Potential Impacts of Georgian Bay Salmon's Proposed Recirculatory Aquaculture System in Colpoy's Bay (Wiarton, ON)

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based on written report by:

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On June 18th, 2021, the Georgian Bay Innovation Group announced their proposal to build the largest land-based Recirculating Aquaculture System (RAS) to produce Atlantic Salmon at 83 Berford Lake Road, South Bruce Peninsula, Ontario (GBS, 2021; see **Figure 1**). Referred to as Georgian Bay Salmon (GBS), they planned to use AquaMoaf, a new RAS technology from Israel to produce up to 15,000 tonnes of Atlantic Salmon annually that would have no impact on other salmon species or other species, no untreated waste returning to Colpoy's Bay, no organic buildup or negative impact on surrounding environment, and no impact from increased greenhouse gas emissions (https://www.gbsalmon.ca/about-us/). GBS also said that the RAS facility would provide over 200 new employment opportunities and stimulate economic growth in the local community (GBS, 2021). Despite these re-assurances, community members from Wiarton raised serious concerns on the effect of the proposed fish farm on local land aesthetics, water quality of Colpoy's Bay, and the intrinsic value of the land.

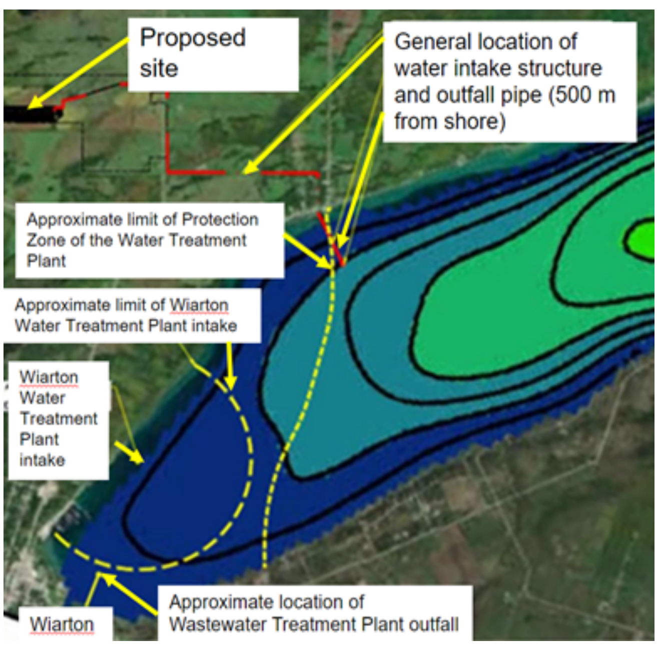

Figure 1: Map of the location of the GBS facility and the proposed discharge pipe route and proximity to the Wiarton Water Treatment Plant and Intake Protection Zones.

What information is required to determine the costs and benefits of this proposal?

In the experiential graduate course taught by Prof Pat Chow-Fraser and Karen Kidd (*Management of Aquatic Ecosystems and Resources, Biology 730),* ten students set about to answer this question. They assembled publicly available information from GBS, published data from primary and grey literature, and consulted the opinions of aquaculture experts and residents of Wiarton (including members of the Saugeen Ojibway Nation (SON)). They also analyzed water samples collected from nearshore areas of Colpoy's Bay during the winter 2022.

This summary includes a list of questions and issues that should be addressed by GBS prior to approval of the project. Their assessment did not contain a comparison of different types of aquaculture production, nor a discussion of the best use of the land at the proposed site. Very simply, it identified potential ecological and socio-economic impacts of the RAS facility to Colpoy's Bay and residents of Wiarton.

Description of RAS

RAS are land-based facilities that rely on consistent recirculation of water, consistent energy input, and manual input of feed to produce fish (Ebeling and Timmons, 2012). Because it is a closed system with a highly controlled environment, it can theoretically be situated anywhere, but it requires input of high-quality water and a reservoir for effluents. The circular tanks, which allows for batch harvesting of various aquatic species must be monitored constantly. Since there is high initial capital cost of RAS (expensive and specialized equipment; Lorsodo et al., 1994), RAS operations must be operated at a larger scale than other types of aquaculture production (Badiola et al., 2012).

In the GBS proposal, water will be pumped directly from Colpoy's Bay at a rate of **1,300 L/min** into intake tank(s) where fish would be reared (GBS 2021; see **Figure 2**). From these tanks, water would probably move through a series of solid-waste separation basins to remove feed particles and feces and then undergo a biofiltration process where specialized bacteria convert ammonia from fish waste into less toxic forms of nitrogen. A degassing technology is typically used to remove excess CO_2 and NO_2 from the water. Finally, water is re-oxygenated and disinfected, usually with ultraviolet light units.

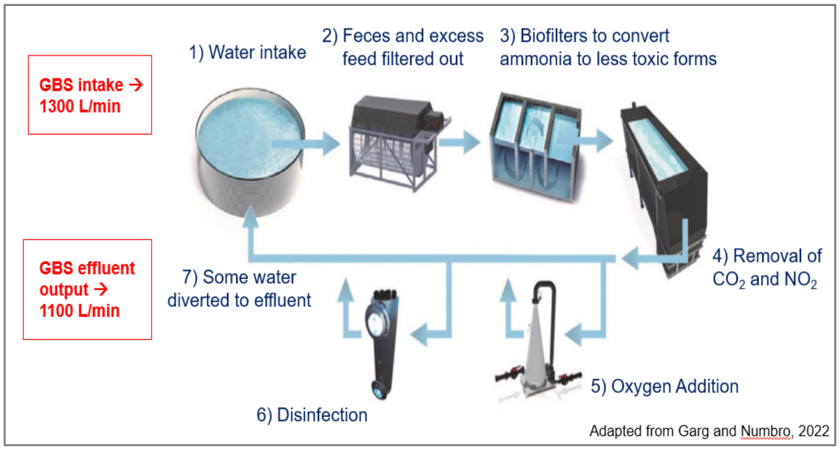

Figure 2: Major steps in the RAS process and the planned water intake and effluent output from the GBS facility. Adapted from Garg and Numbro, 2022

These steps ensure that the quality of the water can be recirculated back into tanks with the addition of a small amount of newly drawn water. There would be some water that cannot be recirculated because it is below standard and must be diverted into effluent pipes (Garg and Numbro, 2022). For the proposed GBS project, the amount of effluent released back into Colpoy's Bay is expected to be **1,100 L/min** (GBS, 2021).

