flight storage –** How many images is the drone expected to carry on a single flight? How much weight would that entail? These are things to consider.

	Battery life and effective range – This is the primary factor regarding where and how we can scan what bodies of water.	**Standard Lithium-Polymer or Lithium-Ion Batteries –** Lithium Polymer batteries are the go-to batteries for such UAV applications due to being very energy dense – however, they are extremely toxic to the environment to both produce and recycle. [3] **Alternative power sources –** Due to the toxicity of the standard Lithium-based battery, it might be worth sacrificing some effective range to be more environmentally friendly and tweak other aspects of the design to accommodate. **Larger battery –** Larger battery = more battery life, at the cost of more weight, requiring a larger drone. There is some balance to be made here, what percentage of the total carrying capacity should be dedicated to the battery, and what total weight of the drone would maximize this ratio. **Adjust flight speed –** There is a balance between expected flight speed and battery usage. Different flight motors powered by different batteries may have different speeds at which they are most energy efficient. It may be worth reducing the flight speed, meaning individual scans take longer to administer, in return for a higher effective range. **Reducing weight** would mean less weight to carry, meaning the motors need to work less hard, resulting in higher fuel efficiency, but as a result we have less weight to work with for components. **Riverside charging stations:** The less the drone needs to fly from a charging and storage station to the body of water it is scanning, the more battery power it can use on longer scans. The exact implementation of this is dependent on how much we value the soil sealing factor of building such an air hub – see **soil sealing factor** in Environmental Impacts down below.

	Propulsion mechanism/ design - Challenges this system face include being sufficiently lightweight while simultaneously able to handle difficult weather, which are conflicting objectives.	**Standard quadcopter –** This is the most common design for aerial reconnaissance. Basing the project on an already proven form of technology may development save resources that may be better allocated elsewhere. **Blimp -** However, there have been promising cases of various militaries using small blimps for aerial reconnaissance of their borders. [17] The idea here is that a blimp would have a much higher theoretical maximize carrying capacity, which we could use for **Terrestrial –** One out-there design we have considered is one inspired by various amphibious wheeled or treaded rovers, such as the Moose UGV by ClearPath robotics [14]. The idea is to use such a rover that is dedicated to housing, charging, and driving a smaller drone towards the middle of a lake. This smaller drone would be little more than motors and a camera, with no purpose past flying straight up some 100 meters, taking a photograph, then docking back on the vehicle.
	Wildlife avoidance systems - Wildlife collisions kill, and we should account to it. Bird strikes are a factor.	**See Environmental Impacts -> Wildlife Impacts below.**

Socio-cultural Appropriateness	**Performance affecting water quality**	**Performance, false-negative bias –** If Algae is visible, it is assumed to be toxic [Appendix A]. It is worth reiterating – accuracy is important. False negatives may result in an algae bloom going undetected and contaminating an entire town's water supply. Therefore, it is critical to minimize false negatives as much as possible. **Performance, false positive bias –** Though if the algorithm is significantly more accurate if its false-positively biased, there is some percentage where the trade-off is worth it, though that in and of itself is an ethical concern.
	Noise - WHO has identified noise as an actual problem. [15]	**Reduce drone size –** The lower the drone's size and weight, the weaker the propulsion required, the less noise created by the propellers. Naturally, this comes at a cost of usable weight for a camera and the like. **Adjust drone propeller type –** There is a potential trade-off between propeller-size and rotational speed required. One would be able to tweak these characteristics to minimize the noise produced. **Fly higher –** So that the drone is further away from people it may disturb, possibly at a cost of image quality. **Urban Planning - "**Noise can be managed via urban planning, such as w/ noise-reducing walls, planning and managing land use, and routing options such as a steeper descent or avoiding quieter villages." [15] Though it is not our job to implement said urban planning, we could contact local authorities and propose such infrastructure.

	Indigenous People's Rights	Though not initially a concern, through our discussion with Hamilton Water (cite appendix A) we have found that this is ABSOLUTELY a factor. **Contact the local community -** The concern of monitoring and flying over Indigenous lands is important to consider as we would not want to infringe on their freedoms. We should contact the local aboriginal community and ensure they approve. **Redefine scanning area –** If we cannot get their permission, we may have to change our location. This may require major reconfiguration of the entire project but may be required as a last resort.
	Flight path and frequency w/ regards to disturbance	**Civilian avoidance –** We should be avoiding areas such as beaches in the flight path to limit the visibility of the drone, as well as limit the chances of noise disturbance. However, doing so requires us to use a sub-optimal flight path, requiring the drone to have a larger effective range. **Time of flight –** The time of day should be during the downtime before people arrive to the lake and/or after the rush hour has ended. **Flight frequency –** Reducing the number of flights per day, or reducing it to one flight every few days, does decrease the disturbance caused, but doing so adds the risk missing an algal bloom. The exact flight frequency would need to be considered with this in mind.

<table>
<tr><th></th><th></th><th></th></tr>
<tr><td>Policy and regulation</td><td>Privacy concerns</td><td> We could adjust flight path to minimize the chances of capturing a civilian within frame. We would fly around beaches and urban structures. [16] To minimize the collection of personal data we could disable the camera on the flight to and from the body of water, using a GPS to determine whether it is or is not over said body of water [6]. Naturally, such a feature would require the addition of a GPS system, adding additional weight. Secure storage – We should take reasonable steps to ensure that no one else can access the data we require. [6] We could adjust the machine learning algorithm to also detect if it picked up a human within frame, where the algorithm would then delete or exclude any images if it detects a person within the frame.
Naturally, doing so would require an additional data set to train and test on, in addition to requiring consent from the people in said frame, a problem that is outside the scope of this project. Blurring people's faces and license plates is also an option. </td></tr>
<tr><td></td><td> Regulations, paperwork – Criteria we must meet, paperwork we must file. [17] </td><td> Weight limits and certification - All drones that weigh between 250 g and 25 kg must be registered with Transport Canada. All pilots of drones that weigh within that range must get a drone pilot certificate and mark their drones with their pilot registration number. As we do not think it is feasible to do this project with a drone below 250 grams, this is regulation we must follow. Drone registration – "Fee $5. You must clearly mark your drone with its registration number." [18] </td></tr>
</table>

	Regulations, flight path limitations.	Fly **below 122 meters (400 feet)** in the air.[7] Fly **away from bystanders**, at a minimum distance of 30 meters for basic operations [7]Do not fly at the site of emergency operations or advertised events [7] Do not fly within 5.6 kilometers (3 nautical miles) from airports or 1.9 kilometers (1 nautical mile) from heliports. **This we have not properly accounted for,** which makes us count as Advanced Operations.[7] **Fly far away from other aircraft** Do not fly anywhere near airplanes, helicopters, and other drones.[7] **Offences against Air or Maritime Safety** To put it simply, don't be a pirate, don't hijack, and don't endanger people on a plane with the drone or other means [19].This legislation does not affect our operating procedures but may apply to those who attempt to interfere with our system.

	Regulations – Type of Operations	“If you meet any 1 of these conditions, you are conducting advanced operations: You want to fly in controlled airspace You want to fly over bystanders You want to fly within 30 metres (100 feet) of bystanders (measured horizontally) You want to fly less than 3 nautical miles from a certified airport or a military aerodrome You want to fly less than 1 nautical mile from a certified heliport” **We are conducting advanced operations** due to our selection of Lake JoJo / Cootes marsh. The proper paperwork will be required, or a change of location entirely. Additionally, we may need to apply for a Special Flight Operations Certificate (SFOC) if: • “You want to fly your drone beyond visual line-of-sight • Your drone weighs over 25 kilograms (kg) • You want to fly your drone at higher altitudes • You want to fly your drone carrying dangerous or hazardous payloads (e.g., chemicals) • You want to fly more than five drones at the same time” [17]

Environmental Impacts	**Wildlife impacts** – noise disturbance as well as bird strikes should be kept to a minimum.	**Decreasing the size of the drone** – A smaller drone would create less noise and disturbance. But naturally that leaves us with less weight for internal components. **Flying at a higher altitude** causes less disturbance, but has higher fuel costs and lowers camera quality. **Adding a pulsing light** has been shown to reduce risk of bird strikes, but adds minor weight. [15] **Apparent Color scheme –** Making the drone a higher contrast to the sky helps birds see and avoid the drone, but that also makes it easier for people to notice. [5] Giving the propellers a bright, distinct pattern helps in a similar manner. **Evasive maneuvers** may be worth considering if bird strikes are common. It would be able to detect if it is about to collide with a bird or other aircraft and be able to swerve appropriately – but that feature in and of itself brings whole host of problems.
	Sensitive areas – We are not to fly over/into environmentally sensitive areas.	**Flying around the sensitive area** will intuitively protect said area, but the additional flight time and battery life required may not make this feasible. **Redefining the scanning area** is an option if we are unable to account for all regulatory or environmental restrictions involved, but doing so should only be a last resort, as doing so may require a total reconfiguration of the project.

	Co2 and greenhouse gas emissions – What other LCA's reveal and how it applies.	**Battery Powered –** Battery powered drones have little to no "tailpipe-emissions" from the use of the drone itself, though it can be lowered further by using green electricity to charge the drone. [3] **Material Choice:** Most of the Co2 involved comes from the production of the drone parts themselves Carbon fibers used in the cargo box and the Li-ion production for the battery is the main thing for human, aquatic, wildlife, etc. toxicity. **Choosing a Non-Li-ion battery** would create less environmental toxicity from the battery. However, alternative power sources may be less energy-dense or efficient. [3] pg. 205 **Locally sourced parts** – By locally sourcing parts, we can lower the Co2 required for transport, but this may come at a cost of performance by limiting our options for said parts. [3], pg. 204
	Soil sealing factor – If any additional infrastructure needs to be built, how much soil would it need to seal?	**Charge on an existing rooftop:** If we were to build a c**harging station on an existing rooftop,** it would have a low soil sealing factor, but such a location may not be compatible with the body of water selected, or with the range of the drone design chosen. **Building an air hub:** Building the infrastructure for drone charging and storage near the required location is obviously ideal but doing so would seal away a good amount of soil. [3] It might be worth considering other options.

	Wind and other factors - wind destabilization, waterfall mist	**Increase density** – Increasing the drone's density would increase stability in wind. There are two methods to do this: **1. Decrease volume of the drone**, as it would provide less surface area for the wind to push on. **2. Increase weight of the drone, without increasing volume.** The drone would have more inertia, making it less susceptible to wind throwing it off course. Option 1 may not be possible past a certain point, because at minimum the outer shell should cover all internal components. Option 2 has its own downsides, as increasing the weight of the drone may lessen the performance of the propulsion system. **Watertight –** Naturally, having a watertight fuselage would be ideal, as it would limit the damage done to both the drone and the environment if it were to crash in a sensitive area. "Watertightness" may be incompatible with various material makeups or technical components, meaning we would need to limit the technical makeup to that which can be made water-tight.

