LAND-BASED AQUACULTURE

Information sharing for developers of recirculating aquaculture systems (RAS)

Development costs of two operating facilities employing RAS

March 2013

KUTERRA, LP



TASTE OF BC



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As world demand for fish increases, market opportunities abound for growers of high quality product with the added social capital provided by environmentally benign land-based production.

'Namgis First Nation (Kuterra LP) and Taste of B.C are two Canadian producers currently demonstrating the technical, biological and economic feasibility of recirculating aquaculture systems (RAS). They offer this cost overview of their newly constructed land-based facilities with the intention of providing useful information to anyone considering development of similar facilities.

Taste of B.C. is a 100 metric tonnes/year "family farm" producing "Steelhead Salmon" (rainbow trout). The 'Namgis FN Atlantic salmon operation is larger: 470 metric tonnes/year facility that intends longer term commercial scale up. Despite the unique aspects of each, the cost structure and identified efficiencies should be applicable to the development of any commercial RAS facility.

In addition to presenting a summary of costs, the report includes potential opportunities for cost reduction that were identified by the operators, builders, engineers, etc. These are simply high-level ideas for consideration and were not fully evaluated as part of this project.

Listed costs are based on expense records, and the assessment assumes that each facility was designed and constructed following best practices and according to local building codes, safety standards and environmental regulations. Unique requirements and standards are flagged.

The costs and other information supplied in this report were based on the status of the 'Namgis project as of May 2013 and the Taste of BC facility as of November 2013. As with all RAS facilities, capital investments and modifications are ongoing. However, the following presents essentially the start-up costs for both facilities.

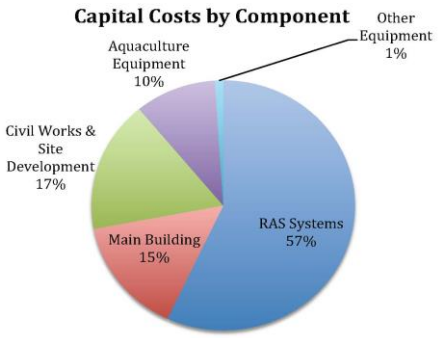
The facilities: basic characteristics

	'Namgis RAS	Taste of B.C. RAS
Location	Port McNeill, B.C.	Nanaimo, B.C.
	43 rural acres 'Namgis First Nation Reserve lands	4 acres near city, privately owned by Taste of BC
Species	Atlantic salmon. Sold under Kuterra brand	Steelhead salmon (Rainbow trout)
Optimal/current production	470 metric tonnes of market size fish/year	100 metric tonnes/year
Long-term goal	Plan to expand capacity to commercial scale (>1000 mt/year)	No current expansion plans
Smolt	Outside purchase. Quarantine used. 3 inputs/year	Outside purchase, certified disease free. No quarantine necessary. 6.5 inputs/year
Feed	1418 kg feed/day	315 kg feed/day
Key components	5, 500 m^3 fiberglass tanks 2, 250 m^3 fiberglass tanks	15 fiberglass tanks, ranging in size from 5 m^3 to 96 m^3
	2 independent RAS systems and purge	Single RAS system and purge
	VSA oxygen generator with LOX back-up	VSA oxygen generator with LOX back-up
	Fluidized sand biofilter	Fluidized sand biofilter
	Groundwater supply (drill wells)	Groundwater supply (artesian wells)
	Low head oxygenators (LHO)	Low head oxygenators (LHO)
	2956 m^2 steel building	1164 m^2 fabric on steel bldg.

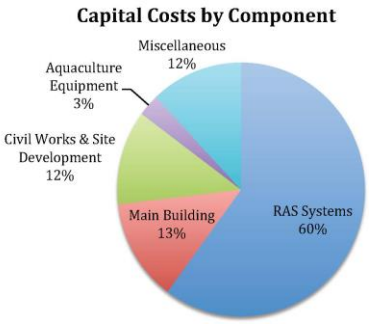
Quick summary of total development costs

	'Namgis RAS			Taste of BC		
	$000		$/kg production	$000		$/kg production
RAS systems	5,068	57%	10.8	913	60%	9.1
Civil works & site prep	1,542	17%	3.3	186	12%	1.9
Main building	1,290	15%	2.7	193	13%	1.9
Aquaculture equipment	864	10%	1.8	42	3%	0.4
Other equipment	79	1%	0.2	187	12%	1.9
TOTAL DEVELOPMENT	8,843	100%	18.8	1,521	100%	15.2
Other: front-end engineering, planning permits	537	65%		None*		
Pre-production operating expenses	295	45%		None*		
TOTAL OTHER	832	100%				

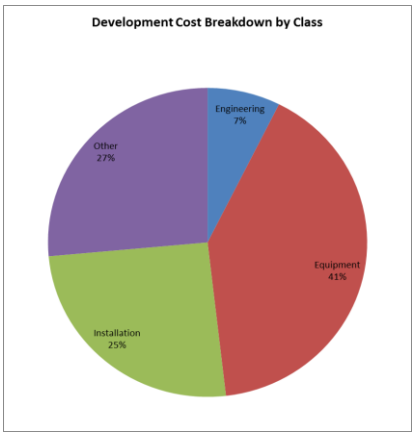
- Upfront planning efforts by owner were not tracked or valued. Minimal up-front permit requirements on private lands (not on a flood plain).