Existing RAS facilities globally

Globally, there exist ten RAS facilities that produce Atlantic salmon. In addition to the proposed GBS, six others have been in operation for at least 3 years, and 3 others are under construction (**Table 1**). The only facility currently using AquaMaof technology is the Global Fish company facility in Poland, which has only been in production since 2016. Kuterra is the first RAS operation in Canada and will be discussed in more detail in this report, and serves as a comparator.

Table 1. Capacities (metric tonnes) of land-based RAS facilities for Atlantic Salmon production

Years in production as of 2019	Company	Location	Capacity
7 years	Shandong Oriental	China	2,000
6 years	Danish Salmon	Denmark	2,000
6 years	Atlantic Sapphire	Denmark	700
3 years	Global Fish/Pure Salmon	Poland	600+
4 years	Kuterra	Canada	370
4 years	Sustainable Blue	Canada	500
Under construction	Atlantic Sapphire	USA	30,000+
Under construction	Whole Oceans	USA	50,000
Under construction	Nordic Aquafarms	USA	33,000+
Proposed	Georgian Bay Salmon	Canada	15,000

Adapted from DFO State of Salmon Aquaculture Technologies, 2019

Kuterra Case Study and Comparator

As Canada's first land-based RAS facility for Atlantic Salmon (Coast Funds, 2018), Kuterra began operation in 2013 on the 'Namgis First Nation ('NFN) Reserve on Northern Vancouver Island. The 'NFN initiated the project due to declining populations of wild Pacific Salmon, which is a culturally important species. They wanted to avoid the negative impacts of ocean-based net-pen aquaculture, which can degrade fish habitat, transmit diseases, and introduce exotic species (Carballeira Braña et al., 2021). Kuterra was developed as proof-of-concept facility with support from conservation organizations, industry, and government and the 'NFN wanted to be transparent about their experience and to catalyze change in the aquaculture industry (Coast Funds, 2018). Kuterra has been producing ~400 tonnes of high quality Atlantic Salmon for several years (Kuterra, 2021; **Table 2**) in an environmentally sustainable fashion as indicated by their Environmental Site Assessment and an Independent Environmental Monitoring Program that both indicated there were no negative impacts to the surrounding ecosystems (Kuterra, 2015; BC Ecosphere Management Ltd, 2017).

Table 2. Design overview of the Kuterra RAS facility compared to the proposed GBS facility

Design Feature	**Kuterra**	**GBS (Proposed)**
Production Volume	400 metric tonnes	15, 000 metric tonnes
On Site Hatchery	No	Yes
Water Source	Production Wells	Intake from Colpoy's Bay
Saltwater Use	~10 ppt	*Unknown*
Solid Waste Management	Fertilizer	Fertilizer
Effluent Management	Treated and Ground Filtration Process	Treated and discharged to Colpoy's Bay

As a pilot-scale facility, Kuterra was designed to produce only 400 tonnes per year, while GBS has a proposed production volume of 15,000 tonnes annually (GBS, 2021; Kuterra, 2015). This large difference in scale is an important consideration when comparing information about the two facilities. Kuterra imports smolts and grows them to market size, while the GBS facility is proposing to have a hatchery on site (BC Ecosphere Management Ltd, 2017; GBS, 2021). The water source for Kuterra is through groundwater production wells, whereas GBS has proposed to take high-quality freshwater from Colpoy's Bay (BC Ecosphere Management Ltd, 2017; GBS, 2021). Lastly, the effluent at Kuterra is managed through a ground filtration process where water is moved through a chlorination tank, dechlorination tank, open-pit settling ponds, and finally into the ground (BC Ecosphere Management Ltd, 2017). **By contrast, the proposed GBS facility plans to discharge the effluent back into Colpoy's Bay after it is treated, though the details of the treatment process are unclear (GBS, 2021).**

Environmental and Biological Implications

*1) **Will effluent from the proposed GBS operation maintain the oligotrophic character of Colpoy's Bay?***

Phosphorus (P) and Nitrogen (N) are the two primary nutrients in freshwater ecosystems that control the growth of algae and aquatic vegetation. A rapid increase in these nutrients in lakes can lead to excessive growth of algae and eventually develop anaerobic conditions when the algae die. In freshwater, total P (TP) is generally more limiting than total N (TN), and is therefore the nutrient of concern. Since the 1970s, springtime TP concentrations measured by Environment Canada's Great Lakes Surveillance Program has consistently been below 5 μg/L, concentrations that are considered oligotrophic (4-10 μg/L) or ultra-oligotrophic (<4 μg/L) (Dove and Chapra 2015). In addition to being oligtrophic, Lake Huron also has low levels of chemical contaminants (Jones et al., 2020; Buell et al., 2021). Based on monitoring reports from sites located outside the outlet of Colpoy's Bay, summer values of TP in offshore areas were less than 2 μg/L (Charlton and Mayne, 2014). al., 2013). Therefore, the trophic status of the Canadian portion of Lake Huron has generally been classified as oligotrophic or ultra-oligotrophic.

We were unable to find any data during any season to serve as baseline for TP in Colpoy's Bay. Therefore, we collected water samples at 19 sites during January and March in 2022 to determine TP concentrations and other limnological data (dissolved oxygen (DO), total dissolved solids (TDS), conductivity, and salinity (**Figure 3**). These data only indicate non-growing season and may not apply to ice-free data. All locations we sampled were located close to shore rather than in offshore waters.