Appendix C: Machine Learning Notebooks provided

Algae.ipynb

```
from zipfile import ZipFile
file_name =  'data.zip'

with ZipFile(file_name, 'r') as zip:
  zip.extractall()
  print('Done')
```

```
import matplotlib.pyplot as plt
import seaborn as sns

import keras
from keras.models import Sequential
from keras.layers import Dense, Conv2D , MaxPool2D , Flatten , Dropout
from keras.preprocessing.image import ImageDataGenerator
from tensorflow.keras.optimizers import Adam

from sklearn.metrics import classification_report,confusion_matrix

import tensorflow as tf

import cv2
import os
import numpy as np

labels = ['alge', 'noalge']
img_size = 224
def get_data(data_dir):
    data = []
    for label in labels:
        path = os.path.join(data_dir, label)
        class_num = labels.index(label)
        for img in os.listdir(path):
            try:
                img_arr = cv2.imread(os.path.join(path, img))[...,::-
1] #convert BGR to RGB format
                resized_arr = cv2.resize(img_arr, (img_size, img_size))
# Reshaping images to preferred size
                data.append([resized_arr, class_num])
            except Exception as e:
                print(e)
```

```
        x = np.array(
           data,
           dtype=object,
        )
    return x

train = get_data('./week7OneTraining/train')
val = get_data('./week7OneTraining/test')


x_train = []
y_train = []
x_val = []
y_val = []

for feature, label in train:
  x_train.append(feature)
  y_train.append(label)

for feature, label in val:
  x_val.append(feature)
  y_val.append(label)

# Normalize the data
x_train = np.array(x_train) / 255
x_val = np.array(x_val) / 255

x_train.reshape(-1, img_size, img_size, 1)
y_train = np.array(y_train)

x_val.reshape(-1, img_size, img_size, 1)
y_val = np.array(y_val)


datagen = ImageDataGenerator(
        featurewise_center=False,  # set input mean to 0 over the datase
t
        samplewise_center=False,  # set each sample mean to 0
        featurewise_std_normalization=False,  # divide inputs by std of
the dataset
        samplewise_std_normalization=False,  # divide each input by its
std
        zca_whitening=False,  # apply ZCA whitening
        rotation_range = 30,  # randomly rotate images in the range (deg
rees, 0 to 180)
```

```
        zoom_range = 0.2, # Randomly zoom image
        width_shift_range=0.1,  # randomly shift images horizontally (fraction of total width)
        height_shift_range=0.1,  # randomly shift images vertically (fraction of total height)
        horizontal_flip = True,  # randomly flip images
        vertical_flip=False)  # randomly flip images


datagen.fit(x_train)

model = Sequential()
model.add(Conv2D(32,3,padding="same", activation="relu", input_shape=(224,224,3)))
model.add(MaxPool2D())

model.add(Conv2D(32, 3, padding="same", activation="relu"))
model.add(MaxPool2D())

model.add(Conv2D(64, 3, padding="same", activation="relu"))
model.add(MaxPool2D())
model.add(Dropout(0.4))

model.add(Flatten())
model.add(Dense(128,activation="relu"))
model.add(Dense(2, activation="softmax"))

model.summary()


opt = Adam(lr=0.000001)
model.compile(optimizer = opt , loss = tf.keras.losses.SparseCategoricalCrossentropy(from_logits=True) , metrics = ['accuracy'])

history = model.fit(x_train,y_train,epochs = 200 , validation_data = (x_val, y_val))

acc = history.history['accuracy']
val_acc = history.history['val_accuracy']
loss = history.history['loss']
val_loss = history.history['val_loss']

epochs_range = range(200)

plt.figure(figsize=(15, 15))
```

```
plt.subplot(2, 2, 1)
plt.plot(epochs_range, acc, label='Training Accuracy')
plt.plot(epochs_range, val_acc, label='Validation Accuracy')
plt.legend(loc='lower right')
plt.title('Training and Validation Accuracy')

plt.subplot(2, 2, 2)
plt.plot(epochs_range, loss, label='Training Loss')
plt.plot(epochs_range, val_loss, label='Validation Loss')
plt.legend(loc='upper right')
plt.title('Training and Validation Loss')
plt.show()
```

Terrain.ipynb:

```
from zipfile import ZipFile
file_name = 'data.zip'

with ZipFile(file_name, 'r') as zip:
  zip.extractall()
  print('Done')
```

```
import matplotlib.pyplot as plt
import seaborn as sns

import keras
from keras.models import Sequential
from keras.layers import Dense, Conv2D , MaxPool2D , Flatten , Dropout
from keras.preprocessing.image import ImageDataGenerator
from tensorflow.keras.optimizers import Adam

from sklearn.metrics import classification_report,confusion_matrix

import tensorflow as tf

import cv2
import os
import numpy as np

labels = ['desert', 'water']
img_size = 224
def get_data(data_dir):
    data = []
    for label in labels:
        path = os.path.join(data_dir, label)
        class_num = labels.index(label)
        for img in os.listdir(path):
            try:
                img_arr = cv2.imread(os.path.join(path, img))[...,::-
1] #convert BGR to RGB format
                resized_arr = cv2.resize(img_arr, (img_size, img_size))
# Reshaping images to preferred size
                data.append([resized_arr, class_num])
            except Exception as e:
                print(e)
        x = np.array(
           data,
           dtype=object,
        )
```

```
    return x

train = get_data('./data/train')
val = get_data('./data/test')


x_train = []
y_train = []
x_val = []
y_val = []

for feature, label in train:
  x_train.append(feature)
  y_train.append(label)

for feature, label in val:
  x_val.append(feature)
  y_val.append(label)

# Normalize the data
x_train = np.array(x_train) / 255
x_val = np.array(x_val) / 255

x_train.reshape(-1, img_size, img_size, 1)
y_train = np.array(y_train)

x_val.reshape(-1, img_size, img_size, 1)
y_val = np.array(y_val)


datagen = ImageDataGenerator(
        featurewise_center=False,  # set input mean to 0 over the datase
t
        samplewise_center=False,  # set each sample mean to 0
        featurewise_std_normalization=False,  # divide inputs by std of
the dataset
        samplewise_std_normalization=False,  # divide each input by its
std
        zca_whitening=False,  # apply ZCA whitening
        rotation_range = 30,  # randomly rotate images in the range (deg
rees, 0 to 180)
        zoom_range = 0.2, # Randomly zoom image
        width_shift_range=0.1,  # randomly shift images horizontally (fr
action of total width)
```

```
        height_shift_range=0.1,  # randomly shift images vertically (fra
ction of total height)
        horizontal_flip = True,  # randomly flip images
        vertical_flip=False)  # randomly flip images


datagen.fit(x_train)

model = Sequential()
model.add(Conv2D(32,3,padding="same", activation="relu", input_shape=(22
4,224,3)))
model.add(MaxPool2D())

model.add(Conv2D(32, 3, padding="same", activation="relu"))
model.add(MaxPool2D())

model.add(Conv2D(64, 3, padding="same", activation="relu"))
model.add(MaxPool2D())
model.add(Dropout(0.4))

model.add(Flatten())
model.add(Dense(128,activation="relu"))
model.add(Dense(2, activation="softmax"))

model.summary()


opt = Adam(lr=0.000001)
model.compile(optimizer = opt , loss = tf.keras.losses.SparseCategorical
Crossentropy(from_logits=True) , metrics = ['accuracy'])

history = model.fit(x_train,y_train,epochs = 100 , validation_data = (x_
val, y_val))

acc = history.history['accuracy']
val_acc = history.history['val_accuracy']
loss = history.history['loss']
val_loss = history.history['val_loss']

epochs_range = range(100)

plt.figure(figsize=(15, 15))
plt.subplot(2, 2, 1)
plt.plot(epochs_range, acc, label='Training Accuracy')
plt.plot(epochs_range, val_acc, label='Validation Accuracy')
```

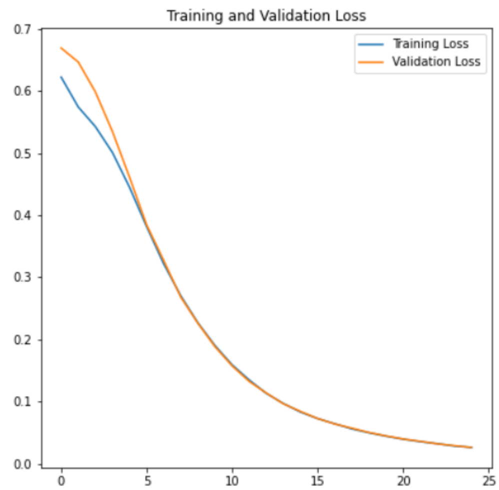
```
plt.legend(loc='lower right')
plt.title('Training and Validation Accuracy')

plt.subplot(2, 2, 2)
plt.plot(epochs_range, loss, label='Training Loss')
plt.plot(epochs_range, val_loss, label='Validation Loss')
plt.legend(loc='upper right')
plt.title('Training and Validation Loss')
plt.show()
```

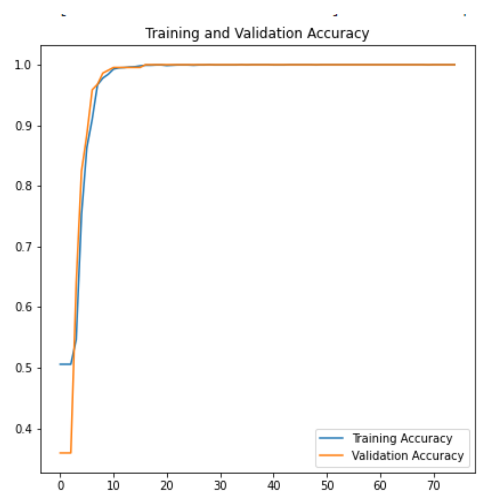
Appendix D: Machine Learning Outputs

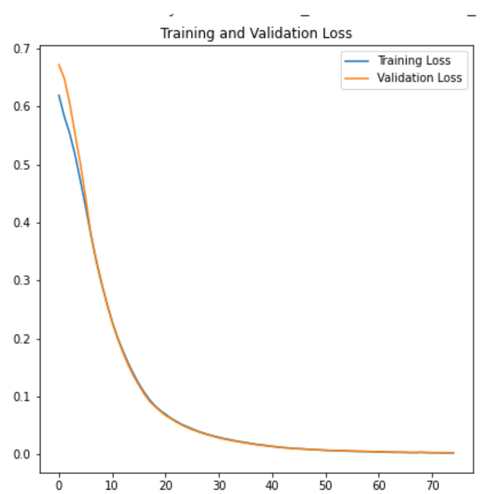
Testing how the m**odels react under different epoch ranges:**

Terrain, dataset 1, 25 epochs

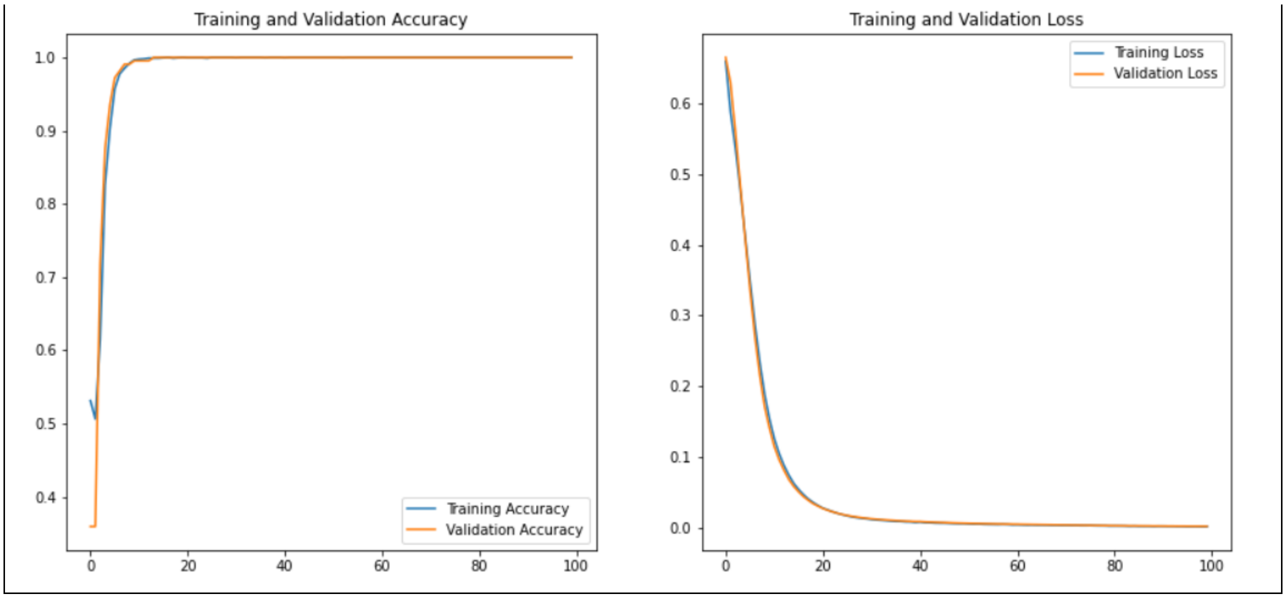


Terrain, dataset 1, 75 epochs

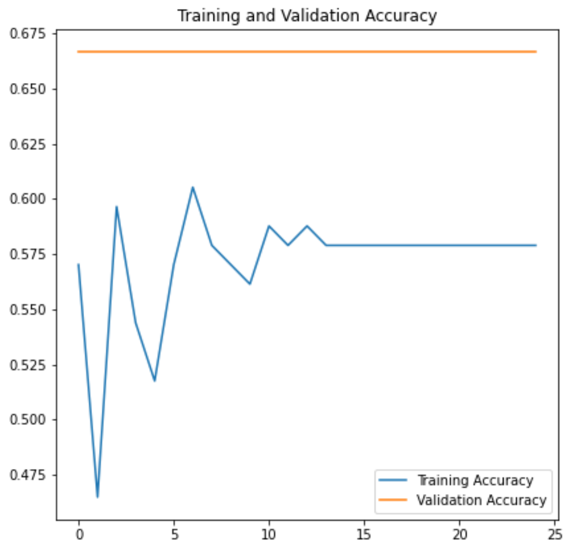




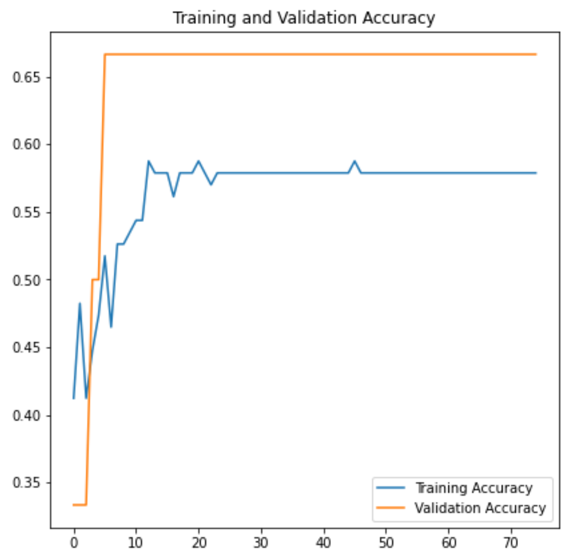
Terrain, dataset 2, 100 epochs


Training and Validation Accuracy
Training Accuracy
Validation Accuracy
Training and Validation Loss
Training Loss
Validation Loss