'Namgis FN RAS



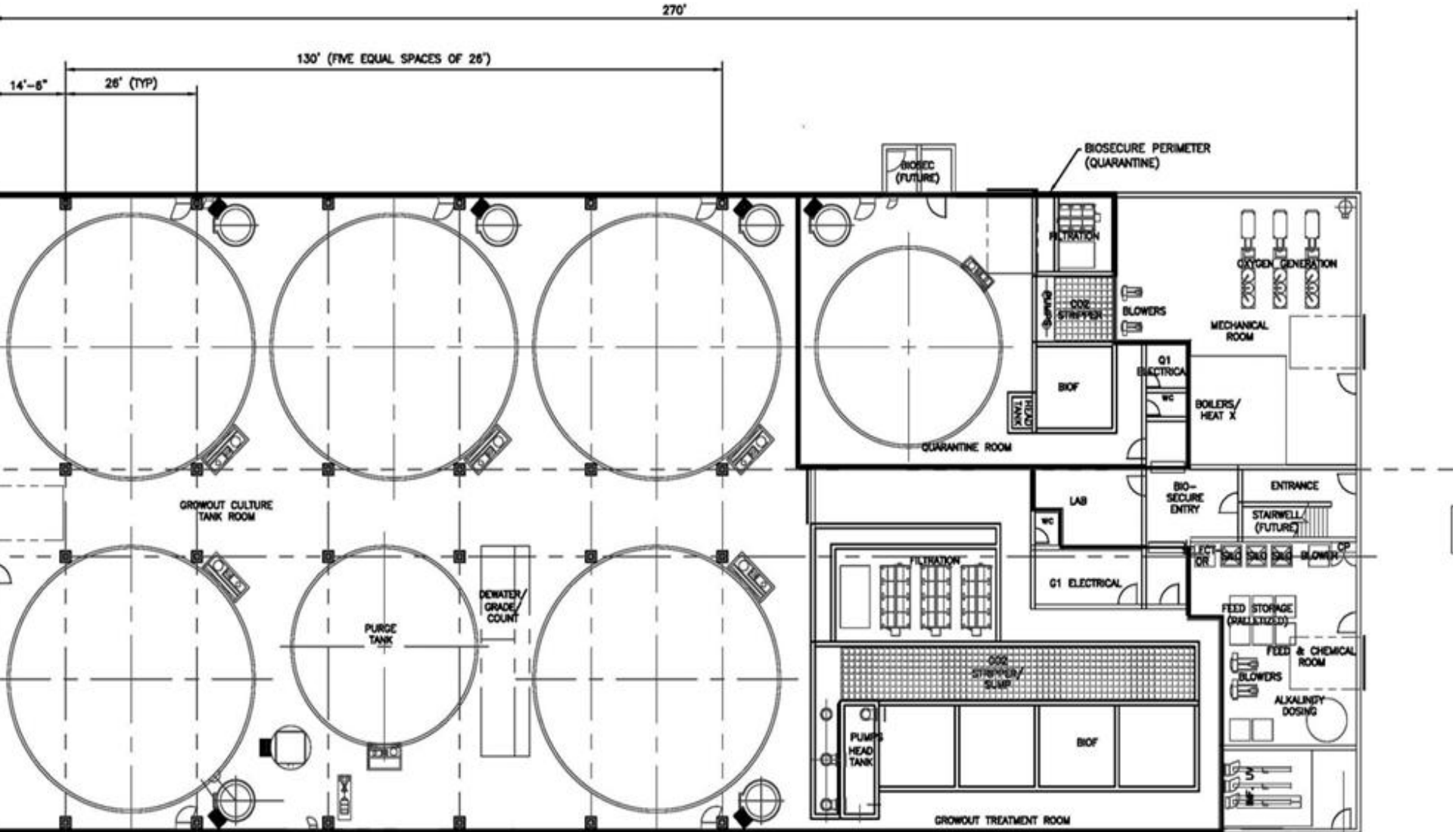
Taste of BC RAS



(No chart available for Taste of BC)

‘Namgis facility

Overview of systems and components



270'
130' (FIVE EQUAL SPACES OF 26')
14'-6"
26' (TYP)
BIOSECURE PERIMETER (QUARANTINE)
BIOSEC (FUTURE)
FILTRATION
OXYGEN GENERATION
CO2 STRIPPER
BLOWERS
MECHANICAL ROOM
Q1 ELECTRICAL
BIOF
WC
BOILERS/ HEAT X
HEAD TANK
QUARANTINE ROOM
GROWOUT CULTURE TANK ROOM
LAB
BIO-SECURE ENTRY
ENTRANCE
STAIRWELL (FUTURE)
ELECTOR
BLOWER
CP
FILTRATION
G1 ELECTRICAL
DEWATER/ GRADE/ COUNT
PURGE TANK
FEED STORAGE (PALLETIZED)
FEED & CHEMICAL ROOM
CO2 STRIPPER/ SUMP
BLOWERS
ALKALINITY DOSING
PUMPS HEAD TANK
BIOF
GROWOUT TREATMENT ROOM

Production, purge and quarantine systems are housed in a 2956 m^2 (31,823 sq. ft.) steel **building** with concrete foundation and floors.

The **main production system** consists of five, 500m^3 fiberglass culture tanks serviced by an RAS treatment system which includes tank-side Low Head Oxygenators (LHOs) plus a centralized water treatment system comprising rotary drum filters, a CO_2 stripper, fluidized sand bed biofilter, pump sump, and header tank. The main recirculating flow pumps (axial flow type) supply a total flow of about 20,000 gal./min. (90 m^3/min.) while maintaining the water level in the header tank, which supplies water by gravity to the LHOs and biofilters. Flow exiting the LHOs enters the adjoining culture tank and flow exiting the biofilters enters the CO_2 stripping unit.

Culture tank volumes are exchanged approximately every 45 minutes. Supplemental oxygen is generated on site and is supplied to the LHOs (and emergency tank sparging system) based on individual tank oxygen levels. Alkalinity is maintained by an automatic sodium hydroxide dosing system based on water PH.