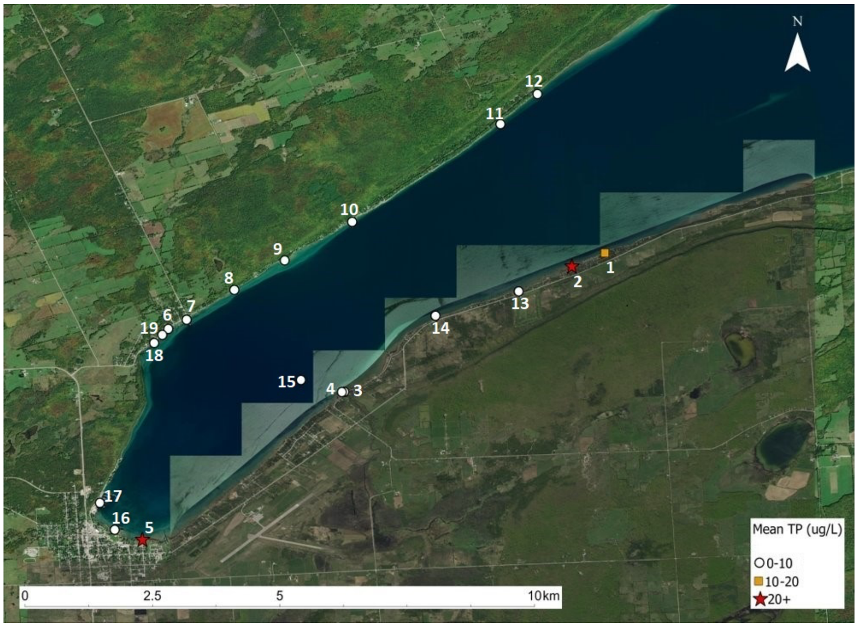

Figure 3. Location of 19 sampling sites in Colpoy's Bay. Grab samples were collected in January and March of 2022 and measured for TP concentrations. All except 3 were oligotrophic (<10 μg/L); one was mesotrophic (10-20 μg/L) and one was eutrophic (>20 μg/L). Sites 1-9 were additionally sampled for DO, TDS, conductivity, and salinity.

The mean TP measured at all 19 sites was 6.66 μg/L, while mean of the four sites closes to the potential GBS effluent discharge was only 1.7 μg/L (ultra-oligotrophic). Based on Chapra and Dobson's (1981) classification, 80% of the sites (16/19) we sampled would be considered **oligotrophic or ultra-oligotrophic**, with one in the mesotrophic range and two others in the eutrophic range. Site 5 was downstream of an agricultural tributary and measured 35 μg/L TP. **The current provincial water quality objective of 20 μg/L is almost six times higher than the baseline value of TP around the effluent discharge.** GBS has not offered information on the maximum limit of TP concentration in their effluent, and this is critical to assessing the potential environmental impacts of the facility. It is worth mentioning that all water samples except one were taken from the shoreline, so they are not truly representative of where the effluent will enter the Bay, which based on the information provided by GBS, would be 500 meters offshore (GBS, 2021). **Offshore areas usually have much lower phosphorus levels because they are further away from urban and agricultural inputs** (Chapra and Dolan, 2012).

DO, TDS, conductivity, and salinity are also important limnological parameters (Meher et al., 2015). To support fish and other aquatic life, DO concentrations should be > 4 mg/L. TDS, a measure of dissolved mineral, metal, organic/inorganic matter will increase with amount of pollutants; at high TDS levels, decreased water clarity may negatively affect foraging ability and growth rate of fish (Jones et al., 2020). Conductivity indicates the ability of water to conduct electricity and measures the level of dissolved salts and other inorganic chemicals in water; thus, higher conductivity might indicate pollution in the area (Chusov et al., 2014). Salinity measures the amount of salt in water and can directly affect growth and feeding rates of fish (Bœuf and Payan, 2001). All of the measured parameters were in the ideal range for operation of the facility (**Figure 3**), as they provide optimal conditions for the healthy growth and survival of Atlantic Salmon (Johansson et al., 2007).

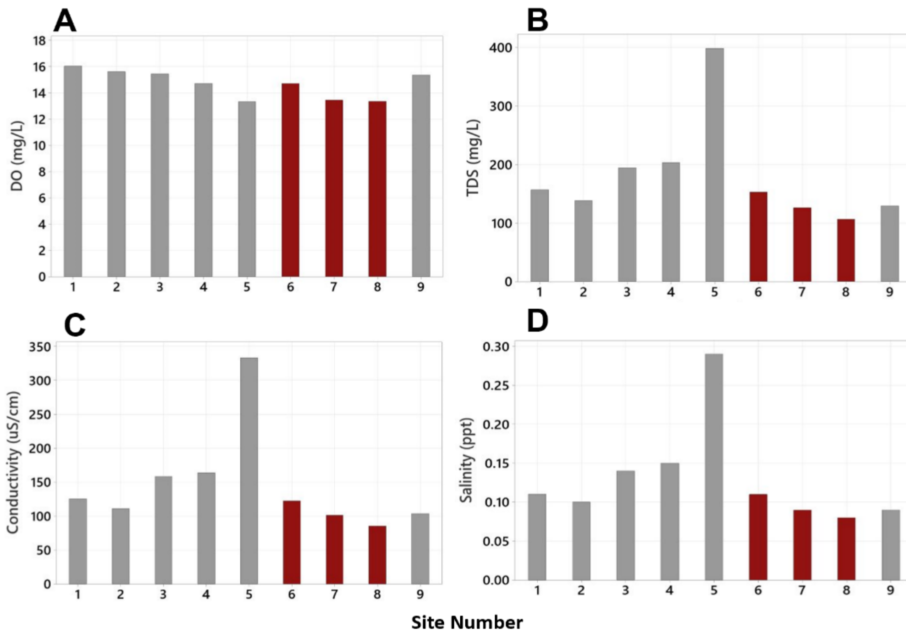

Figure 4. Bar plots of (A) dissolved oxygen (DO; mg/L), (B) total dissolved solids (TDS; mg/L), (C) conductivity (µs/cm), and (D) salinity (ppt) measurements from Sites 1 to 9 (see Figure 3). Sites nearest the proposed discharge location are highlighted in red.

2) *What Biosecurity Plan does GBS have to prevent spread of fish disease?*

Biosecurity is a vital part of any aquaculture facility; the protocols are designed to maintain fish health and reduce the risk of disease. Diseases can have serious impacts on the economic viability of a facility, as well as the local wild fish populations. In a confined aquaculture facility such as this RAS operation, there are closer interactions among fish and this facilitates the spread of diseases and parasites (Yanong et al., 2021). An outbreak of *infectious salmon anemia* (ISA) in Chile (2009-2010) cost $2 billion USD and reduced fish production from 386,000 to 8,000 metric tonnes (Mardones et al., 2014). Furthermore, biosecurity will also protect the wild fish in the area by preventing disease such as sea lice in net pens (Krkosek et al., 2007). RAS systems can amplify diseases because recirculated water that contains pathogens or parasites would be spread to every tank throughout the facility. This could lead to a large loss of fish, or a shutdown of the entire facility if disinfection is required (Hjeltnes, 2012). **This problem intensifies if the amplified disease is released into the natural environment through the effluent, where it could infect wild fish.**