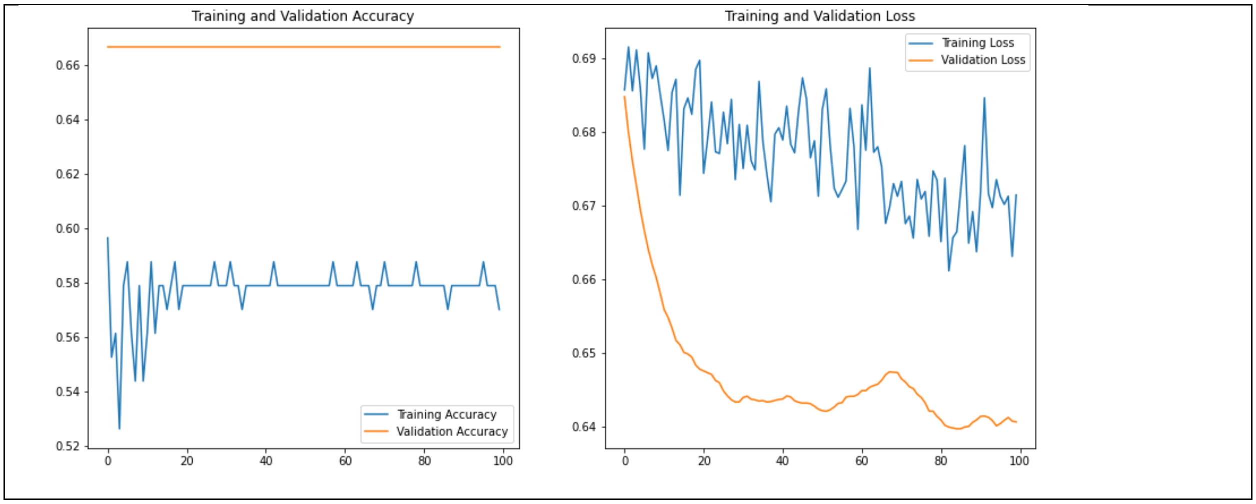
Algae, dataset 2, 25 epochs.



Algae, dataset 2, 75 epochs.



Algae, dataset 2, 100 epochs.



Appendix E: Synchronous Worksheets:

Week 2 - Team Building and Lessons Learned

Stage 1: Team Charter

As you are getting started to work on your project, one of the very first steps is to create a team charter. A team charter is a document that outlines the purpose of your team (i.e. your end goal), as well as detailed information about the team members.

Please list all the team members' information below.

Member	Full name	Preferred name	Email
Team Member 1	Andrew Piotrowski	Andrew	Piotroa@mcmaster.ca
Team Member 2	Cole Robichaud	Cole	thecoaler@gmail.com, robicc1@mcmaster.ca
Team Member 3	W. Tisuka Perera	Tisuka	pererw2@mcmaster.ca
Team Member 4	Nathan Rodrigues	Nathan	rodrin11@mcmaster.ca

Take a picture of your team. Be creative! Paste your team portrait below.

In a few sentences, please describe your team's goal for ENGINEER 2PX3 and what you are aiming to achieve.

Outside of basic survival, we intend to efficiently apply machine learning algorithms to identify algae blooms and notify the appropriate stakeholders. Our intention is to lean into the drone portion of the design, as we are made up of electrical and mechatronics students, we think it is within our strengths to do so.

Please outline 3 strengths for **team member 1** with one example or specific experience for each.

Strength	Example
Video Editing	My youtube channel, my previous projects video. My youtube channel may be mostly memes and humour, the editing techniques are applicable to whatever presentations I may need to prepare in the future.
Test Cases	My co-op term last summer focused on the automation of test cases on backup software – this workflow can be applied to testing our solution.
Team leadership	I've proven myself capable of task delegation and group automation with my experiences in ENG 1P13 and my time as the club president of my highschool's VEX robotics team.

Please outline one area of improvement for **team member 1**.

Anxiety, programming skills. I mean I know how to program, but once in awhile I get stuck on something very basic then I am unable to see the very rudimentary error until it is pointed out to me. As for anxiety: Yes, stuff is bad at times. But I am in a group, I can ask for help.

Please outline 3 strengths for **team member 2** with one example or specific experience for each.

Strength	Example
Cad Modeling	First year co-op primarily working in Inventor for TRK Attachments
Programming	Started programming in grade 10, used practically through Vex Robotics
3D printing experience	I own and have used a 3D printer for robotics and puzzle building

Please outline one area of improvement for **team member 2**.

Punctuality - getting to class on time and responding to team messages more quickly at times.

Please outline 3 strengths for **team member 3** with one example or specific experience for each.

Strength	Example
Video Editing (Premiere Pro, iMovie)	Aside from some personal projects, I edited my group and I's final 1P13 video presentation, which demonstrated our project.
CAD Modelling (Autodesk Inventor)	Got very familiar with it during the 1P13 course. Modelled final 1P13 project.
Photo Editing (Photoshop)	I edited multiple personal projects, including family portraits etc.

Please outline one area of improvement for **team member 3**.

(Tisuka) I need to work on programming more, deepening my understanding of languages. I still only have a very basic understanding of programming.

Please outline 3 strengths for **team member 4** with one example or specific experience for each.

Strength	Example
programming	I have experience with coding in C, C++ and python
Cad modeling	Have experience from first year using Autodesk inventor
Knowledge of drones	Have experience flying drones

Please outline one area of improvement for **team member 4**.

One area of improvement for team member 4(Nathan) is organization. I don’t take the extra time to keep organized and stay on track, which causes me to waste time.

Lastly, please outline the order of student presentations of your team.

Week	Member(s)
Weeks 3 and 7 *	Nathan
Weeks 4 and 8	Andrew Piotrowski
Weeks 5 and 9	Tisuka
Weeks 6 and 10	Cole
Which Group are you paired with? **Self driving 38, Water 21**	

*For teams of 5, 2 members can present on their chosen weeks other than weeks 3 and 7

Stage 2: EDI

Have you ever been on a team and felt like you weren't being heard? Alternatively, maybe your role in teams has usually been one of directing the group's work. If you have been in either situation, it may be time for a change. Go through the activities on Avenue to Learn under [4-Design Studios → Week 2 → EDI]

Personal Journal

1. (Andrew Piotrowski) - Encourage people to ask questions and get help if needed. - Focus on task delegation and relying on teammates. I find myself dominating conversations at times, which only works if my ideas are consistently infallible. Obviously, that is not the case – it's better to bounce my ideas off of others rather than press forward. - Balance this project work as well as my other courses.
2. (Cole Robichaud) - Include all team members in group conversation - Focus on healthy communication - Keep workload fairly balanced
3. (W. Tisuka Perera) - Take initiative by participating more, and offering more ideas - Helping others if they are in need - Ask for help if I need it, reaching out

4. (Nathan Rodrigues)

- respect everybody’s ideas and respect their inputs.
- Speak up if you have an idea even if it's bad.
- Call people in and not call them out
- Divide up the work fairly and evenly

Stage 3: Project Activity #1

Each of the 4 projects in this course were chosen because they highlight the interdisciplinary concepts between the different fields. With this in mind, each engineer interprets a problem and creates objective and constraints based on their experience and background. In this activity, you will be learning about your team members' disciplines and how it impacts your project.

Please state your project, the disciplines it focuses on and the specific aspects of each discipline (e.g., Electrical Engineering - Electromagnetics, Mechanical Engineering – CAD, etc.)

Project: Source Water Monitoring			
	Field 1	Field 2	Field 3 (Optional)
Discipline	Software Engineering	Mechatronics Engineering	Electrical Engineering
Aspect	Programming, Machine Learning	Interfacing between software and the hardware, applying the stuff to real world applications.	Any custom electronics work needed to make the drone operate as desired

Consolidate the technical performance constraints each member came up with in the asynchronous activity

Field 1	Field 2	Field 3 (Optional)
Time, memory and computational complexity.	Software must conform hardware limitations.	Hardware must be within the outlined budget (TBD)
Skill of the programmers	Drone must be stable enough to capture high quality images	Battery life
Limited image count	Durability/image variation in different conditions	Sensor Applicability
Structural constraints imposed by chosen programming language(s). I.e., not being able to use classes	Flight path limitations according to battery life	Weight limitations and related mechanical constraints

As a team, discuss the technical constraints and decide on one important constraint per field. Make sure you justify your reasoning.

Field 1	Field 2	Field 3 (Optional)
Time, memory and computational complexity	Software must conform hardware limitations	Battery life

Justification:

Battery life directly limits what we can do with the project overall – it limits how computationally expensive the code can be, as well as limits the flight plan opportunities.

The rest of the PERSEID layers include Environmental, Regulatory, and Socio-cultural constraints. As a team, brainstorm on the constraints that correspond to these layers and are relevant to your project. Make sure you justify your reasoning.

Layer	Constraint
Environmental	Must not significantly harm surrounding environment and inhabitants through use and eventual disposal.
Regulatory	Drone pathing must not cross into no-fly zones and occur within any existing time restrictions if present.
Socio-cultural	Must not be ugly, noisy, or distracting.

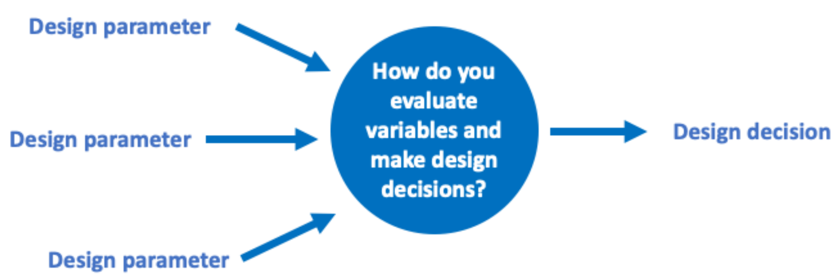
Justification:

Our goal is to create a feasible design. If the project directly or indirectly harms or distresses any stakeholders, that is a red flag and should be reassessed.

OVERVIEW

This activity helps you identify the most important elements of the complex challenge. Engineers call this process System Definition or defining the Design Scope. In either case, it is about choosing the things you want to consider for your design and putting aside others that you simply do not have time for and may not influence the outcome of your design as much as other factors. For example, in considering the design of a source water monitoring system you will likely not consider the impact of extreme weather events on image quality – you are likely to land drones during these times to avoid damage.

In general, even the most complex design process will attempt to break down all possible considerations into a smaller, more manageable set of design variables and ways to compare the merits of each consideration.



In this activity, you are asked to decide on the key variables that you will be considering to help you make design decisions.

<u>Once you have identified the principal design factors or parameters and have a sense of how you will assess the merits of each as compared to others, you have effectively defined your "System" – i.e., a reduced and more practical representation of the real application that you can more effectively work with to make design decisions.</u>

KEY ASSUMPTIONS PROVIDED

To identify key parameters, you will need some basic assumptions to reduce the total number of possible choices.