A **controls** system monitors and regulates pump speed, drum filter backwash cycles, oxygen delivery, and sodium hydroxide dosing (for alkalinity control) based on pre-set and monitored conditions. An ozone system has recently been added to facilitate removal of fine suspended and dissolved solids.

Smolts are purchased from outside sources., so a smaller separate **quarantine facility** (one 250 m^3 tank with independent RAS system) was constructed as a biosecurity measure. This ensures that new fish are disease free before moving them in with the rest of the population. The Quarantine RAS system is essentially a duplicate of the main system at a smaller scale and so serves as an interesting cost comparison.

A pre-harvest off-flavour **purge facility** consists of a 250m^3 tank serviced by a partial reuse facility, including a recirculating pump, sump header tank, LHO and CO_2 stripper. Water exchange rates are variable depending on purge needs. Recirculating flow is about 1500 gal/min. (5700 liters/min.). Purge discharge water feeds the main production system. Controls are similar to the main system but without the alkalinity controls.

Water is supplied from groundwater wells and disinfected with UV dosage of 60mj/cm^2 (designed for 2x maximum flow).

Effluent: Filter solid wastes (drum filter backwash) flow into gravity thickening tanks. These were designed to produce 10% thickened solids (sludge). The sludge that collects at the base of these tanks is regularly pumped to a main storage tank, which is emptied as required (pumped) to a transport truck. The supernatant from the settlement tanks and main effluent from the facility flows by gravity into a chlorination tank, then a de-chlorination tank, then into one of two infiltration basins, and then to ground. Only one basin is used at a time, so regular fallowing can maintain sediment permeability.

Geothermal wells provide heat sources and sinks for two heat pumps and heat exchangers. The heat pumps move heat to and from the geothermal wells, culture tanks (tank base heating/cooling coils) and air heating/cooling units. Building ventilation is also used to control air heat retention, humidity/condensation and CO_2 levels.

A single **backup generator** with automatic switching provides emergency power.

Significant factors affecting development costs of 'Namgis facility, and related opportunities for cost savings

Objective to achieve best fish performance:

- Conservative water quality criteria were incorporated which increased facility cost, including limits on dissolved oxygen, carbon dioxide, total ammonia nitrogen, and nitrite nitrogen. UV disinfection system was designed to provide considerable redundancy to ensure stocks were protected.
- HVAC system and insulation were installed to control temperatures.
- Biosecurity: Smolts are being purchased from outside sources. Therefore, as a biosecurity measure a separate quarantine facility (an independent RAS system) was constructed to hold newly introduced fish, ensuring that new smolts are disease free before moving them in with the rest of the population.

Objective to serve as a model and information source for other RAS developments:

- The facility is equipped with additional research-related monitoring equipment for many types of system performance metrics, including real time power use on key components. The monitoring and control system is designed to maximize data capture and storage.

Objective to meet 'Namgis sustainability goals:

- The facility has several unique features designed to address environmental questions and concerns, including groundwater monitoring wells (for monitoring effluent impacts on groundwater quality) and effluent disinfection. These are in addition to the "normal" biosolids removal and effluent ground discharge systems, and partially determined by the facility's proximity to a salmon-bearing stream.
- In order to generate a positive cash flow, the facility had to be capable of providing a consistent supply of fish to the markets.

Relatively remote location:

- Cost efficiencies in purchase, maintenance and transport of materials and equipment and considerable savings in terms of living out allowances for workers, competitive pricing, direct labour costs etc. could be achieved in a site closer to larger supply and service centers.

Objective to expand to commercial scale eventually:

- The project is smaller than what could be considered "commercial scale", which is generally thought to be greater than 1000mt/year. Increasing production scale in the near future will reduce unit capital (particularly for concrete) and operating costs, as

well as risk (redundancies are more affordable). Original designs made specific provision for this by creating a robust system that could be modified or expanded easily using proven industrial grade components, components that could be sourced and maintained locally, and designs that offered maximum flexibility.

Land ownership:

- The site is on 'Namgis First Nation Reserve Land

Opportunities for construction cost savings based on this project:

- Minimize overlaps between funding, design and construction to ensure effective tendering processes and to minimize higher costs resulting from interruptions during construction, e.g.,
    - Disruption of project task sequencing caused by a delay in heating system funding meant the concrete floor and then LHOs had to be installed after the roof was in place, and some roof girders had to be replaced to provide access.
    - Seasonally related cost increases resulted when some summertime activities had to be shifted to fall and winter.
    - Stop-starts incurred additional remobilization and travel costs.

- Ensure that engineering assumptions are appropriate for the project. Standard engineering design assumptions are not necessarily appropriate for RAS systems. For example, a re-examination of the standard assumptions for the design of concrete tank structures resulted in a considerable change in wall thickness (and rebar requirements) on many elements with considerable savings.

- Develop engineering design standards (best design practices) specifically for land-based aquaculture facilities. Consider, for example, aquaculture-appropriate risk vs. cost and longevity vs. technological depreciation. Similarly, choice of appropriate materials and components should take into account all costs, longevity and risk, as well as Return On Investment (ROI). For example, when sizing plumbing, consider capital and operating costs as well as hydraulic needs.

- Structural designs/ engineering should integrate as many elements of the facility as possible to reduce costs. For example, concrete tank bases, treatment systems and building foundations could be integrated into one design so that loads can be shared, overall structure complexity reduced and sizing of elements (concrete costs) reduced.

- Fabric over steel building structures can be considerably less expensive than pre-engineered steel buildings if optimal width and minimum scale thresholds for these types of buildings are observed during facility design.