GBS indicated that "the Atlantic Salmon egg are supplied from Iceland" https://www.gbsalmon.ca/faqs/. Prior to November 2021, the virus that causes ISA, which has no treatment and causes high mortality in farmed Atlantic salmon, was diagnosed for the first time in Icelandic waters (https://www.icelandreview.com/business/first-ever-cases-of-infectious-salmon-anaemia-in-iceland/). Then in June 2022, Ice Fish Farm in Iceland confirmed that two of his sites have been infected with ISA. (https://www.intrafish.com/salmon/icelandic-salmon-farmer-ice-fish-farm-confirms-isa-says-virus-hit-second-site-with-1-1-million-fish/2-1-1230385), **We need to know where GBS intends to source ISA-free Atlantic salmon eggs?**

Fungal infections are a common problem during the freshwater phase of salmon farming (Kuterra, 2015). Kuterra found no issues with any diseases or parasites due to their strict biosecurity protocols, except for the occasional issue with fungus (Davidson et al., 2016; Kuterra, 2015). The fungal infections were believed to be from monthly fish handling which disturbed their protective scales and mucus layers and increased their vulnerability to fungus (Davidson et al., 2016). Typically, fungal infections are controlled through the addition of salt, or formalin in some extreme cases (Kuterra, 2015). Kuterra found that the optimal level of salinity needed to reduce the risk of fungal infections is 10 ppt (Kuterra, 2015). **Will GBS implement a protocol to prevent and treat fungal infections and explain how these treatments may impact the effluent entering Colpoy's Bay**.

RAS such as Kuterra has the advantage of not relying on antibiotics to reduce the incidence of disease or parasite outbreaks (Kuterra, 2015). Other Canadian aquaculture facilities required over 14,000 kg of antibiotics in 2017, and Schar and colleagues (2020) projected that global usage of antibiotics in aquaculture will reach 13 million kg by 2030 (Government of Canada, 2017). **GBS has indicated the proposed facility will operate without the use of antibiotics or other antimicrobials or biocides** (GBS, 2021). Even if it is used, smaller amounts of antibiotic are required (Sha, et al., 2022). Usage of antibiotics has other unintended consequences in aquaculture, including contributing to proliferation of the global problem of antibiotic resistance genes. **Therefore, fish production by GBS would be a better option than conventional farming methods that rely on use of antibiotics**.

*3) **What is GBS' strategy for solid waste and dead fish management?***

RAS operations must have a robust system to manage solid wastes (uneaten feed, undigested substances (feces) and dead fish (Van Rijn, 2013). Otherwise, as wastes accumulate and break down, water quality in tanks would deteriorate and pose a threat to fish health (Van Rijn, 2013; Cripps & Bergheim, 2000). The amount and type of solid wastes produced depends on the type of feed that is used and could also contain contaminants if the food contains wild fish (Cole et al., 2009). GBS proposes to use AquaMaof's filtering system, which uses a series of settling tanks to collect large solids in slow moving water, which is suggested to save energy compared to other waste separation methods (AquaMaof, 2021; GBS, 2021). Settling tanks will collect heavier particles that sink to the bottom of a basin (Van Rijn, 2013), but will not remove the smaller particles and anything that is dissolved, which would require microscreens and filters. After the solids are separated from the water, they are collected and condensed into sludge (Bergheim & Cripps, 1993; Van Rijn, 2013), which is commonly stored onsite before they are transported to disposal sites (Sharrer, 2009). GBS proposes to use AquaMaof's proprietary Denitrification System as a method to help reduce sludge production (Norconsult, 2020; AquaMaof, 2021; GBS, 2021). GBS proposes to use the sludge as fertilizer but has not indicated the amount that will be produced, where they will be applied or how. If salt water is used to raise the salmon, the salt content of the sludge may not be suitable as agricultural fertilizer (Van Rijn, 2013). In that case, sludge would have to be disposed of at a landfill or a compost facility. The amount of sludge produced can be considerable. Nordic Aquafarms in Humbolt County, California, raises 25,000 Atlantic salmon and produces 8,000 to 12,000 tonnes of waste per year. This amounts to two to four trucks of sludge per day (Humbolt County, 2022). **On a proportional basis, GBS would produce 4,800 to 7,200 tonnes of waste annually, translating to 1 to 2 trucks per day**. **GBS must share their solid waste management strategy in terms of estimated salt content in their sludge, how it will be used, and how it will be disposed of.**

Dead fish is a form of solid waste, but they must be handled differently than fecal matter or uneaten feed because they may contain contaminants and must be treated as a biohazard (Van Rijn, 2013; DFO, 2018). They must be sent to compost facilities as outlined by the Ministry of Northern Development, Mines, Natural Resources, and Forestry (B. Burdick, personal communication). **How will GBS transport and dispose of dead fish from their facility? They should include in their assessment associated transportation/handling costs and greenhouse gas emissions**.

*4) **What is GBS' strategy for management of dissolved nutrients in their effluent?***

Effluent from the GBS facility will contain elevated nutrients and potentially other pollutants (e.g. contaminants from feed, antibiotics, salt) that would enter Colpoy's Bay. The effluent from GBS is proposed to exit into a 'mixing zone' approximately 500 m from the shore of Colpoy's Bay (GBS, 2021). A mixing zone is defined as an area of water adjacent to a point source of pollution, where the water quality does not meet one or more of the Ontario Provincial Water Quality Objectives; however, water-quality conditions within a mixing zone *cannot* result in environmental damage, risk to aquatic life or human health and cannot interfere with drinking water supply (Ontario Ministry of the Environment, 2021). When a new effluent discharge is proposed for a waterbody, enforceable requirements are derived on a case-by-case basis based on mixing zone sizes, volume of discharge, baseline water quality, and Provincial Water Quality Objectives.