System Components

Consider the many necessary components of an aerial monitoring system. You will not have time to specify/design every single component. What components will you focus on (knowing that you must use machine learning and image analysis to conduct a false positive/negative analysis)?

Brainstorm all possible system components and discuss key considerations as a group. As appropriate, research and review resources.

Step 1 (20 minutes): Brainstorm all possible physical system components. What are some of the challenging decisions that you can foresee? What kind of potentially conflicting design choices can you see ahead of you?

The relevant physical components of this system include the components of the drone itself: its mobility system, battery system, camera, and microcontroller, as well as parts of the system on the ground.

The mobility system includes potential terrestrial components (to move the drone around the border of the body of water), blades, other sources of lift (like a blimp), and motors.

Challenges this system face include being sufficiently lightweight while simultaneously able to handle difficult weather, which are conflicting objectives.

The battery system is comprised of the battery on the drone and its charging station.

Challenges faced by this system include battery degradation, charge limitations, ease of charging (for automated docking).

Increasing the battery life also increases drone weight, which could result in more regulatory restrictions, which could result in a conflict. Additionally, battery type and its environmental impact may come at a cost of battery life, another conflict.

The camera system consists of just the camera and its capabilities.

Challenges facing this system are its visual requirements, I.e., image quality, potential use of IR/UV, and ease of automation with the drone.

Better cameras will weigh more, which conflicts with the objective of the drone being light and increasing battery life. Additionally, we will need to decide whether a single downwards facing camera is enough, or will additional redundant cameras are required for controlling its flight path.

The microcontroller system consists of the main controller for the drone, its storage, and a potential additional controller on the docking system.

Challenges facing this system include power consumption, I.e., a faster controller may be able to control things more effectively, but would also use more power, storage size and speed to be able to handle the rate of image capture, and once again, weight.

As mentioned in challenges, processing speed and battery life conflict, as well as size of microcontroller and weight. Additional considerations such as an altitude sensor, windspeed sensor, gyroscope, those would need to be considered as a part of this system.

The docking system consists of a safe place for a drone to land, a means of charging the drone, and keeping it safe from weather and wildlife. This system could include the portion of the project that does the machine learning image analysis, or the system that sends the image's off-site for analysis.

Challenges facing this system include determining how to automate charging a drone built with charging mechanisms designed for human interaction and keeping the drone sufficiently safe and theft-proof.

The main conflict with having this system at all is that it could significantly increase cost, which makes it difficult to keep things somewhat affordable.

Step 2 (20 minutes): What will the operating specifications and guidelines of your system be? These may be associated with the geographic area, extent, and conditions, as well as the combination of accuracy requirements and physical system elements. List all the operating specifications that you can think of.

Geographic area – What body of water are we monitoring? Most important, defines what we need to do. If it is a great lake, we need to design the infrastructure to go along with it, because one big drone is not feasible. If it's a smaller body of water, how small, where will it be located, what geography or human privacy do we need to account for, etc.

"Scope" of photo, accuracy of photo – Surface area covered. This defines how high it needs to fly and what camera we need. Can we use IR or UV? Etc.

Redundancy of drone – Can it function in suboptimal conditions? How suboptimal? Suboptimal, how? How much redundancy is feasible?

Number of drones – Consider it in proportion of size of body of water as well as range of drones. Are multiple doc points required?

Effective range – Battery life, flight path, etcetera. What does it NEED to cover, and can it do 150% percent of that (for redundancy).

Assumption is that we are not flying at night, not in inclement or extreme weather, not in the cold. Ideally, we do not need to fly high enough where the temperature drops and becomes a factor of consideration.

Evasive maneuvers - Do birds attack drones? Do we need to consider this?

Noise – How loud is it, How loud is acceptable?

IDENTIFYING DESIGN PARAMETERS

Principal screening considerations

Additionally, you are provided with a reduced starting set of factors to consider for the design relative to the PERSEID screening process. They are as follows:

Performance

1. Rate of false detects and false non-detects. Have these been minimized through the specified physical system components and operating conditions?
2. What are the data collection requirements?

Socio-cultural

1. Privacy
2. Noise
3. Unintended consequences

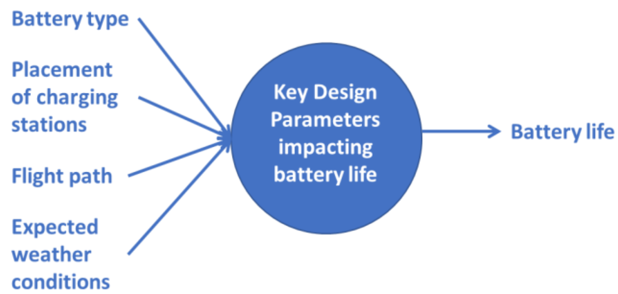
Policy/Regulatory

1. Canadian Aviation Regulation
2. Trespass Act
3. Offences against Air or Maritime Safety

Environmental

1. Impact of crashes on ecosystems
2. Noise pollution
3. Battery life

For each of these, you will need to discuss and decide on which factors will influence a particular design decision the most. For example, the following diagram illustrates a hypothetical set of design parameters that could influence the flight path.



So, the design team would have to decide which factors affecting the value of the parameter would optimize battery life and flight path while minimizing the number of charging stations required. In a real project, there would be more factors influencing the battery life, but we must be careful to keep the scope of this project manageable within the timeframe of this course.

For this Design Studio activity, you will consider in more detail, the design parameters that you believe are more important or influential to the function of your design. AS A FIRST STEP IN THIS ACTIVITY, FOCUS ONLY ON THE TECHNICAL PERFORMANCE CONSIDERATION.

Step 3 (50 minutes): Design parameter decisions

Based on the discussion in Steps 1 and 2 above,

1. What are the parameters that the team believes would be most important in helping you make design decisions for the above considerations?
2. For each of the parameters, what are some of the key considerations that you can inform with these parameter inputs? It is entirely acceptable and even preferable for a single parameter to help you with multiple considerations.
3. How will you measure, quantify, or assess the parameter? Is it measurably objective or more subjective?

4. Are there any important assumptions that you will make when applying a particular parameter? e.g., for weather-related parameters, you could assume that you will ground your drone whenever the wind exceeds a certain threshold, but that this assumption will leave you with enough fly time to obtain whatever your required number of images is.

Please use the following table. At this stage, it is normal to begin with a larger set of parameters that focus on technical performance screening but try not to exceed 5 as an initial number. The list should attempt to address as many of the design concerns as possible be useful for assessing options for both physical system and operating conditions. Note that we expect the table might look "ugly" afterwards, filled with line breaks, extra spaces etc. Remember, this is your opportunity to brainstorm!

Parameter choice	**Which consideration is impacted?**	**How will you measure, calculate, or assess the impact of the parameter?**	**Any important assumptions?**
1. Battery Life	Which battery is needed, how power-hungry components can be, drone weight, chemical makeup of the battery.	By calculating the lifetime based on the drone's power consumption while flying and testing actual flight in different conditions	We can access whatever battery is needed Our battery will perform according to its specifications Battery will need maintenance, though minimal.
2. False detects/ False non-detects	Software design (false detects must be accounted for), storage (to hold sufficient images for accurate analysis) Camera/image-taking capability – does it take images that can accurately reflect what's happening?	Using machine learning and feeding information to the algorithm to try and prevent this from occurring By manually checking the results to verify their accuracy in initial tests	Our data set will be large enough to train the algorithm well Our test set will be large enough to weed out false detects using % accuracy Some experimentation in camera specifications will be required, but the camera

			will be consistent once chosen.
3. Privacy (Canadian Aviation Regulation)	Pathing and battery life (software, hardware, regulatory) Drone weight: 250 g and 25 kg, limiting our drone tonnage. Flight height capped at 122m. (110m soft limit) Misc other considerations.	By comparing the optimal path when ignoring sensitive areas to the path generated when blocking off these areas. With this information the difference in battery life can also be determined	Bodies of water we will need to survey will be around sensitive areas Our drone will be heavy enough to fall under weight-based rules Fines and regulations will be enforced
4. Unintended consequences/ environmental impact.	The software in the drone Makeup of the drone itself – parts involved, is it a biohazard? If it were to crash, how are we to recover it? Bird strikes?	Cost of a drone crash + fees to find and pick it up Frequency of instances where wildlife is harmed by the system (could be estimated by existing drone crash data)	The most likely landing location is in water so land crashes aren't the highest priority Drone will have some form of tracking for easy finding and cleanup Recovery is possible
5. Noise/noise pollution	Motor type, engines, propellor design	We can measure the loudness of the drone using a dB meter and estimate how it reacts at range	The drone will be high enough that some noise would be ok Noise output is relatively consistent

Step 4: Global Assumptions (20 min)

List any major assumptions that you made when identifying the five parameters. Describe how they are helpful to explain, support, and affect your parameter choices to some extent. Examples would include: (1) You will be able to specify a battery to meet the needs of your technical specifications, and so battery life is outside the scope of your design; (2) Algal blooms will not occur during very cold or freezing periods, and flights only need to occur during relatively temperate periods.

- We need to be able to deal with large bodies of water like the great lakes - We are not flying at night. - We are not flying in inclement or harsh weather. - We are not flying high enough where temperature drop is a factor. - Regulatory fines will be enforced. - Some redundancy is good. - #(2) above

Week 4: Synchronous Design Studio - System Definition Continued

Overview and Goals

This activity is a continuation of last week's activity on system definition, in which you took your first pass in discussing the various considerations and choices. This week, you will:

- Identify formal metrics of the system. Explore how an underlying metric such as false detects and false non-detects can be used in several ways.
- Consider parameters/input and outputs to the system.
- Think about what quality attributes are important for source water quality monitoring systems.
- Formally describe your system.

By this point, you should have an idea about the physical components you will need for your system, as well as the types of operating protocols / guidelines you need to specify. You will need to choose a geographic area to obtain necessary data (e.g., for Hamilton, you can access weather information, map ecologically sensitive areas Cootes Paradise Marsh in Hamilton, etc.). If you have not done so, please take a few minutes either before the Design Studio or at the beginning to confirm your group's choice of geographic area. Google Earth may be a helpful tool in choosing your geographical area.

Ethics and unintended consequences (15 minutes)

In your team, discuss the asynchronous activity you completed this week. Have each group member share an unintended consequence that they identified. Consider two or three unintended consequences and consider how these might be mitigated. Document this discussion below.

Privacy- We could minimize invading the privacy of people near by the lake by flying during off-peak hours. If people are living near the lake, we could change the path of the drones to avoid the area that they live in. End of life battery toxicity: An unintended consequence that could occur as a result of choosing a type of battery that favours performance without considering its long-term degradation, both in the case of crashes and intentional disposal. This is an example of why environmental impact should be considered for every decision. Reuse and/or recycling of said batteries is paramount.

Abuse of technology – We should minimize the ways that this technology can be abused. There is a balance here, because ultimately, we have a drone with a camera attached. We will need a way to distinguish between malicious uses and other beneficial ones.

Revisit constraints and parameters (60 minutes)

Last week, you began considering the constraints and parameters. Now that you have had more time to think about your source water quality monitoring system, revisit those discussions and see if your thoughts have changed or you now have more information, input, or a clarification that may influence your decision. In a real-world engineering initiative, this sort of rapid re-assessment and iteration is very common, and in fact it is necessary as so many real problems do not have clean definitions and perspectives can shift often. A good engineering team needs to develop the skills to quickly assess, and address needed changes.

Recall that some of the design assessments and considerations that were suggested for each PERSEID layer. To repeat, they are:

Performance

- Rate of false detects and false non-detects.
- Data

Socio-cultural

- Privacy
- Noise
- Unintended consequences

Policy/Regulatory

- Canadian Aviation Regulations
- Trespass Act
- Offences against Air or Maritime Safety
- Privacy laws

Environmental

- Impact of crashes on ecosystems
- Noise pollution
- Battery life

One of the more obvious metrics for your project would be the rate of false detects and false non-detects. What other metrics would be of interest to you? Think of these as the outputs of the system. What information would you or others be interested in? For each metric assign a single PERSIED layer which you believe best corresponds.

- Survey Speed

Survey speed will partially determine the effectiveness of the system, since its job is to alert water suppliers *before* it becomes an issue. This metric would be determined by drone count, battery life, speed, and storage. While this metric primarily links to **performance**, it also impacts all other parts of the PERSEID funnel indirectly.