- Increase use of modular designs and components that are refined and cost efficient to build, and reduce engineering cost by amortizing fixed designs over multiple projects.

- Incorporate consideration of the most cost-efficient construction methods in all new designs, e.g. use of precast concrete components or stay-in-place forming.

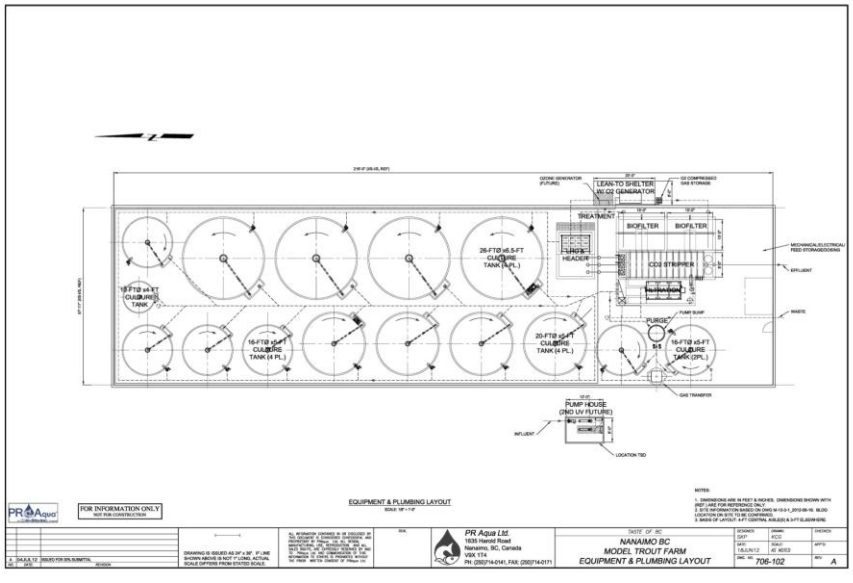
- Increase scale: use larger (>1000m^3) and deeper tanks as an avenue to reduced capital cost, reduced operating costs and potentially improved fish performance. Extend this to the design and construction of other components.

- New designs should incorporate consideration of the most cost efficient construction methods (e.g., use of precast concrete components or stay in place forming).

The HVAC system, quarantine tank, and automation contributed to higher electrical costs compared with the Taste of BC's facilities, which did not include these.

Taste of BC

Overview of systems and components



All systems are housed in a fabric on steel frame **building** roughly 1164 m^2 (12,528 sq. ft.). Flooring is primarily gravel with one section of concrete next to the purge facility.

The **main production system** consists of 13 fiberglass tanks ranging from 8m^3 to 96m^3 serviced by a centralized water treatment system that includes a fluidized sand bed biofilter, Low Head Oxygenator (LHO), rotary drum filters, CO_2 stripper, pump sump, and header tank. Three recirculating axial flow pumps supply a total flow of 6845 usgpm (26m^3/min) to the header tank. The header tank supplies water by gravity to the adjacent LHO, biofilter and CO_2 stripper; flow exiting the LHO enters culture tanks and flow exiting the biofilter enters the CO_2 stripping unit.

Culture tank volumes are exchanged approximately once every 20 to 60 minutes depending on biomass. Supplemental oxygen is provided from an oxygen generator and/or liquid oxygen (LOX) storage tank to the LHOs based on manual adjustment. A manually adjusted dosing station using NaOH or $CaCl_2$ solution maintains alkalinity.

The **controls system** relies on 1) manual response to monitored parameters and alarm conditions for key equipment and 2) automatic response to oxygen concentration in the main treatment system. Large recirculation pumps and blowers incorporate variable speed drives for manual speed control. Smaller pumps and blower use manual on/off switches. Influent water supply is regulated using a combination of manual and automated (water level) control.

An off-flavour **purge facility** consists of two, 25m^3 fiberglass tanks serviced by a partial reuse facility (PRAqua Oxytower) that includes LHO, CO2 stripper and header tank unit. Centrifugal pumps with a combined flow of 500 usgpm (1.9m^3/min) lift water to the top of the header tank. Treated water then flows by gravity to the fish rearing tanks. Controls are similar to the main system with the exception of alkalinity control. Purge culture tank volumes are exchanged approximately once every 40 minutes. It is anticipated that total flow rates in the purge system will average about 21 gal./min. (79.5 liters/min., 418 l/kg annual production) at steady state operation. Purge discharge water feeds the main production system.

The main **water** supply is pumped from a groundwater supplied pond (artesian), filtered through sand then UV disinfected. Influent water is disinfected with a UV dose of 55 mJ/cm^2 (new lamp capacity).

Effluent: Filtered solid wastes (drum filter backwash) flow into septic tanks which serve as partial gravity thickening tanks. The settled thickened solids that collect at the base of these tanks are pumped out as required to a transport truck. Effluents flow untreated to ground through a closed loop system involving a pond/ ditch and wetlands.

At time of writing there was no **back-up generator** or **heatin**g/ cooling system. A back-up generator has since been added but was not included in this cost analysis.

Significant factors affecting development costs of Taste of B.C. facility, and related opportunities for cost savings

Location near city of Nanaimo:

- Next to a city that serves as a major supply and service center, including a major RAS system and designer, PRAqua Ltd.
- Close to Vancouver Island University

Fish and water factors:

- No quarantine facility was necessary. Certified disease-free trout fry (20g) are available every 8 weeks as required.
- Water quality requirements were less stringent compared with 'Namgis Atlantic salmon project.
- The ToBC bioplan is based on grading and transferring the fish three times prior to harvest. While this results in better capacity utilization compared with fewer handling events, the benefit will be offset to some degree by higher labour costs and reduced fish performance.