GBS is proposing an effluent outflow of 1,100 L/min into Colpoy's Bay (GBS, 2021) while Kuterra averages around 900 L/min. *GBS is planning to produce 40 times the number of salmon per year compared to Kuterra, but only plans to release 1.2 times the amount of effluent* (GBS, 2021; Kuterra, 2015). GBS is also proposing to dilute their effluent with 20 parts of pristine input water to one part of their liquid waste discharge (GBS, 2021) whereas Nordic Aquafarms, a RAS facility in Maine with an average outflow of 24,000 L/min has an average dilution rate of 530:1. *This dilution rate is 26 times higher than that of GBS, even though the production capacity of Nordic Aquafarms is only two times larger* (City of Belfast, 2020; Maine Department of Environmental Protection, 2020). **Can GBS explain how they came up with the effluent outflow rate and dilution rate?**

Among the dissolved forms of nitrogen, ammonia is the primary nitrogenous waste product from aquatic animals and is also the most toxic form when absorbed. It can cause lethal effects such as elevated blood pH, enzyme system disruption, gill damage and reduced blood-oxygen carrying capacity (Boyd, 2015a; Park et al., 2018). It can be oxidized and transformed to nitrites and subsequently nitrates by nitrifying bacteria (e.g., *Nitrosomonas*). Nitrites, when absorbed by fish and other aquatic species, can bind to hemoglobin, forming methemoglobin, which can cause oxygen deficiency and lethal effects (Boyd, 2015a; Kocour Kroupová et al., 2018). **Therefore, it is important for GBS to effectively filter the various toxic forms of nitrogen from their discharge water to avoid impacting the aquatic species in Colpoy's Bay.**

RAS facilities can limit the amount of nutrients in their effluent by reducing the amount of nutrients used and by using various water treatment procedures such as biofiltration (Dauda et al., 2019). N removal efficiency in RAS has varied from 85% to 98% (Schneider et al., 2007; de Schryver & Verstraete, 2009), but P removal rate can range from 32% to 95% due to the limitations of removal techniques (Kujala et al., 2020). Although RAS can remove a large percentage of dissolved nutrients, at a stocking capacity of 15,000 tonnes/y, GBS will still release a large amount of phosphorus and nitrogen in their effluent (GBS, 2021). At a stocking capacity of only 400 tonnes/year, nitrate concentrations in the Kuterra outlet was 57 times higher than that in the inlet, while phosphorus concentrations were 34 times higher and ammonia was only 3 times higher (**Table 3**; Kuterra, 2015). Proportionately, we calculated that **GBS has the potential to increase nutrient loading into Colpoy's Bay by approximately 4,000 to 50,000 kg of P and 10,000 to 74,000 kg of N annually;** this nutrient loading is based on GBS' proposed stocking capacity, Atlantic Salmon nutrient excretion rates, and average dissolved nutrient removal efficiencies (Strain & Hargrave, 2005; Schneider et al., 2007; de Schryver & Verstraete, 2009; Dauda et al., 2019; Kujala et al., 2020). **By comparison, the Wiarton sewage plant's nutrient load into Colpoy's Bay in 2015 was only 112 kg of P and 2,556 kg of N (Ontario Clean Water Agency, 2016).**

Table 3. Water quality characteristics of the inlet and outlet from Kuterra (adapted from Kuterra, 2015)

Water quality parameter	Inlet Average	Outlet Average	Times increase in outlet over inlet values
Temp (C)	10.3	14.0	1.4
Ammonia (mg/L)	0.26	0.7	2.7
Nitrite (mg/L)	3.55	0.2	0.06
Nitrate (mg/L)	0.9	51.6	57.3
TP (mg/L)	0.04	1.35	33.8
Salinity (ppt)	4.0	3.0	0.75
Total Volume (L/min)	*Unknown*	821	

Since Kuterra is in close proximity to the Pacific Ocean, the salinity level of their intake water was about 4 ppt (**Table 3**), higher than typical freshwater sources which are less than 0.5 ppt (Kuterra, 2015). Kuterra further increases the salinity of their intake water to 10 ppt to optimize fish health and product quality. At the proposed GBS facility, the salinity of the intake water from Colpoy's Bay will be approximately **0.1 ppt** (**Figure 4**). The salinity level in Kuterra's effluent is around 3 ppt (Table 3), which is similar to their intake water level (Kuterra, 2015). Since Colpoy's Bay has a lower baseline salinity, effluent with a salinity level around 3 ppt would have a larger impact on Colpoy's Bay due to freshwater salinization. **If GBS is planning to stock the Atlantic Salmon in brackish water, the treatment of salinity in their effluent needs to be outlined.**

Socioeconomic Implications

*1) **Is the GBS project environmentally sustainable?***

RAS facilities require high energy consumption for continuous operation of lights and pumps, heating and cooling systems, oxygen generation, feeding systems, ultraviolet units, backup generators, waste disposal, transportation and desalinization processes (Badiola et al., 2018; Bergman et al., 2020; Nistad, 2020; Wambua et al., 2021). GBS expects to use 2-2.5 kwh/kg salmon (GBS, 2021) compared to Kuterra's 5.8 kwh/kg salmon (Kuterra, 2015; **Table 4**). To make the two facilities directly comparable, production of produce 15,000 tonnes of Atlantic salmon per year at the GBS facility would require only 30 – 37.5 million kwh whereas producing it at the Kuterra facility would require almost 3 times more energy (87 million kwh of energy). At an estimated rate of 26 g of CO_2/kwh (IESO, 2021), Kuterra would produce 2,262 tonnes of greenhouse gases whereas GBS would only produce 780 – 975 tonnes of greenhouse gases per year. Kuterra has been very transparent about details of their operation have proven that their estimates are reliable. **Given that GBS is estimating almost one-third lower energy requirements than Kuterra, it is incumbent on them to show how they came up with their energy budget, including their transportation requirements, which can increase greenhouse gas emission, noise, habitat fragmentation and other disturbances within the community** (Litman, 2013).

Table 4. Estimated energy use of the Kuterra RAS facility compared to the proposed GBS facility

Category	Kuterra	GBS (Proposed)
Production volume	400 tonnes	15, 000 tonnes
Energy use per kg	5.8 kwh/kg	2 – 2.5 kwh/kg
Energy use for 15 000 tonnes	87 million kwh	30 - 37.5 million kwh
GHG Emissions for 15 000 tonnes production	2,262 tonnes GHG	780 – 975 tonnes GHG
Transportation emissions	*Unknown*	*Unknown*

*2) **Is the GBS project economically viable?***

Land-based RAS facilities have high preliminary capital costs which are typically 4-5 times greater than traditional aquaculture methods (Fisheries and Oceans Canada, 2011). For example, Kuterra has faced many financial challenges despite several years of successful Atlantic Salmon production and a high demand for their product (Kuterra, 2015). Kuterra did not reach a steady state of operations until four years after initial operations, and the company is still not highly profitable (Mayer & Gonzalez, 2017). To improve profitability for future RAS facilities, Kuterra has provided several recommendations which they estimate will reduce startup costs for other companies by up to 40% (Kuterra 2015; Hobson, 2016).