- Durability, performance, environmental

Durability is an important metric because the drones need to be able to function if something is thrown at them or if they accidently hit something. The PERSIED layer that best corresponds to this metric is **performance**.

- Bird Strikes, **subcategory of Environmental**

  Though the drone's capability to survive a bird strike is defined by its Durability, the design should consider this a possible threat. Birds of prey are very territorial about their nesting areas- drones may be perceived to be a threat, in which case the bird will attack. Some number of bird strikes are unavoidable, but if there is something about the drone's design that particularly aggravates local birds of prey, we will need to account for it.

Consider three different source water quality monitoring system designs. The rate of false detects, false non-detects, crashes, and grounding due to weather, as well as the flight time between charges are listed below for each system design. Units have been left off on purpose.

Design	False detect	False non-detect	Crash frequency	Weather-related grounding frequency	Flight time between charges
Design 1	30	10	1	2	30
Design 2	10	30	5	6	60
Design 3	15	15	20	4	15

Which element of each design has the best performance? How do you prioritise these performance metrics to choose the best design? Why? Think about this from your stakeholders' points of view. Which design do you think each of them would rather have implemented, and why? (Note that economics are *not* a consideration in this course – more on economics in third year!)

Which element of each design has the best performance?

Design 1 has the best performance overall, followed by 2 and 3.

Design 1 has the least number of crashes and weather-related grounding and is middle of the pack in terms of battery life. False detects are far less dangerous than false non-detects (See below), making design 1 the best in terms of reliability at a cost of only slightly reduced flight time. For all stakeholders involved, the relevant criteria are the best or adequate.

Design 2 has the best battery life, followed by 1 then 3.

Design 3 has the least number of total mistakes in detections.

How do you prioritise these performance metrics to choose the best design? Why?

False-non detection has far more dangerous consequences than a false detect. False detect might just be a hassle for local water authorities; if the drone false detects something, someone on the ground will check and confirm it to be false. A false non detect might lead to poisoning an entire community's water supply.

This is what made design 1's accuracy more appealing than design 2, as the numbers are the same otherwise. Next, we looked at crashes, because these would produce waste in the environment, and then flight time and weather grounding, which would limit performance. While design 2 wins in flight time, because of the priority on reduced false non-detects, design 1 won with decent margins.

In systems engineering "quality attributes" are used to evaluate aspects of the system which are difficult to measure. For example, we have all had experience with products which are easier/more intuitive to use than others (think about websites and phone apps), but how would an engineer measure useability?

Take a look at this article: List of system quality attributes

Which attributes do you think apply to this project? Choose five, and state what each attribute is explicitly referring to in the context of a source water quality monitoring system.

Precision - We must be the precise in the detection of algae blooms. The algorithm should match human interpretation as close as possible.

Durability - The drone should be durable and long lasting. Some redundant systems should be in

Deploy-ability - Should be able to take off and land at stations, without issue. Should be able to launch and dock with minimal start-up/wind-down time.

Customizability - The drone and its flight path must be customizable to different types of lakes and bodies of water.

Failure Transparency – A key factor in our design. If the drone fails to get a good picture due to flight conditions or a crash, or if the machine learning algorithm fails to come up with a concrete result, the system should notify a human operator with exactly how it failed, what picture it *did* get, flight and GPS parameters in the failed flight, etc. If the flight goes wrong, we want to know *exactly* why, where, and how. A "black box" documenting all flight parameters should be built into each drone.

Up to this point you have been looking at performance metrics, or outputs, of the system. What are the inputs? What describes your design and operating protocol / guidelines? What are the parameters?

Camera input – How clear the image captured is, helps determine accuracy of algal blooms. Relating to this, lens type will impact how much a single photo can capture and may impact accuracy depending on how well the algorithm can handle something like a fisheye.

Flightpath input – the assumption is that the drone is given a human-planned flight path, and an algorithm to procedurally generate a flight path is not necessary. This path would need to avoid sensitive airspace while covering sufficient area. It is possible that plans may change, and automated path generation is pursued as well.

Go/no-go signal – A human operator will be able to tell the system to "stand down" for a period if necessary. This may be used if the weather is bad enough that the operators don't want to leave the decision up to the drone system, for example.

To assess designs and operating protocols/guidelines formally, you will be implementing machine learning and error models provided. Applying these models and refining your design will start next week and will be ongoing over the next few weeks. Start by thinking about your vision for your system. What assumptions will you need to make? For example, an assumption could be:

- The client/owner/user will be responsible for data management
- Operators will ensure the system is grounded during inclement weather – the UAV does not need to be equipped to measure wind speeds/follow weather reports itself

These will help you scope your design. List some assumptions (you can relax/remove them later).

- All facets of the system will be managed by the same party, whether said party allocates specific groups to manage the various parts of this.
- The user of the system will manually handle the decision to contact water treatment operators based on the results the system outputs.
- The drones will be able to operate without frequent operator intervention (I.e., other than crashes and mechanical failures). Ideally this would *include* making simple weather-based decisions.
- The system will be able to be easily and securely shut down or packed away during extended periods of non-operation (I.e., winter).
- Regulatory fines will be enforced

Preparing for Milestone 1 (30 minutes)

The Milestone 1 report requires you to review all of the conclusions and decisions that you have come up with so far then integrate them into a single cohesive document that offers a clear articulation of the engineering system that you will be working with. Take the time in this Design Studio to see if your conclusions are clear and complete enough to continue to make good design decisions. You should also discuss whether you are content with the emerging concept. One good way of testing the clarity of thought and cohesiveness of conclusions is to write a compact summary. Complete the following:

We chose **Lake Jojo** as our geographical area.

Based on initial assessment and consideration of stakeholder input, some specific and particularly difficult challenges that we need to address are:

A difficult challenge is not invading the privacy of people around the lake, by taking pictures of the lake that they may be in or live on the border of. This impacts pathfinding and accuracy if the drone must be closer to the water to avoid capturing undesired areas of the border.

The next specific stakeholder input that represents a challenge is that of the treatment plant. This is the driving force behind the importance of performance and adds to the struggle between the different parts of PERSEID.

To resolve and reconcile these challenges, we will be emphasizing the following key design parameters for each of the PERSEID design layers.

Accuracy of Detection Battery life / flight time Adherence to Canadian Aviation Regulation legislation

After completing this portion if the combination of your answers to each portion reads well and makes sense then you have a good start. If you notice that some elements seem out of place or do not connect well with the others, you may want to revisit that element with the team.

If the above is in good shape, it becomes a great first step in composing the Executive Summary of the Milestone 1 report and a will help you to more efficiently write up the remainder of the report.

Week 5: Synchronous Design Studio - Modeling – Performance Layer in PERSEID

OVERVIEW

This activity helps you identify and incorporate some of the technical constraints related to the operational characteristic of the drones and the desired performance metrics. From the Week 5 Asynchronous activity, all team members should now have some level of familiarity with the function of the machine learning module as well as the overall accuracy performance metric. Additionally, as a group, you should have some capacity to confidently discuss how the effects the size of the training database may play a role on the accuracy of the system.

In this Synchronous studio, you are asked to use/adapt the model to begin answering some of the key concerns for the design with emphasis on the technical PERFORMANCE of the design. You should recall the various discussions you have had in previous studios in terms of any constraints, assumptions, and key parameters as they will be helpful in assessing merits of design ideas.

KEY KNOWLEDGE PROVIDED

Confusion Matrix and Accuracy

Let us first introduce some of the essential definitions of the performance metrics and establish relationship to terms false detects and false non-detects. Let us consider a case of training database that has 1000 images so that 800 images have no algal blooms, and 200 images show algal blooms. Let us say that out of the 800 no-algae images we correctly identify that 750 of them do not have algal blooms and let us say that in 200 of algal images we correctly identify that 180 of them have algal blooms. Obviously in this case we made two types of errors. The number of false detects or false positives (FP) is 50 and number of false non-detects or false negatives (FN) is 20. Opposed to this are true positives (TP) and true negatives (TN) where we assumed that term positive refers to the presence of algal bloom. We often summarize these results in something we call a confusion matrix:

Truth algae, Decision algae = 180 (TP)	Truth algae, Decision no algae = 20 (FN)
Truth no algae, Decision algae = 50 (FP)	Truth no algae, Decision no algae = 750 (TN)

The overall accuracy is then defined as (TP+TN)/total = (180+750)/1000=93%

Step 1 (30 minutes): Close Gaps in Understanding

First, survey everyone in the team and determine if there are any gaps in understanding of the model and definition of accuracy. If a member needs a bit of guidance, take the time now to help that team member align their understanding with the team. Then as a team discuss what are some of the drone operating characteristics that may affect the performance of your system. Some possibilities include drone velocity, robustness to environmental conditions, flight altitude, etc.

One option is to have the drone stationary while taking pictures. In this case, as it has a short exposure time and is relatively stable it should be fine.

However, if pictures could be taken in flight, less battery life would be needed and surveys would take less time, and pictures could be taken automatically based on the drone's velocity (I.e., only when it is traveling in a straight line). This would require a better camera.

Fogging of the lens and moisture from temperature and conditions like rain could significantly obscure images, reducing accuracy of results.

Altitude should be compatible with the camera – the maximum allowable altitude for our classification of drone is ~120m. We should be flying between 100-110, and the camera should be scoped for ~80 to ~150 meters.

Can the camera lens be knocked out of focus? Can it self-correct, or is human maintenance required? Durability should be maximized to limit how "finicky" the drone is – by finicky, I mean "it only works in this position at this altitude on every third Wednesday under a full moon." The camera should just *work* under a variety of conditions, minimizing how often human hands need to adjust characteristics.

Step 2 (30 minutes): Explore system options related to the performance of the model

Now consider the following three types of drones and discuss as a group which two of the enclosed three choices would be the best option for the region you selected in previous design studios. Justify your choices. Note that flight stability refers to robustness of your drone to weather conditions such as wind i.e., your ability to control and predict exact location of the drone in windy conditions.

Name	Speed	Image quality	Flight stability	Battery Life	Ability to store/transfer images
Flying Fortress	Low	Medium	High	Low	High
Hawkeye	High	High	Low	Medium	Low
Great Horned Owl	Medium	Low	Medium	High	Medium

Flying Fortress is the least appealing drone. While it has high ability to store images, this is not a useful trait if it cannot stay in flight long enough to make use of this. This is especially true in cases where it would have to go far enough that it could not transmit data back to base stations. The only real advantage this drone has is stability.

Hawkeye is a good option if we only wanted to take few pictures in a short period of time (I.e., in an emergency). For this drone to be used to its full potential, more docking stations would be needed, though flight stability is still a concern, as it could cause more crashes.

Great Horned Owl would be the most optimal for our area, as it will allow us to get more images than Hawkeye, which can help get the most accuracy from the machine learning AI. Additionally, the longer battery life will allow for said drone to take more pictures in fewer flights, and the higher stability than Hawkeye makes it less of an environmental concern. It is a good drone overall, with okay-good characteristics in each category, making it the most versatile and reliable. Its only major disadvantage is the low image quality, but if the algorithm were trained with similar images this would probably not be a problem.

Step 3 (30 minutes): Explore model options

This design challenge and sample machine learning model may have different variations and parameters that may affect your final design choices. Although the design of your own machine learning module is out of the scope for this course consider the following different algorithms: deep neural networks (DNN), recurrent neural networks (RNN), and convolutional neural networks (CNN). Note that computational time for these algorithms and their robustness to noise levels are not part of this discussion and will be included in a design studio later in this course.

Using the table below discuss as a group which of the following algorithms you would choose and explain/justify your reasons. Discuss the possibility of using multiple algorithms to improve the overall accuracy. List possible suggestions of how you would make the decision if the different algorithms cannot agree whether a particular lake image contains an algal bloom.

Model Name	Database Size	FP	FN
DNN	~10000 images	1%	3%
DNN	~ 1000 images	3%	7%
DNN	~ 100 images	29%	41%
RNN	~ 10000 images	5%	2%
RNN	~ 1000 images	10%	6%
RNN	~ 100 images	21%	20%
CNN	~10000 images	4%	1%
CNN	~1000 images	9%	12%
CNN	~100 images	39%	41%

Chosen method: RNN, ~1000 images, 10%, 6%. Though at every scale of images, there is an objective best algorithm, 10,000 is a lot of images and we are concerned about the viability of getting a dataset of that size. As a good balance, we think ~1000 is viable, and from there we chose to minimize the number of false non-detects. False positives are much less concerning compared to false negatives due to the fact that having a false negative means that the water is contaminated with algae is undetected, which can be harmful. In contrast, a false positive should simply be a minor inconvenience.