Objective to remain small scale (100 metric tonnes/year), and to develop a "family farm" model for land-based aquaculture:

- Adherence to strict capital cost limits and the use of simple, practical and proven technologies were priorities. To achieve these goals, some sacrifice in risk, reliability and labour cost were acceptable to the owners. Some examples of cost savings:
    - No heating/cooling system
    - Predominance of manual controls over automation
    - Fabric on steel building with primarily gravel floor
    - No backup generator (initially). It was assumed that oxygen would be able to maintain fish for 2 days, and other parameters also manageable for that time.
    - Artesian groundwater supply given minimal UV disinfection
    - Extensive use of used equipment and stringent procurement processes.

- The facility will serve as a research and development test facility for PRAqua Ltd.., a training facility for Vancouver Island University, and a Canadian "Model Aquafarm" demonstration and research facility (http://www.ipsfad.ca). These additional functions can be supported without significant additional capital expense while providing potential future support and offsets to operating costs, which will help meet the challenge of operating on a smaller scale than farms serving mainstream markets.

Land ownership:

- Taste of BC owners/managers live on-site and personally own the freehold land. ToBC Aquafarms holds a 20-year lease, under generally accepted commercial lease structure and rate (70% of current value amortized over 30 years).

- Owner/management structure and multiple roles assumed by the owners during construction and operation provided savings in non-capital costs.

Existing equipment included a fish health laboratory, infiltration ditches and pond from a small pre-existing trout farm.

- Minimal new aquaculture equipment was purchased.
- Some trout are grown on-site in an older facility with established equipment.

‘Namgis FN and Taste of BC: capital cost comparison

Summary

Capital costs can be minimized through sacrifices of risk, component longevity, operating costs, fish performance and/or direct profitability, but the economic “sweet spot” is difficult to determine. With the continued sharing of results for these types of projects over the next few years, the solutions will become more optimal and ultimately the industry more profitable.

	‘Namgis	Taste of B.C.
Production	470mt/year Atlantic salmon	100mt/year Rainbow trout (“Steelhead salmon”)
RAS systems	$10.80/kg	$9.10/kg
Main building	$2.80/kg ($444/m^2)	$1.90/kg ($144/m^2)
Civil works and other site developments	$3.3/kg	$3.7/kg
Equipment	$2.00/kg	$0.42/kg
Total Development Cost (development cost /kg annual production)	**$19/kg**	**$15/kg**

The Taste of BC facility was built at a considerably lower unit cost compared with the ‘Namgis FN facility, with differences largely attributable to a number of underlying decision elements and trade-offs which should be taken into consideration by developers of future RAS facilities:

Location:

- A site close to a major supply, service and labour center helps ensure competitive tendering processes, minimize living-out allowances and equipment mobilization and other transportation costs. These advantages over a relatively remote location carry forward into operating costs involving supplies, services and labour. Cost of land, flood risk, site drainage, water supply and access to infrastructure such as processing must be taken into account..

Land ownership:

- Private land may offer a faster track to a secure lease and asset protection, and be therefore more attractive to lenders or investors, compared to special regulated situations such as public lands or First Nation sites where there may be time-

consuming requirements for government approvals or environmental due diligence.

- Funding gaps proved expensive for the 'Namgis FN development.
- There is no direct evidence regarding how the ownership/management structure impacted relative costs, and while owner-operator may prove the lowest-cost development model, it depends on the capability of the owner(s). With the Taste of BC owner-operator, costs seemed more easily and efficiently controlled because there was only one stakeholder. Conversely, the 'Namgis FN project had multiple stakeholders to satisfy, so the number of features and requirements (and costs) tended to increase with time.

Risk:

- Acceptably higher ToBC risk allowed for cost savings by minimizing equipment redundancy, back-up systems, biosecurity measures, etc.

Production scale:

- Component and installation economies of scale for 'Namgis FN meant higher capital costs but lower future operating costs.

Automation:

- Higher capital costs of more automated feeding, heating and other systems established by 'Namgis FN are also expected to pay back in lower operating costs, particularly with increasing scale.

Species

- Locally, certified disease-free Steelhead salmon fry are available when required and have less stringent water quality requirements compared with Atlantic salmon. Atlantic salmon smolts are not certified disease-free (so quarantine facility required) and availability is limited.

Engineering and design:

- Lacking engineering standard best design practices specifically for RAS facility construction, the 'Namgis FN facility was designed using standard industrial design engineering practices, which may have resulted in in some components being overbuilt in some respects..
- ToBC benefitted from being able to use some existing equipment.
- Fabric on steel buildings (ToBC) can be considerably less expensive than steel structures ('Namgis FN), depending on building size and configuration.

- ToBC budgeted for but did not employ temperature controls, whereas "Namgis FN installed a heating and cooling system with the expectation of better fish performance. There is probably an optimum degree of temperature control that will provide the best return on investment. A system allowing some seasonal drift in temperatures is probably more cost efficient than tightly controlling or not controlling temperature. In a temperate climate, use of (a) an insulated building, (b) effective management of evaporative cooling in the CO_2 stripper or other aeration equipment, and (c) fans and ducting to direct air borne heat loads (e.g. from mechanical equipment), has the potential to significantly reduce heating and cooling needs at minimal cost.