1. Kuterra recommends a minimum production rate of 1,500 to 3,000 tonnes per year to benefit from the economies of scale. It started as a small, pilot scale facility with only 400 tonnes of production, which limited their profitability.
2. Kuterra recommends that new facilities have an on-site hatchery to ensure an adequate supply of smolts. Kuterra imported smolts rather than producing their own on site and faced many challenges with the timing and quality of smolts.
3. Kuterra recommends that fish be kept at a salinity level of approximately 10 ppt to ensure optimal fish health and to reduce profit losses. At lower levels of salinity Kuterra faced issues with profit losses due to fish mortality, slow growth rates, and early maturation (which impacts the color of the final product, making it more difficult to sell).

GBS' proposal satisfies the first 2 recommendations, but they do not explain what level of salinity will be used.

3) What type of contaminants and nutrients are in GBS salmon and their feed?

Fish naturally provide a rich source of nutrients, including minerals like selenium, iodine, and magnesium, vitamins like A, B_{12}, and D, and are most notably a primary source of omega-3 fatty acids, specifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Fish can also accumulate harmful contaminants in their tissue. A broad class of contaminants commonly found in fish are persistent organic pollutants (POPs), which include contaminants like methylmercury (the organic and more toxic form of mercury), polychlorinated biphenyls (PCBs) and organic pesticides (e.g., DDT). Since contaminants can counteract the positive health effects of fish consumption, both the risks and benefits of fish consumption should be considered in product quality analyses. As both wild and farmed fish obtain their contaminants and nutrients primarily from their diet, aquaculture companies should carefully select their feed.

Three primary fish feed ingredients used are: 1) Fishmeal and oil, which consist of small pelagic fish harvested from the ocean, or from other fish processing by-products 2) Plant meal and oil, which are extracted from agricultural products (e.g., flaxseed or canola oil) and; 3) Single-celled ingredients (SCIs), which are lab-grown microalgae, bacteria, or fungi. Each feed has tradeoffs in terms of its nutrient and contaminant concentrations, sustainability, and cost, which are outlined in **Table 5**. In summary, fishmeal and oils provide a good source of beneficial omega-3 fatty acids; however, they can contain high levels of POPs and are a finite resource. Plant meal and oils have lower levels of POPs and tend to be cheaper than fishmeal; however, they are lower in omega-3 fatty acids and produce fish with higher omega-6:omega-3 ratios, which can have negative health effects on humans. Lastly, SCIs can significantly reduce the number of POPs in fish, as they are grown in a controlled environment while providing a good source of omega-3 fatty acids. The tradeoff is that they are expensive compared to other feed ingredients and the production of omega-3 fatty acids needs to be optimized (Glencross et al., 2020; Sprague et al., 2015). It is important to mention that these different feed ingredients are often combined, which can be beneficial in balancing their benefits and risks (e.g., Friesen et al., 2008; Kousoulaki et al., 2016).

The product quality of GBS's farmed salmon can also be compared to the fish available for consumption in the Georgian Bay area. Firstly, the contaminants and nutrients reported in the literature for farmed salmon can be used to predict content of the salmon produced by GBS. Some studies have found that farmed salmon have higher concentrations of POPs compared to wild salmon; however, this comparison will depend on the type of feed used and the location of the wild-caught salmon (Dewailly et al., 2007; Hamilton et al., 2005; Hites et al., 2004; Ikonomou et al. 2007; Shaw et al., 2006). Farmed salmon tend to have higher total lipids and omega-6:omega-3 ratios than wild salmon (Friesen et al., 2008; Hamilton et al., 2005; Lundebye et al., 2017; Ikonomou et al. 2007), which is likely due to increased use of plant oils in feed. Nevertheless, numerous studies show that farmed salmon still provide a rich source of omega-3 fatty acids (Davidson et al., 2016; Dewailly et al., 2007; Friesen et al., 2008; Jensen et al., 2020; Sprague et al., 2020).

Table 5. Comparison of nutrients, contaminants, sustainability, and cost of three fish feed ingredients commonly used in aquaculture.

	Type of Fish Feed		
	Fishmeal and Oil	**Plant Meal and Oils**	**Single-Cell Ingredients**
Source ingredients	Extracted from wild pelagic fish or from fish processing by-products	Extracted from agricultural crops (e.g. canola and flaxseed oil)	Lab grown microalgae, bacteria or fungi
Nutrients	High in omega-3 fatty acids (Friesen et al., 2008; Hites et al., 2004)	Higher in omega-6 fatty acids (produces fish with higher omega-6:omega-3 ratios) (Friesen et al., 2008; Hamilton et al., 2005; Ikonomou et al., 2007; Lundebye et al., 2017). Tendency to need higher supplementation of vitamins and minerals (Vera et al., 2020)	Certain species can provide a rich source of omega-3 fatty acids (Glencross et al., 2020; Kousoulaki et al., 2016; Sprague et al., 2015) EPA concentrations need to be optimized in certain species (Sprague et al., 2015)
Contaminants	Generally higher levels of POPs (Friesen et al., 2008; Hites et al., 2004)	Generally lower levels of POPs (Berntssen et al., 2010; Friesen et al., 2008)	Can significantly reduce levels of POPs (Glencross et al., 2020; Kousoulaki et al., 2016; Sprague et al., 2015)
Sustainability	Wild-harvested fish are a finite resource subject to environmental impacts Reduces availability of pelagic fish for community consumption, increases food insecurity (Hasan and Halwart et al., 2009) Reduces waste when using fish processing by-products	Increased water, land and fertilizer demand compared to fishmeal and oils (Malcorps et al., 2019) Increases competition for land, which is under pressure to meet demands for food, feed, biofuels, and biobased materials (Malcorps et al., 2019)	Life-cycle analysis shows higher greenhouse gas emissions compared to plant oils (Bonatsos et al., 2020) Can use atmospheric CO_2 as fuel (Government of Canada, 2021)
Relative Cost	Relatively expensive, dependent on source (Hasan and Halwart, 2009)	Relatively cheap, but rising prices due to competition for land space (Cole et al., 2009)	Tends to be the most expensive compared to the two other feeds (Glencross et al., 2020)

Where fish in Georgian Bay is concerned, the most detailed information is provided for Lake Trout and Lake Whitefish, which appear to be important species to local fishers (Buell, 2021; Johnston-Weiser, 2016). Lake Trout can have relatively high levels of contaminants, mainly PCBs, which has led to stricter consumption advisories set out by the Ontario government, especially for larger fish (Government of Ontario, 2021; Strandberg et al., 2020). Nevertheless, in Lake Huron, Strandberg et al. (2020) showed that the recommended daily intake of EPA and DHA can be obtained by eating these species while still following consumption advisories. Since this research has focused on the consumption of fish filets, there is no information regarding contaminants and nutrients in other fish organs in the Georgian Bay area. Other fish organs are sometimes consumed by Indigenous communities and contaminant and nutrient levels vary by organ (Wei et al., 2014).