Step 4: Summary of current state

Based on today's work, summarize the current state of your thinking and to the best of your ability, state your design recommendations with respect to Objectives 2, 3 and 4 from your original project module. Note, this is not your final conclusion. You will continue to iterate and refine your thoughts. But if you were to have to conclude today based on these activities, what would your recommendations be?

We feel that we have prepared to the best of our abilities to produce a "low height aerial monitoring system to monitor drinking water sources," though we know that no plan survives implementation and execution unchanged. We are prepared to get into the actual practical details of the technical aspects, because based on real-world details. We may need to improvise, adapt, and overcome a variety of issues that arise as a result of adding these extra factors, but that is an expected part of refining and finalizing the design of this system. God, this is boring to copy paste into the final report. I wonder if anyone is going to read this line. If so, hello!

In terms of error analysis, we have looked at theoretical algorithms and drone designs to better determine how much we value certain technical characteristics. We consider false negatives *significantly* more dangerous than false positives.

False positives can be called off – false negatives risk not being recognized until *after* the consequences, which are more harmful than those of a false positive.

We have also gained insight on the kind of error caused by data set size from this week's asynchronous, which showed that it is important to not use too few images for training, and even for verification.

Using the PERSEID method, we have considered the legislations and the ethics of implementing a system like this while taking everybody's needs into consideration. We have done the preliminary planning and research to ensure we are able to comply with all Canadian Aviation Regulation litigation. On the technical side of things, we have decided concluded that we need to maximize the range of the drone via maximizing drone speed and battery life, but in doing so we need to consider the environmental impacts of the materials involved. If the best battery is one that can seep toxins into the water supply, we are supposed to monitor, that is clearly unideal. Other various technical aspects have been considered, but we have yet to get into the actual parts required. We have weighed the conflicting requests from various socio-cultural stakeholders and believe that we understand the ways in which we may need to compensate our design and operation of this system based on the surrounding factors. This may include using more inefficient pathing at the cost of more flights and reconsidering the type of battery used.

Week 6: **Synchronous Design Studio - Socio-Cultural Considerations**

Overview and Goals

This activity is a continuation previous weeks' activities using the PERSEID methodology to refine and optimize your design options. Based on the asynchronous activity this week, your team should now come together and reconcile each member's thoughts into a single, cohesive set of conclusions. At this point, it is important to differentiate between the terms "socio-cultural considerations" and "socio-cultural constraints." Merriam-Webster defines consideration as "a matter weighed or considered when formulating an opinion or plan" and constraint as "a constraining condition, agency, or force." We have used the term "consideration" thus far, as the factors you identify should be considered when formulating your design. A constraint is a more rigid boundary that you cannot cross. Your team may decide, either on your own or based on input from a community, stakeholder, etc., to treat some of the considerations you have identified as constraints. Please use the terms "consideration" and "constraint" carefully.

One more note – in the steps below, the term "design" refers to both the physical system components and the recommended operating conditions.

Step 1 – key issues (30 minutes)

a. Based on the article by Sandbrook (2015)[1] and each group member's thoughts and research, what are the most important socio-cultural considerations (i.e., the considerations that your team members have the strongest agreement on)?

Performance accuracy affecting water quality – Obviously, the accuracy of algae detection is our first and foremost priority. In addition to being the primary purpose of this project, failing to do so has the most direct and immediate consequences – a false non-detection risks shutting down the local water treatment plant, leaving a city without water, or sending contaminated water into it.

Wildlife and environmental concerns – These concerns come from the unintentional consequences of operating a drone in areas of wildlife. Is our flight path disturbing the wildlife? And in case of a crash, is our drone going to release toxic waste? Failure to consider these things may harm the water source we are meant to protect.

Indigenous People's rights – The concern of monitoring and flying over Indigenous lands is important to consider as we would not want to harm/insult them by going over their land.

[1] Sandbrook, C. The social implications of using drones for biodiversity conservation. *Ambio* 44, 636–647 (2015). https://doi.org/10.1007/s13280-015-0714-0

Nearby residents and Privacy – A major ethical consideration is invading the privacy of people near the lake. The drones can potentially capture pictures of people near the lake without their consent. Additionally, if our drone subject to “hacking” it may mean someone uses the technology for malicious purposes – something we need to keep in mind.

Canadian Aviation Regulation – Abiding by the aviation laws is important as flying over certain air spaces can and will be illegal.

b. Are there any significant disagreements among your group members regarding socio-cultural considerations? Please list these here, together with the reasons behind your disagreements.

A disagreement between our group members exists regarding whether or not we need to concern ourselves with pictures that may include people in them. This is because, given how high up our drone flies, they would not even be distinguishable as people. However, a counterargument to this rationale is that these pictures could have legal ramifications, regardless of how many pixels the people take up in the image.

Step 2 – changes in thinking (30 minutes)

Now that you have had several weeks of deliberation as well as this special focus on socio-cultural considerations, have any of your thoughts shifted when considering the key design regarding technical system specifications or operating conditions? Does this stage challenge anything that you concluded in the performance stage of PERSEID?

Whenever we start designing, we need to actively start ensuring anything we decide on follows the rules and considerations set above – as a result, we should start designing details as soon as possible so we can work out any kinks that are sure to arise. One thought that shifted from the first week was that we thought one drone would be enough. But, now looking at bigger bodies of water we realized that we that will need to use multiple drones to cover the whole lake. We started thinking about other communities that might be affected from our drones. The indigenous community was a community that we did not think about at first. This is an important community, and we should do your best to respect their privacy and take their input about our design project.

Also, we might need to consider another body of water. Lake Jojo, the lake we initially decided on, is within a no-fly zone. We are going to need to decide whether it is worth going through the legislation to fly over it.

Step 3 – model adjustment (15 minutes)

Last week your group completed a machine learning exercise and then provided a qualitative discussion on the expected performance of the algorithm as a function of several parameters. We will be investigating the impact of design parameters on performance further in the coming weeks. However, based on what you have discussed so far, is there be any way that you could adjust your design parameters to augment and mitigate positive and negative socio-cultural considerations, respectively? Please discuss.

Image quality – We can adjust our design to prioritize image quality, which will in turn increase detection accuracy, and minimize the possibility of false detects and false non-detects. The most direct factor in our socio-cultural considerations and consequences is the actual performance of our design – we should do everything in our power to maximize accuracy (within reason). Previously, we considered this of middle-priority, but we have increased its importance since.

Battery life / Flight Duration / Image Number – Having a larger battery could potentially increase the flight range of individual flights, allowing more images per flight, which lowers the need for multiple flights, and therefore the total amount of time the drone is in the air for.

The less time the drone spends in flight, the lower the chances of disturbing nearby residents with either noise or privacy concerns.

Stability of flight – When it comes to safety, the stability of the drone and its resistance to weather conditions is a big concern, as potential drone crash-landings could be very harmful to residents and wildlife. If the pathing is automatic, we could create restrictions over certain areas so that the drone knows what to avoid. If manual path is implemented, the use of a PID controller can make the drone's movement smoother and target-based, letting it recover if blown off course without manual adjustment.

Weight of Learning and Detection – False non-detects are more dangerous than false detects. We could tweak the learning constants of the algorithm so that it weighs false detects as less important than false-non-detects to improve its weighted performance.

Step 4 – Where are you now? (45 minutes)

Now that you have completed PERFORMANCE and SOCIO-CULTURAL layers of the PERSEID method, what do you need to know to be able to make design decisions? Decide how you will get this done. Consider assigning tasks to each group member, and then reconvening to revise and refine your design. It is normal for the team to revisit past decisions and make changes. This is the design iteration.

Now that we are getting to the technical aspect of this project, the consideration of the materials we will use to eventually build a feasible drone is important to our research, as we would have to make sure it would not harm the nearby environment in the eventuality of a drone crash-landing. Additionally, if we decide to not go forward with Lake Jojo as our main "test subject," knowing the terrain of the body of water we intend to monitor will be important as it will give us insight into the nearby residents and wildlife that inhabitants the area, helping us design an effective flight path. We will do more research on this, while also considering the socio-cultural constraints, which can help us refine our final design and project.

Week 7: **Synchronous Design Studio - Regulatory Considerations**

Overview

This activity is a continuation previous weeks' activities using the PERSEID methodology to refine and optimize your design options. Based on the asynchronous activity this week, your team should now come together and reconcile each member's thoughts into a single, cohesive set of conclusions regarding the regulatory considerations that apply to your design.

Last week, we differentiated between the terms "consideration" and "constraint". Note that a regulation is a hard constraint – your design must comply with regulations if it is to be implemented. However, the widespread use of drones for monitoring is an emerging area, and the regulatory landscape for drones is likely to become stricter in the (not so distant) future. Your team would be wise to ensure *sustainability* of your design by i) considering the kinds of regulations that may be in place in the future; and ii) ensuring that your design complies (or will be able to comply with minimal modifications). This type of information can be found by looking to other jurisdictions that are further ahead with this technology.

Additionally, in Week 5 you were given two Python codes for identifying a particular structure in images contained in a dataset: a) Terrain detecting water vs. desert areas; and b) Algae detecting lakes with and without algal blooms. This week you will be expected to explore the impacts of i) data structure organization; and ii) dataset size on the overall accuracy of the system.

Step 1 - Initial assessment of the REGULATORY layer (30 minutes)

a) Based on each group member's research, what are the most important regulatory constraints and considerations (i.e., the considerations that your team members have the strongest agreement on)?

The Canadian Aviation stipulates:

- All drones that weigh between 250 g and 25 kg must be registered with Transport Canada. Pilots must mark their drones with their registration number before they fly. All pilots of drones that weigh between 250 g and 25 kg must get a drone pilot certificate. Fly your drone where you can see it at all times.
- Fly below 122 meters (400 feet) in the air
- Fly away from bystanders, at a minimum distance of 30 meters for basic operations
- Do not fly at the site of emergency operations or advertised events
- Avoid forest fires, outdoor concerts, and parades
- Do not fly within 5.6 kilometers (3 nautical miles) from airports or 1.9 kilometers (1 nautical mile) from heliports **This we haven't properly accounted for.**
- Fly far away from other aircraft

- Do not fly anywhere near airplanes, helicopters, and other drones
- Always respect the privacy of others while flying

We must make our drone follow these regulations given its physical specifications, which is important because it impacts most of the project and adds work to what may be needed to get the system running.

Communities such as r/drones on reddit may also be helpful for more specific questions. Our team has also already compiled much of the relevant information in our previous work and other notes, which we refer to as needed.

We count as Advanced Operations:
"You want to fly in controlled airspace"
This is because the area we intend to survey is normally a no-fly zone.
List of good drones that follow various laws as examples
https://tc.canada.ca/en/aviation/drone-safety/learn-rules-you-fly-your-drone/choosing-right-drone

Offences against Air or Maritime Safety
Don't be a pirate, don't hijack.
Don't endanger people on a plane with the drone or other means.
This legislation does not affect our operating procedures but may apply to those who attempt to interfere with our system.

Drone safety
Information on flying drones, unmanned air vehicles or unmanned aircraft systems for recreation, work, or research
Report drone incident

If a drone were to crash, we would need a system to report it, as well as potential control systems that help it avoid crashing into sensitive areas.

Drone registration:

Register drone. Fee $5. You must clearly mark your drone with its registration number.
If you lose your drone, registration may help in returning it to you if it is found
If there is a recall from the manufacturer, we may be able to notify you. The process is easy: https://tc.canada.ca/en/aviation/drone-safety/registering-your-drone-overview

If it is beneficial to the project, we may apply for an actual license and fly a drone over the intended area as a conceptual test run.

b) Are there any significant disagreements among your group members regarding Regulatory considerations? Please list these here, together with the reasons behind your disagreements.

Our group had a disagreement on if it is worth it to continue with Lake JoJo, as it has more advanced operations license requirement. We have discussed switching to a different location where these additional regulations do not need to be considered. Currently, Lake JoJo is a no-fly zone, meaning that without a certified license, flying drones over the lake and its surrounding area, is not an option. Some of us believe that it would be easier to just find another lake with fewer regulations at all for that matter, as we would not have to go into the rabbit-hole of having to work with these legislations.