Comparison of major general specifications, with cost advantages

Category	**Namgis First Nation** (NFN)			**Taste of BC** (TOBC)		
General	**Metric**	Comments & Relative Impact (savings= •)		**Metric**	Comments & Relative Impact (savings= •)	
Species	Salmon	Atlantic salmon		Trout	Rainbow trout (Steelhead)	
Annual Production	470 mt/year	More production => Better economies of scale	•	100 mt/year		
Cohorts/year	3 /year	Stock every four months		6.5 /year	Stock every 8 weeks. More stable biomass/ Higher throughput.=> Better capacity utilization.	•
Production Cycle (average weeks)	54 weeks			45 weeks		
Tank management		Fish graded and transferred once prior to harvest. Better fish performance			Fish graded once and transferred three times prior to harvest. Better capacity utilization.	•
Fry/ smolt size	100 gm			20 gm		
Quarantine System for new fry/smolts	Yes	Independent RAS system for new smolts. Risk mitigation		No	No Quarantine system	•
Harvest size	5000 gm			2000 gm		
Harvest schedule	bi-weekly	(Every two weeks) 17 weeks/cohort		weekly	8 weeks/cohort	
Total Mortality (with culls)	11%			15%		
FCRb	1.05	Lower feed cost	•	1.10		
Total feed	494 mt/yr			127 mt/yr		
Maximum density	75 kg/m3			80 kg/m3	Slightly better tank utilization	•
TGC (cycle)	2.4 /cycle			2.1 /cycle		
Temperature	15 C	Temperature is controlled. Better fish performance.		15 C	Budgeted but not controlled (no heat/cool equipment)	
Tank turn over	45 min	Main production tanks		40 min	Main production tanks	
Oxygen	100%	Better fish performance (?)		80%	Reduced Oxygen supply capacity /cost	•
CO2	12 mg/l			16 mg/l	Reduced CO2 stripping capacity /cost	•
Unionized Ammonia	0.010 mg/l			0.012 mg/l		
Nitrate	75 mg/l			75 mg/l		
Influent UV dose (end of lamp)	60 mj/cm2	Risk mitigation (required due to location)		40 mj/cm2	Reduce equipment capacity requirement.	•
Water use (unit average)	550 l/kg feed			330 l/kg feed	Should be the same as NFN given the same nitrate limits (?)	
Technologies	Fluidized Sand Biofilter				Fluidized Sand Biofilter	
	Low head oxygenator				Low head oxygenator	
	CO2 stripper: Flat orifice plate crown nozzles				CO2 stripper: Flat orifice plate crown nozzles	
	Rotary drum filter (54 micron)				Rotary drum filter (54 micron)	
	Dual drain "Cornel style tanks				Dual drain "Cornel style tanks	
	VSA oxygen generator				VSA oxygen generator	
	Ground water supply with UV disinfection				Ground water supply with UV disinfection	

Comparison of RAS system costs

Category	Namgis First Nation (NFN)				Taste of BC (TOBC)			
	Cost (k)	Metric	Comments & Relative Impact (savings= •)		Cost (k)	Metric	Comments & Relative Impact (savings= •)	
RAS Systems (1)	**5,068**	**$10.8** /kg			**913**	**$9.1** /kg		
RAS Engineering	551	$1.17 /kg			131	$1.31 /kg		
RAS	x		(359k) Schematic, process, construction drawings		x			
Support & Commissioning	x		(140k) Includes research		x		Minimal value engineering and alternative concept exploration	•
Heating & Cooling	x		(52k)				No HVAC system	•
Other			Geotechnical included in Civil works. Structural and Electrical engineering included in RAS engineering		9		Total geotechnical, electrical and structural engineering for the project. Details and scope = ?	•
Equipment								
Tanks	669	$194 /m3	500m3 tanks. Concrete bases, fiberglass sides, drains, side boxes, mort recovery, etc, Includes assembly/ Installation.. Larger tank size	•	162	$231 /m3	8m3 - 96m3 tanks purchased used. Fiberglass sides and bottom. Installation not included. No mort recovery.	
Biofilter equipment	226	$0.48 /kg	Fittings & plumbing materials (not assembly). Includes Quarantine System. Larger system=> better economy of scale	•	62	$0.62 /kg	No Quarantine system	
Gas transfer Equipment	378	$0.80 /kg	Blowers, Tank based LHO's, oxygen solenoids, lines to tanks, diffusers etc.		85	$0.85 /kg	Central LHO	
Treatment System	530	$1.13 /kg	Concrete work and equipment installation. Includes Quarantine system, growout and purge systems.		62	$0.62 /kg	No Quarantine. Concrete only. Equipment installation costs in "plumbing".	•
Drum Filter	208	$10- $13 /usgpm	80 micron screen		44	$11.5 /usgpm	54 micron screen	
Recirc Pumps	197	$5 - $21 /usgpm	Axial flow, 16' TDH		52	$7 /usgpm	Axial flow and centrifugal, 13' - 16' TDH	
Monitoring, Controls and Alarm System (MCAS)	349	$0.74	PLC, SCADA system, motor control center. DO, PH and Temperature are monitored. Water flows, oxygen supply, alkalinity dosing are automatically controlled. Includes Quarantine system. Better economy of scale	•	95	$0.95	PLC, Motor control center, Instrumentation, Alkalinity dosing system, Primarily manual controls/ Minimal automation. DO, temperature, PH and ORP are monitored.	
Oxygen	152	299 /lpm	2 oxygen generators (VSA, 500lpm) Includes installation. Better economy of scale	•	48	388 /lpm	1 oxygen generator (VSA,250 lpm). Does not include installation	