In summary, fish feed will dictate the contaminants and nutrients in farmed fish, but each type of feed has tradeoffs. Wild fish from Georgian Bay and Lake Huron are important to the Saugeen-Ojibway Nation and other local fishers and these fish are shown to provide a good source of nutrients while contaminants can be limited by following Ontario's consumption advisories. **Farmed salmon produced by GBS will be sold as market fish and therefore, GBS must ensure the fish are below governmental guidelines for contaminants in market fish, while still providing a good source of nutrients to the consumer**. Although GBS has indicated on their website that there are benefits of using fishmeal and oils (GBS, 2021), **they should fully disclose the type of fish feed they plan to use and estimate the potential load of POPs in fish tissue.** The National Research Council of Canada is collaborating with a SCI company (DeNova) to develop more sustainable feeds (Government of Canada, 2021). As SCIs are a promising healthy and sustainable feed ingredient, it may be worthwhile for GBS to explore potential government subsidies for the use of DeNova's SCIs.

3) What is the potential impact of the GBS operation on the Saugeen Ojibway Nation (SON)?

The SON consists of the Saugeen and Nawash bands that share the Ojibway culture and have inhabited the peninsula long before European settlement (Plain, 2018). Currently, the SON includes the Saugeen reserve (approx. 720 residents) on the west end of the peninsula, Nawash reserve (approx. 720 residents) on the eastern end of the peninsula, and less than 2000 individuals that reside off-reserve (Figure 5; Indigenous and Northern Affairs Canada, 2016). Notably, the Nawash reserve is located near the outlet of Colpoy's Bay, in close proximity to the proposed site of the RAS facility. The SON Environment Office is involved in this project because GBS is required to consult the Nation due to their request to withdraw water from Georgian Bay. The RAS facility can potentially impact the SON, as the community has unique Aboriginal and Treaty rights to fishing, as well as a strong tie to the land, waters, and fish through their culture and values. **As of April 2022, GBS has not communicated any potential opportunities for shared benefits with the SON.**

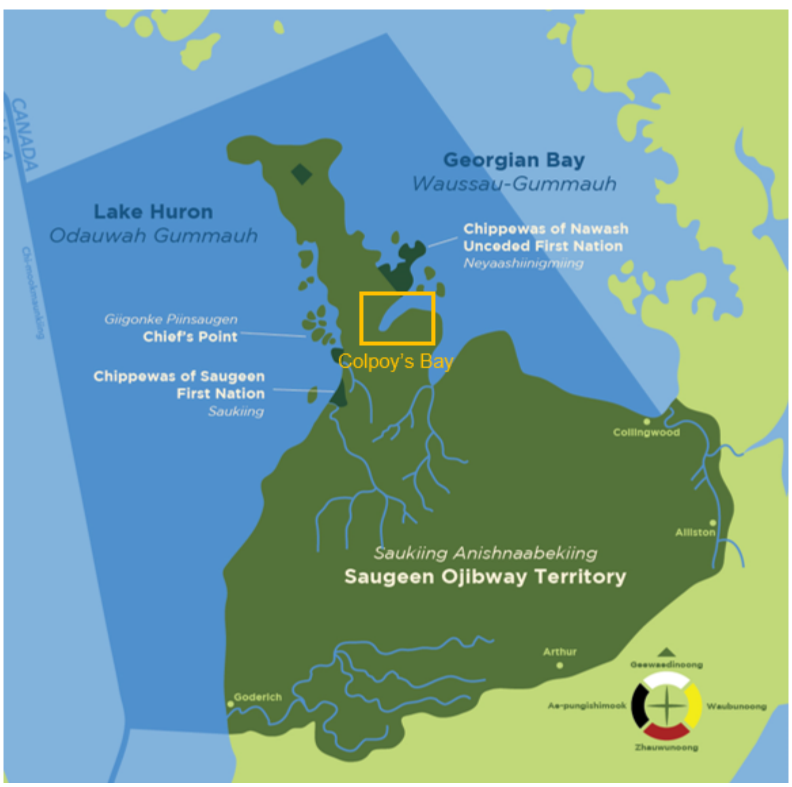

Figure A2. The Saugeen Ojibway Territory, including the Chippewas of Saugeen First Nation reserve and Chippewas of Nawash Unceded First Nation reserve, and Colpoy's Bay. Adapted from Saugeen Ojibway Nation Environment Office, 2022

Fish are important for culture, livelihood, and sustenance amongst the SON. Fish is a traditional food for the SON and Indigenous food sovereignty fosters a connection to the earth and culture (Lowitt, 2019). The SON holds the largest Indigenous commercial fishing quota of the Canadian Great Lakes, which employs 30-40 harvesters that target lake whitefish and lake trout. These jobs are significant to the community, which has a lower per-capita income and higher unemployment compared to the average rates in Ontario (Indigenous and Northern Affairs Canada, 2016). The SON community members also fish for subsistence, as per their rights. Furthermore, the SON is represented by a Joint Council that co-manages the local fisheries with the government of Ontario and integrates their Traditional Ecological Knowledge. The SON Joint Council is committed to promoting the long-term viability of local fish stocks by monitoring, reporting, and setting catch limits for commercial fisheries (Saugeen Ojibway Nation Fishing, 2022). **GBS must consider the rights of the SON as the project moves forward. While meaningful discussions have not been made yet, there are still opportunities to collaborate and explore mutual benefits.** Both GBS and SON have a shared interest in producing and processing fish, and the Kuterra case study shows that the RAS facility has the potential to produce fish sustainably while engaging the local First Nations community.

4) How will the GBS operation influence the residents in Wiarton and vicinity?

This section will discuss the main concerns of local residents that can be summarized into five categories: increase in number and type of jobs, deterioration in water quality, traffic disruption/increase, inconsistency with local cultural values, and lack of overall transparency from GBS.