Step 2 – changes in thinking (20 minutes)

Now that you have had several weeks of deliberation as well as this special focus on regulatory issues, have any of your thoughts shifted when considering the key design decisions regarding technical system specifications or operating conditions? Does this stage challenge anything that you concluded in the performance or socio-cultural layers of PERSEID?

Fundamentally, we have not changed too much.

We did a significant amount of research regarding the regulatory considerations early on in this project, for we knew that it would directly influence every other aspect of our design. We knew we are not to do anything illegal, so we made sure to be at least vaguely aware of any legislation we had to follow.

This week we just went from "vaguely aware" to "aware," re-emphasizing the points we covered before as well as doing more in depth where needed, while also documenting important sites with regulations we should reference again later.

One thing we have noticed is how our priorities shift gradually towards whatever area we are researching for the week. By the end we will need to scope out and ensure all considerations are actively in our headspace as we move forward.

One thing is that we are now more aware of the fact that this legislation is still being developed, meaning it would be better to implement more modularity into our design philosophy so that we can better adapt to changes in legislation as required.

Step 3 – model adjustment (15 minutes)

For this PERSEID step, would there be any way that you could adjust your source water quality monitoring system design to include constraints and considerations identified this week? If so, please suggest any strategies for doing so. If not, why are the regulatory constraints and considerations that you have identified consistent with the current design?

You may need to modify your strategies multiple times as you further explore your design in future sessions. List the relevant design parameter(s) associated with each constraint or consideration, and briefly mention your strategies for employing these considerations in your design.

We looked at a lot of regulation before this week, so our design already considered a lot of laws and regulations. For example, all drones that weigh between 250 g and 25 kg must be registered with Transport Canada. With this in mind, we would want to have a drone that weighs less than 25kg. We also know that we needed to fly below 122 meters and stay away from bystanders, which affects our flight pathing.

We found out that when we decrease the size of the training data, the accuracy decreases also.

We would want to get an HD camera, which would be optimal as it would provide clearer images to process, but this is more of a technical aspect than a modelling aspect.

Step 4 – Where are you now? (30 minutes)

Now that you have completed the PERFORMANCE, SOCIO-CULTURAL, and REGULATORY layers of the PERSEID method, what are your current design decisions? It is normal for the team to revisit past decisions and make changes. This is design iteration.

Physical system components:

The physical system components will be directly based on the list of the list of "Drones eligible for advanced operations" as approved by Canada.

As we have not built anything yet, in the future, if we plan to build an actual drone, adhering to the advanced operation legislations would be ideal. Additionally, considering the material the drone(s) would be made of is important when considering the environmental aspect of PERSEID – ideally all components are recyclable and non-toxic, but some compromise may be required as the best components may not be the most environmentally friendly.

Operating conditions:

We will be operating during the day, performing two flights each. The drone will not need to fly during severe weather or during the colder months but may have to deal with some rain or wind to capture data on some days. How these conditions impact the drone is also a factor of the regulatory portion that restricts the heights at which we can fly.

Which decision was the most difficult? Which screening layers do you think will be the most problematic in the upcoming PERSEID steps, and why?

The environmental portion of PERSEID may be problematic, due to the lack of easily recyclable or decomposable drone parts that would also last long enough for the system to function effectively. Some regulatory hurdles may only be treated as theoretical as well, depending on how much this project requires being implemented.

Step 5 - Explore the trade-off between database size and overall accuracy (35 minutes)

In Week 5 you were given a Python code and the corresponding database compiled into the Python notebook Algae. By now you should have identified that the overall accuracy of the system is very dependent on the size of the database available for training.
In this session you are required to share your individual findings with your teammates and brainstorm to:

1. Explore and find the effect of different training/testing ratios by creating your own test/train folders using the database of lake images available on A2L.

Through testing on our own time, we concluded our initial assumptions. More training data as well as more epochs leads to greater model accuracy, though epochs have greater diminishing returns when compared to database size.
Halving the training database size had only a minor effect on accuracy Decreasing it by factors of five significantly affected accuracy, and the algorithm is a coin flip in terms of accuracy when it is trained off a single image.

2. Explore the trade-off between the database size and overall accuracy (qualitative more than quantitative). Explore difference in the performance between the Algae and Terrain notebooks (the latter of which contains a much larger number of images).

More training data is obviously better, however accuracy is hard capped based on the accuracy of the training data you feed it. If the training data is only 2/3rds accurate, it is not feasible for the algorithm to be any more accurate.

In the example of the given algae and terrain data, the terrain data algorithm can more quickly become accurate, and has a higher performance cap, as shown by the testing done in the week that introduced it. Increasing the database size has asymptotically diminishing benefit, so at some point it is no longer worthwhile, especially on the testing data side where human labeling is required.

3. List other reasonable and feasible recommendations for improving the accuracy of the algae identification process.

Maximizing the camera quality of the image will increase accuracy on test data.

Maximizing the accuracy of the training data is vital. The training data provided is only 2/3rds accurate - (why???). It acts as a hard cap on the accuracy of the algorithm. What would be best is if we have a human look over ~1000 images of training data and manually sorted them into algae/non algae and then let the algorithm train itself from there.

Better camera stability –> higher image quality.

Week 8: Synchronous Design Studio - Environmental Considerations
Overview

This activity is a continuation previous weeks' activities using the PERSEID methodology to refine and optimize your design options. Based on the asynchronous activity this week, your team should now come together and reconcile each member's thoughts into a single, cohesive set of conclusions regarding the environmental considerations that apply to your design.
Step 1 - Initial assessment of the ENVIRONMENTAL layer (30 minutes)

b) Based on the article and group member's thoughts and research, what are the most important environmental constraints and considerations (i.e., the considerations that your team members have the strongest agreement on)?

Wildlife Impacts

Wildlife collisions kill, and we should account to it. Bird strikes are ABSOLUTELY a factor.

Also, b/c they are at low altitudes, disturb wildlife

The larger the drone, the more threatening they may become, resulting in more disturbance. Higher altitude or smaller drone helps.

Flightless and large birds more likely to be affected than small birds, but mammals are less likely to be affected.

A **pulsing light has been** shown to reduce the risk of bird strikes, as well as applying patterns to the propellers of turboprop aircraft.

Higher contrast to the sky helps birds see and avoid the drone.

Legally, remain flexible.

Co2 Impacts

- No tailpipe emissions, but live cycle assessment would be a more accurate reading of its co2 impact. More fuel efficient than trucks for small payloads, but drop off quickly, but this can be mitigated by having multiple "deliveries" in a single trip.
- 1/8th energy efficient, but 2/8 times more efficient w/ c02 w/ respect to regular trucks, but w/ electric trucks it loses to.
- Drones may use more direct routes than delivery truck which should help, less distance, but may require more trips back to recharge.
- Significant C02 emissions from the LCA. High number of sensors.
- Overall, they still have lower GHG emissions than trucks, but only when charged with green electricity, and if they are routed and planned properly.

• Once again, politicians can do things but in our case all that matters is that we have a flexible design.

Noise exposure can lead to annoyance, stress, sleep disturbance, poor mental health and well-being, impaired cognitive function in children, and negative effects on the cardiovascular and metabolic system (Fons-Esteve, 2018).

Soil Sealing

Drones require minor soil sealing if built upon existing rooftops, but if required to operate in more urban areas and an air hub is required, soil will have to be built over. Minor thing to consider.

Carbon fibers used in the cargo box and the Li-ion production for the battery is the main thing for human, aquatic, wildlife, etc. toxicity. Drone *operation* is the least impactful part of the equation, though it can be lowered by using green electricity to charge the drone.

Air Pollution Impacts

If they are electricity powered, they help, not causing any local air pollution.
DO NOT RUN THEM W/ FUEL (ideally also applies to charging electricity)

c) Are there any significant disagreements among your group members regarding environmental considerations? Please list these here, together with the reasons behind your disagreements.

We had a disagreement w/ regards to the importance of noise pollution.

Some members consider it less of an issue due to the body of water not being a recreational beach, but the counter argument was that it was a nature preserve with trails. Noise is always a factor.

Step 2 – changes in thinking (20 minutes)

Now that you have had several weeks of deliberation as well as this special focus on environmental considerations, have any of your thoughts shifted when considering the key design decisions regarding technical system specifications or operating conditions? Does this stage challenge anything that you concluded in the performance, socio-cultural, or regulatory layers of PERSEID?

Drone parts and sourcing where they come from – this needs to be at least vaguely mentioned as a consideration in the design iteration phase.

Bird strike applications – what patterns could be applied, blinky light.

How to approach the drone design – amalgamation of features, not design then iteration.

Waterfall mist is a factor – may interfere with electronics.

Step 3 – model adjustment (15 minutes)

For this PERSEID step, are there adjustments that you could make to your source water quality monitoring system design to include constraints and considerations identified this week? If so, please suggest any strategies for doing so. If not, why are the environmental constraints and considerations that you have identified consistent with the current design?

List the relevant design parameter(s) associated with each constraint or consideration, and briefly mention your strategies for employing these considerations in your design.

Fly at a higher altitude -
Causes less disturbance but has higher fuel costs but may lower camera quality.

Add a pulsing light - has been shown to reduce risk of bird strikes but adds minor weight.

Charging on existing rooftop:
Low soil sealing factor, but due to the location, it may require more range to accommodate.
Building an air hub: Building the infrastructure for charging and storage near the location to be scanned will lower the range required, but will require additional resources and will seal way soil

Add solar panels on to the drone charging station.

Step 4 – Where are you now? (30 minutes)

Now that you have completed the PERFORMANCE, SOCIO-CULTURAL, REGULATORY, and ENVIRONMENTAL layers of the PERSID method, what are your current design decisions? It is normal for the team to revisit past decisions and make changes. This is design iteration.

Physical system components:

Additional components have been added to the list of considerations

As we have not built anything yet, in the future, if we plan to build an actual drone, adhering to the advanced operation legislations would be ideal. Additionally, considering the material the drone(s) would be made of is important when considering the environmental aspect of PERSEID – ideally all components are recyclable and nontoxic, but some compromise may be required as the best components may not be the most environmentally friendly. Pulsing lights was also another aspect to think about, as it can help with reducing accidents with birds and mammals.

Operating conditions:

We will be operating during the day, performing two flights each. The drone will not need to fly during severe weather or during the colder months but may have to deal with some rain or wind to capture data on some days. How these conditions impact the drone is also a factor of the regulatory portion that restricts the heights at which we can fly.
The environmental portion of PERSEID may be problematic, due to the lack of easily recyclable or decomposable drone parts that would also last long enough for the system to function

effectively. Some regulatory hurdles may only be treated as theoretical as well, depending on how much this project requires being implemented.

Which decision was the most difficult? Which screening layers do you think will be the most problematic in the upcoming PERSEID steps, and why?

Step 5: Preparing for Milestone 2 (15 minutes)

For the next milestone, you are asked to "provide a summary table showing the broad funnel constraints, short descriptions of specific considerations that you eventually used". Please discuss and decide as a group, what your table structure should be. How will you organize all of your past discussions to represent your design decisions clearly and concisely? Feel free to adapt any of the tables that you have been provided through the various Design Studio stages.

Basically, the idea would be to have a table as follows:

Constraints to filter through	**Description of constraints**	**Design Configuration/Iteration/Element**
Technical	Camera quality Accuracy of detection	- How to achieve this - Features to include - Other pros and cons to consider
Societal	Noise Visibility	Etc

We organize by what part of the PERSEID method the considerations apply to, how they apply functionally, and how we can implement features or considerations that affect those things.

Week 9: **Synchronous Design Studio - PERSEID Method: Validation and Testing**

Overview

In continuation of last weeks' activities on PERSEID methodology for refining and optimizing your design options, this week you are required to design matrix-based decisions to your design projects. You are required to share and discuss the criteria and design choices with your teammates and apply the necessary steps in making sure the important design options are taken into consideration in your designs.

Initial selection of design matrix

From your asynchronous activity conclusions, share with your teammates the main criteria and design configurations / design choices that you have identified. All teammates should review others' suggestions.

a) **List the criteria that your team members have the strongest agreements on. Aim for at least 3 criteria.**

1. Carrying capacity
2. (Lack of) Noise Pollution
3. Visual appeal
4. (Lack of) Regulatory Risk
5. Simplicity
6. Environmental friendliness factor
7. Scanning time

Note: All these criteria are phrased in such a way so that more of it is good so that the decision matrix is easy to make.