Category	Namgis First Nation (NFN)				Taste of BC (TOBC)			
	Cost (k)	Metric	Comments & Relative Impact (savings= •)		Cost (k)	Metric	Comments & Relative Impact (savings= •)	
RAS Systems (2)								
Ozone	182	$152 /kg O3 /hr	1200 gm/hr, Single generator, distributed injection (to LHO's), automated control. Includes installation. (Future purchase)		0.6	$6 /kg O3 /hr	100 gm/hr, Single, used generator (15 yr old). No controls. Does not include installation (Installation budget not included in total costs)	?
Photoperiod Lighting	35		Underwater LED sized and programmed to minimize grilse production		0		No specific photoperiod regime. Building lighting (included in electrical) + Natural light (through building fabric).	•
Alkalinity Control	5		Automatic NaOH dosing system.				Part of Monitoring and Controls system costs (above)	
Heating & Cooling	633	$1.35 /kg	Heat pumps, under tank heating coils, geothermal well (heat sink), installation. Equipment + Install (>400k install).		0		No heating/ cooling system. Temperature changes with seasons.	•
Installation Components								
Concrete Mix		$318 /m3	25-35mpa average strength, $237/m3 base mix average			$163 /m3	Total Cost= $52,842. 26 mpa average strength (10-32mpa), $132/m3 base mix average (lower unit cost concrete mix)	•
Concrete Total		$2.41 /kg	Total cost = $1,131,000. Includes quarantine system, purge treatment system, forklift capable concrete floor, tank bases, steel building foundation, Higher seismic rating than Nanaimo			$1.28 /kg	Total cost =$127,719. Includes main treatment system, fabric on steel building foundation, partial concrete floor. Note: Tank bases are fiberglass.	•
Electrical- Component Connection	185	$0.39 /kg	Includes quarantine system, more automation/ controls and some redundant wiring. Electrician = $70/hr		8	$0.08 /kg	No Quarantine, simple controls, Electrician = $60/hr, relative component quality = ?	•
Plumbing	444	$0.94 /kg	Materials, labour, fill/ excavation. Excludes plumbing at tanks, treatment system and oxygen system (about 60k).		125	$1.25 /kg	The effluent valve is self actuating. All other valves are manual	
Management & Planning	151		Construction management & LOA for RAS installation only				Included in Misc below. No living out allowance (LOA)	•
Freight	43		Equipment freight (including sand !)				Included in other costs	
Misc	132		Insurance, equipment mobilization, facility footprint development & fill		29		Unclassified RAS supplies, invoice adjustments etc.No construction insurance. Minimal mobilization costs	•

Comparison of equipment and main building costs

Category	Namgis First Nation (NFN)			Taste of BC (TOBC)			
	Cost (k)	Metric	Comments & Relative Impact (savings= •)	Cost (k)	Metric	Comments & Relative Impact (savings= •)	
Aquaculture Equipment	**853**	**$1.8** /kg		**42.3**	**$0.42** /kg		
Feeding	186		Central feed system and bulk storage hoppers.	1.3		Four demand feeders. Mostly feeding by hand	•
Fish handling	307		fish pump, grader, pipes, fish Crowder	0		Use dip nets for all fish movement	•
Inventory	28		fish counters (Note: biomass scanners are leased)	0		Use hand counters	•
Harvesting	155		percussion stunners, chutes	30		Estimate. Equipment has not been purchased	
Lab and Other	177		Lab, cameras, mort storage, "contingency" (used primarily for fish handling)	11		Estimate of purchased and existing water quality and lab equipment	
Other Equipment	**79**	**$0.2** /kg			**$0.00** /kg	Using existing site equipment	•
Lifting	24			0			
Health & Safety & Security	18			0		Use existing site equipment	
Tools & Maintenance	25			0		Existing site tools and tools purchased during construction (in costs above).	
Office	6			0		Equipment in existing residence	
Communications and IT	3			0		Equipment in existing residence	
vehicle	3			0		Use owners existing vehicle.	

Category	Namgis First Nation (NFN)			Taste of BC (TOBC)			
	Cost (k)	Metric	Comments & Relative Impact (savings= •)	Cost (k)	Metric	Comments & Relative Impact (savings= •)	
Main Building	**1,311**	**$444 /m2**	Insulated, 2956 m2 (31,823 sq ft)	**193**	**$144 /m2**	No insulation, 1346m2 (14,490 sq ft)	
Design-Build building	635	$215 /m2	$20/sq ft Pre-engineered steel building with steel cladding. Insulated, Roof venting and access hatches, several doors.	167	$124 /m2	$12/ sq ft. Fabric on steel building (lower cost). No insulation, No roof vents, One door	•
Foundation	287	$97 /m2	$9/sq ft. Higher concrete mix costs, Larger foundation required for heavier building, higher seismic rating.	18	$14 /m2	$1/ sq ft. Smaller foundation due to lighter building and lower seismic rating. Foundation not engineered (?)	•
Floor	160	$109 /m2	Forklift capable floor throughout	7	$5 /m2	2400sq ft / 17% concrete + 83% gravel	•
Interior structures	174		Includes building electrical, walls/ interior cladding (7 rooms and mezzanine), grading station, washrooms, lab.			One room, no internal structures	•
Over tank lifting beams	54		Lifting I-Beams over every tank			no overhead lifting capacity	

Category	Taste of BC (TOBC)				Namgis First Nation (NFN)			
	Cost (k)	Metric	Comments & Relative Impact (savings= x)		Cost (k)	Metric	Comments & Relative Impact (savings= x)	
Main Building	**193**	**$144 /m2**	No insulation, 1346m2 (14,490 sq ft)		**1,311**	**$444 /m2**	Insulated, 2956 m2 (31,823 sq ft)	
Design-Build building	167	$124 /m2	$12/ sq ft. Fabric on steel building (lower cost). No insulation, No roof vents, One door	x	635	$215 /m2	$20/sq ft Pre-engineered steel building with steel cladding. Insulated, Roof venting and access hatches, several doors.	
Foundation	18	$14 /m2	$1/ sq ft. Smaller foundation due to lighter building and lower seismic rating. Foundation not engineered (?)	x	287	$97 /m2	$9/sq ft. Higher concrete mix costs, Larger foundation required for heavier building, higher seismic rating.	
Floor	7	$5 /m2	2400sq ft / 17% concrete + 83% gravel	x	160	$109 /m2	Forklift capable floor throughout	
Interior structures			One room, no internal structures	x	174		Includes building electrical, walls/ interior cladding (7 rooms and mezzanine), grading station, washrooms, lab.	
Over tank lifting beams			no overhead lifting capacity		54		Lifting I-Beams over every tank	