Increase in number and type of jobs

GBS has indicated that the project will create approximately 200 jobs, which will be both directly and indirectly associated with their aquacultural operations (GBS, 2021). The increase in jobs can be a potential benefit and contribute to the steady increase in employment rates within the community (Statistics Canada, 2001-2016). Indirect jobs, such as those in sales and management, are likely to be in demand, as the three major occupations in the region are in sales and service, business and finance, and management (Statistics Canada, 2016). Based on the Kuterra experience, the proposed RAS facility should have a relatively low number of direct jobs; there were only 4 jobs per 400 tonnes of salmon. On a proportionate basis, 15 jobs may be expected for a facility producing 15,000 tonnes. **What kind of new jobs will be created because of the proposed facility and will these be sustainable or attract a growing population? Will these jobs benefit the SON or local residents?** This is an important consideration as the SON unemployment rate is 12.5 % in Nawash and 17.2 % in Saugeen, which is considerably higher than the Ontario average unemployment rate of 8.3 %, and the community has cultural ties and Aboriginal rights to fish and fishing (Indigenous and Northern Affairs Canada 2016; Lowitt et al., 2018).

Deterioration in water quality

Georgian Bay and Colpoy's Bay are well known for their pristine water source that are used by more than 4,000 people for both essential (e.g., drinking water, bathing) and recreational (e.g. boating, swimming, fishing) activities. Deterioration in water quality of Colpoy's Bay as a result of the GBS operation could affect these activities and is therefore of major concern to local residents and cottagers. There are two main components of the proposed facility that are of particular concern to the community. Firstly, the **facility and discharge pipe appear to be located on or near wetlands and highly vulnerable aquifers** (Drinking Water Source Protection, 2011). There is one provincially significant wetland located approximately 65 meters north-west of the RAS facility (OMNRF, 2021). Secondly, **the discharge pipe is close to the Intake Protection Zone of the Wiarton Water Treatment Plant** (GBS, 2021), which is shown in **Figure 1**. **Ultimately these concerns are exacerbated by the uncertainty of the effluent quality that will be released from the facility into Colpoy's Bay**.

Traffic disruption/increase

There are only two main roads that can be used to access the proposed facility. There will be increased traffic during the construction phase as well as after the facility becomes operational. We do not know where the salmon will be processed and where the waste products will be managed. **How many trucks and when will they be operating on a daily basis? How might this disrupt traffic through the region during peak periods, especially during the summer when tourists are visiting the area?** More information regarding transportation is needed from GBS to fully evaluate the transportation logistics and concerns

Inconsistency with local cultural values

The Bruce Peninsula is an environmentally focused community with strong Indigenous ties to the SON. The community values the pristine waters of Colpoy's Bay, a healthy fishery and diverse wildlife populations. Any negative effects of the aquacultural facility on the surrounding environment, including fish and wildlife, would threaten the lifestyle and sensibility of the community. For example, one of the main concerns is whether there will be any lights, noises or smells coming from the facility. **The Bruce Peninsula is a dark sky preserve (Explore the Bruce, n.d.), and lights from the facility will cause light pollution. Noises and smells from the proposed facility may alter bird and wildlife behaviour.** Additionally, fish may become entrapped in the water intake pipe and may be harmed.

Lack of overall transparency by GBS

There has been a lack of transparency regarding the key components of the GBS operations that has strained the relationship between GBS and a large portion of the community. This resistance has been vocalized by the Bruce Peninsula Water Watch, who has launched a website entitled “smellsfishy.org” that details why they oppose the proposed project. **GBS needs to be forthcoming with details on how the facility will be operated, and allow all studies involving water-quality modeling to be peer reviewed by independent researchers.**

Conclusion

As the global population continues to grow, the world needs to consider novel ways to produce food. The RAS system proposed by GBS has the potential to minimize the environmental impacts of operating aquaculture facilities as the closed system can avoid many of the issues associated with more traditional, aquatic-based facilities. Nevertheless, the facility can still have negative impacts on the local community and environment, and these must be factored into the equation. There is a lack of transparency about how the technology specific to this facility will operate, maintain the pristine conditions found in Colpoy’s Bay, and fit in with the ideals and values of the local community. These concerns are also magnified by the novel approach of using saline water within the facility while drawing and returning water to Colpoy’s Bay, a body of freshwater. This report has identified relevant concerns and questions to fill information gaps that would be useful in assessing the costs and benefits of the proposed RAS facility.

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Appendix: Checklist of knowledge gaps on ecological and socioeconomic information

Ecological Information Checklist	
Biosecurity	◻ Plans for antibiotic administration ◻ Egg and feed source ◻ Control of bacteria and viruses Plans for potential usage of biocides, antibiotics
Solid waste	
- *Sludge treatment/thickening*	◻ Methods & protocol for sludge treatment & storage?
- *Sludge disposal & recycling*	◻ Use as fertilizer & methods for testing salinity & contaminants ◻ Plan for sludge transportation & disposal, costs & GHG emissions ◻ Sustainability assessment of waste management at current proposed scale
- *Disposal of dead fish*	◻ Protocol for transportation & disposal of dead fish ◻ Viability of transportation to nearest facility & GHG emissions
Liquid waste	◻ Size and location of mixing zone ◻ Enforceable effluent water quality parameters ◻ Salinity removal plans ◻ Mixing zone model needs to be peer reviewed and open to the public
Socioeconomic Information Checklist	
Product Quality	◻ What feed will GBS use to limit contaminants and optimize nutrients in their fillet?
Water Quality	◻ Will the water quality in Colpoy's Bay be reduced?
Energy	◻ How GBS plans to minimize energy use ◻ Government subsidy availability to lower energy costs
Saugeen-Ojibway Nation	◻ Respect the rights and interests of the SON ◻ Will GBS facilitate discussions on potential mutual benefits?
Community	
- *Cultural Values*	◻ Smells, noises, and lights from facility? ◻ Potential entrapment of aquatic species within intake pipe? ◻ Detraction of tourist to area due to artificial facility?
- *Jobs*	◻ Out of the 200 jobs, how many of those will be indirectly and/or directly to the aquaculture facility? ◻ Will the indirect and direct jobs be able to sustain/attract a growing population? ◻ Will any jobs be directly for the Saugeen-Ojibway?
- *Traffic*	◻ Location and distance to processing facility

Web App: https://arcg.is/0O1aXS

Story Map: https://arcg.is/054ia81