- **What are the most significant disagreements?** If there is a disagreement among the team members on a suggestion(s), list those points here. What are the reasons behind the disagreements?

- Coverage of the body of water was considered as a criterion, but we ended up not using it since we have been assuming all our designs could cover the whole thing.
- "Range" is not a valid factor, because the (lack of) individual range of a drone can mitigated via drone amount/orientation and other factors.

- "Weight/Size" is not a valid criterion, because bigger is not always better. Being bigger and heavier may give us more carrying capacity, at a cost of speed/noise/etc. "Carrying capacity" is a more valid measurement to consider.

In the past session, you discussed several design choices and several unique designs for your final product. This week we expect you will be moving towards final decision/selections.

To do so, you are required to organize your design decisions into a systematic/quantifiable approach using design matrix. Using outcomes of your asynchronous activity and the previous task create a design matrix consisting of three different criteria and 2-3 unique design configurations / choices.

For example, using Tables describing drones and machine learning algorithms from Week 5 you could create a design matrix consisting of several drone/algorithm combinations and select optimal choice using criteria you selected as a team in the previous task.

You may need to come back and modify your weights/grades and/or configurations/choices before you finalize your decision. Furthermore, in the following week, you will be provided with an additional model including environmental noise that will enable you to refine your design choices considering weather conditions in the area you selected for monitoring.

	Weights (1-10)	Two Drone Crew	High-Capacity Blimp	Drone swarm
Carrying Capacity	7	5	10	9
(Lack of) Noise	4	5	8	4
Visual appeal	3	5	3	3
(Lack of) Regulatory risk	9	8	5	5
Simplicity	4	6	4	4
Environmental friendlyness factor	5	8	5	4
Scanning Time	5	5	3	9
Grade		231	212	214

Based on the above weighted decision matrix, the “Two Drone Crew” design is the best overall. However, the other two designs are close contenders, due to the way that their strengths help compensate for where they are weaker. Despite “Two Drone Crew” being the best overall, the other two contenders are better in significantly different areas, and as a result they are both still worth considering.

Our weightings were based on the importance of the factors for the system’s performance, as well as how necessary they are.

Week 10: Synchronous Design Studio - PERSEID Method: Validation and Testing

Overview

This week you will be performing the final steps of your design. Specifically, you will be validating/testing your design choices with respect to performance metrics discussed in previous design studios. In your asynchronous activity you were asked to perform a preliminary qualitative/quantitative error analysis. In this synchronous activity you are expected to share your findings within your group and finalize certain design choices based on your previous selections and desired performance thus validating your design with respect to the performance it offers.

Desired Performance:

Recall that we use false positive (FP) to refer to scenario in which your monitoring system decides there is an algal bloom while in reality, there is no bloom in the lake. Similarly, false negative (FN) refers to the scenario in which your monitoring system decides there is no algal bloom in the lake, while in reality, there is an algal bloom. Selecting the FP and FN rates is a complicated process involving both expert opinion and a cost analysis. In this exercise, you are asked to make certain decisions based on your group consensus. You will not be graded on the decision that your group makes; rather you will be graded on the discussion and justification of your group's decision.

Please be aware of the following: a) the FP rate means that FP% of times you will be sending someone to obtain a water sample from the lake (potentially remote depending on your site choice), b) the FN rate means that FN% of times you will allow an algal bloom to grow without managing lake usage or downstream treatment strategies until you send your areal monitoring system back to that area again, and c) 0% error, while desirable, is not technically feasible.

1. Error Analysis: Discuss as a group what you believe reasonable to be choices for FP and FN rates. Include in your discussion the role (if any) that your location choice plays in these choices. In real-world designs you often need to balance these decisions because they cannot both be arbitrarily small. Assume that FP and FN are empirically modeled using the following relationship

$$FP = \frac{1 - 2 * FN}{4 * FN + 2}$$

where FP and FN represent false positives and false negative rates on a scale of 0-1 (i.e., percentage values divided by 100%). Reconsider your group's choices for FP and FN and decide whether they would remain the same under the above constraint.

	FN	FP	total
	0	0.5	0.5
1	0.01	0.480392	0.490392
2	0.02	0.461538	0.481538

3	0.03	0.443396	0.473396
4	0.04	0.425926	0.465926
5	0.05	0.409091	0.459091
6	0.06	0.392857	0.452857
7	0.07	0.377193	0.447193
8	0.08	0.362069	0.442069
9	0.09	0.347458	0.437458
10	0.1	0.333333	0.433333
11	0.11	0.319672	0.429672
12	0.12	0.306452	0.426452
13	0.13	0.293651	0.423651
14	0.14	0.28125	0.42125
15	0.15	0.269231	0.419231
16	0.16	0.257576	0.417576
17	0.17	0.246269	0.416269
18	0.18	0.235294	0.415294
19	0.19	0.224638	0.414638
20	0.2	0.214286	0.414286
21	0.21	0.204225	0.414225
22	0.22	0.194444	0.414444
23	0.23	0.184932	0.414932
24	0.24	0.175676	0.415676
25	0.25	0.166667	0.416667
26	0.26	0.157895	0.417895
27	0.27	0.149351	0.419351
28	0.28	0.141026	0.421026
29	0.29	0.132911	0.422911
30	0.3	0.125	0.425
31	0.31	0.117284	0.427284
32	0.32	0.109756	0.429756
33	0.33	0.10241	0.43241
34	0.34	0.095238	0.435238
35	0.35	0.088235	0.438235
36	0.36	0.081395	0.441395
37	0.37	0.074713	0.444713
38	0.38	0.068182	0.448182

39	0.39	0.061798	0.451798
40	0.4	0.055556	0.455556

Having a percentage of 0% FN is ideal, because false negatives can be extremely dangerous as it would make the entire system ineffective as not being able to detect the algae, can harm the residents and wildlife that use the municipal water source. Realistically, the optimal amount would be 20% as this would return the lowest amount of total error.

2. Model Selection: Reconsider the machine learning algorithms and drones from Week 5 of your design studio, and discuss whether which of these models are more, or less, appropriate considering the choices you made in this week's design studio. Please explain/justify your choices.

Model Name	Database Size	FP	FN
DNN	~10000 images	1%	3%
DNN	~ 1000 images	3%	7%
DNN	~ 100 images	29%	41%
RNN	~ 10000 images	5%	2%
RNN	~ 1000 images	10%	6%
RNN	~ 100 images	21%	20%
CNN	~10000 images	4%	1%
CNN	~1000 images	9%	12%
CNN	~100 images	39%	41%

Name	Speed	Image quality	Flight stability	Battery Life	Ability to store/transfer images
Flying Fortress	Low	Medium	High	Low	High
Hawkeye	High	High	Low	Medium	Low
Great Horned Owl	Medium	Low	Medium	High	Medium

Chosen method: RNN, ~1000 images, 10%, 6%. Though at every scale of images, there is an objective best algorithm, 10,000 is a lot of images and we are concerned about the viability of getting a dataset of that size. As a good balance, we think ~1000 is viable, and from there we chose to minimize the number of false non-detects. False positives are much less concerning compared to false negatives since having a false negative means that the water is contaminated with algae is undetected, which can be harmful. In contrast, a false positive should simply be a minor inconvenience.

Great Horned Owl would be the most optimal for our area, as it will allow us to get more images than Hawkeye, which can help get the most accuracy from the machine learning AI. Additionally, the longer battery life will allow for said drone to take more pictures in fewer flights, and the higher stability than Hawkeye makes it less of an environmental concern. **It is a good drone overall, with okay-good characteristics in each category, making it the most versatile and dependable**. Its only major disadvantage is the low image quality, but if the algorithm were trained with similar images this would probably not be a problem.

"Okay-good in each category" seems to be what we are going for with our final design decision – getting this reaffirmed is a big boost to our confidence.

3. In this week's asynchronous activity, you were asked to consider how combining different decisions using different algorithms can potentially improve the performance of your system. To assist you in your reasoning, consider the following example in which we combine two algorithms. Let's assume that the FP and FN rates of the two algorithms are FP1, FN1, FP2, and FN2, respectively. Let us assume that our decision-making scenario specifies that an algal bloom is detected only if both algorithms say that a bloom is present. The FP rate for this scenario is FP1*FP2, which is smaller than either of two individual algorithms because both would need to make an error. However, the probability of FN under this scenario is given by:

$$FN = 1 - (1 - FN1)(1 - FN2)$$

Is this false negative larger or smaller than the false negative values based on the individual algorithms? Calculate these values for several (FP, FN) pairs using the constraint from Scenario 1. Do you believe combining the decisions using this scenario is a good choice? Justify your reasoning.

								FP rate for Prob 3	
								1-(1-FN1)(1-FN2)	FP1*FP2
	FN1	FP1	total		FN2	FP2	total		
	0	0.5	0.5		0	0.5	0.5	0	0.25
1	0.01	0.480392	0.490392	0	0	0.5	0.5	0.01	0.240196
2	0.02	0.461538	0.481538	4	0.04	0.425926	0.465926	0.0592	0.196581
3	0.03	0.443396	0.473396	8	0.08	0.362069	0.442069	0.1076	0.16054
4	0.04	0.425926	0.465926	12	0.12	0.306452	0.426452	0.1552	0.130526
5	0.05	0.409091	0.459091	16	0.16	0.257576	0.417576	0.202	0.105372
6	0.06	0.392857	0.452857	20	0.2	0.214286	0.414286	0.248	0.084184
7	0.07	0.377193	0.447193	24	0.24	0.175676	0.415676	0.2932	0.066264

8	0.08	0.362069	0.442069	28	0.28	0.141026	0.421026	0.3376	0.051061
9	0.09	0.347458	0.469420	32	0.32	0.109756	0.429756	0.3812	0.038136
10	0.1	0.333333	0.433333	36	0.36	0.081395	0.441395	0.424	0.027132
11	0.11	0.319672	0.429672	40	0.4	0.055556	0.455556	0.466	0.01776
12	0.12	0.306452	0.426452	44	0.44	0.031915	0.471915	0.5072	0.00978
13	0.13	0.293651	0.423651	48	0.48	0.010204	0.490204	0.5476	0.002996

For this example, the first data set is incremented by 1%s, where the second increments by 4% as to have different values for each dataset.

We noticed that the false negative values in this 2-input model are actually much higher than for either dataset individually. Though false positives are barely an issue anymore, because of how false negatives are far more dangerous than false positives, combining the decisions using this scenario is **not** a good idea.

4. Based on today's work, describe how you would test the performance of your proposed source water monitoring system. Note that the performance of a system calculated based on a lab/simulation environment is usually different from the actual performance obtained on site. You are expected to clearly state your proposed experiment, including location, sampling times (what part of year, how many flights, environmental conditions, etc.), in situ sampling of the water, as well as machine learning algorithm (or algorithms if you decide that combination of multiple algorithms is viable option).

We would evaluate the performance of our system by analyzing the number of detections reported compared with the number that is verified over time, assuming that after action is taken the water monitoring plant would manually confirm. Of course, false non-detects would be more obvious due to the problems they would cause. Other metrics such as crash frequency and maintenance needed could also be factored into overall performance. Given our current considerations, our 2-drone design is leading contender.

Appendix F: Miscellaneous Considerations.

In our research, we have found reports of people using unmanned aerial in a fireworks display, and documentation of the damage the drones sustain attempting to photograph them from the inside. As a result, we will not be flying our drones in live fireworks displays.

Infrared homing avoidance measures exist for both conventional military aircraft as well as drone UAVs – usually by dropping flares behind the aircraft to provide false heat sources for the missile to lock on to. Fortunately, unless something goes catastrophically wrong, such infrared homing countermeasures will not be necessary for our purposes.

A series of underwater sensors was considered – the idea was that the sensor array would detect an increase in phosphoric runoff, followed by a decrease in oxygen in the water and a decrease of light reaching the sensor array as the algae blooms on the lake above. However, upon research and discussion w/ Hamilton Water, we have found that such a technology is not yet feasible and would cause a whole new host of problems.

Other considerations include ways of reducing the odds of an algae bloom in the first place, such as educating farmers on how to use more environmentally safe fertilizer and how to minimize such runoff in the first place, as well implementing a carbon tax on corporations to discourage the pollution that causes the rising temperatures that such algal blooms tend to favor. Alas, such a solution is outside the scope of the project