Comparison of civil works, pre-construction and miscellaneous site development costs

Category	Namgis First Nation (NFN)			Taste of BC (TOBC)			
	Cost (k)	Metric	Comments & Relative Impact (savings= •)	Cost (k)	Metric	Comments & Relative Impact (savings= •)	
Civil Works & Misc Site Development	**1,542**	**$3.3** /kg		**373**	**$3.7** /kg		
Engineering	35	$0.07 /kg	Geotechnical. Full site assessment (with samples) then inspections during construction.			Geotechnical assessment (Visual, $200) part of RAS engineering	
Management, Planning and General Civil	220	$0.47 /kg	Construction management, Accounting services, LOA, Equipment mobilization for Civil work and all other work.	150	$1.50 /kg	Construction & Project Management, Administrative services for all work	
Site preparation	311	0.66 /kg		152	$1.5 /kg		
Clearing & Debris removal	x		(62k) Clearing offset by timber sales. 150 truck loads of stumps ! Debris chipped and stored on site.	x			•
Fill	x		(249k) Most fill sourced on-site. Primarily excavation costs. Fill required to raise road and building site above flood risk elevation.	x		Includes removal and rebuilding 3.6m of material/ fill to deal with site drainage issues.	•
Environmental	37		Archaeological monitoring during clearing, Installation of groundwater monitoring wells.	0		No environmental or archaeological monitoring work required- **private lands**)	•
Effluents							
Sludge thickening and storage system.	111		Purpose built gravity thickening tanks, sludge storage tank, sludge pump, installation.	0		Two septic tanks. Installation part of Site Preparation.	
Infiltration Basins	111		Engineered Infiltration basin. Excavation costs recorded as Fill cost. Includes engineering and plumbing.	0		No engineered infiltration basin. Used existing pond a ditches as infiltration structures.	•
Effluent disinfection	37		Chlorination/ De-chlorination system installed due to stakeholder concerns	0		No effluent disinfection required	•
Effluent other	24		Domestic sewage field, tank and plumbing	0		No domestic sewage system (Use existing washroom residence)	•
Supply Water		$0.5 /kg			$0.1 /kg		
Wells, pumps & hookup	188		Three production wells. Excludes geothermal well. Includes well developed prior to start of construction	0.4		Spring fed (artesian) water source. No drilling required. Use submersible pump in pond.	•
UV treatment	32	$118 /usgpm	2 units in parallel each 60mj/cm2 @ 135gpm & 90% Transmissivity. High dose required due proximity to salmon bearing river.	7.5	$139 /usgpm	1 unit @ 40mj/cm2, 54usgpm, 90% transmissivity. (no backup)	•
Power							
Main supply	64		800amp, Three phase 347/600v service	20		600amp, Single phase 480/600v service	
Back up Power	167		generator (300kva, 600v), electrical switching, fuel storage	0		No back up power. Will rely on 2 day oxygen supply and not worry about other parameters	•
Other Structures	206		Office Building, Harvest area, Site lighting, Gates and Fencing	5.6		Storage container (feed). Office is in existing residence.	
Misc Costs				37		Unclassified development costs	

Category	Namgis First Nation (NFN)			Taste of BC (TOBC)			
	Cost (k)	Metric	Comments & Relative Impact (savings= •)	Cost (k)	Metric	Comments & Relative Impact (savings= •)	
Front End Engineering,	**537**			**0**			•
Environment & Permitting	43		CEAA screening, DFO License, FH management plan, Archaeological survey	0		No CEAA screening or Pre-Construction surveys required. Other permitting included in management costs above	
Project Management, Planning & Admin	378		Business plan, project management, market research, funding management	0		Included in Management costs above	
Site Assessment & Survey	59		flood risk, groundwater survey	0		No surveys required	
Preliminary Engineering and Design	57		Early concept designs and cost estimates	0		No early concept designs developed	
Pre Production Operating	**295**			**0**			•
Recruitment	60					Owner is facility manager. Staff are students from local college	
Salaries & Benefits (pre-operational)	97						
Other	138		Supplies, Communications, Sm Equipment, Admin, Loan Interest, heating	?		Pre-operational expenses not identified	

Appendix 1 – ‘Namgis FN facility

Detailed breakdown of system components and costs, with opportunities for cost savings





‘Namgis FN RAS Components

RAS Systems Summaries

	Purge	Quarantine	Growout
Drum Filter	1	1	3
CO2 Stripper	1	1	1
LHO (1/tank)	1	1	5
Biofilter		1	1
Recirculation Pumps	1	2	3
Total Cost	$250,381	$932,421	$3,420,499
Production Capacity		50mt/yr	420mt/yr
Unit Cost		$18/kg	$8/kg

Main Production Facility
The main production facility represented about 67% of total RAS system costs. However, it supported about 89% of the total production. The capital cost for the installed equipment was about $8/mt of annual production.

Quarantine Facility
The quarantine facility represented about 18% of the RAS system cost. However, it only supported about 11% of the total production. The quarantine facility was a completely separate system (in a separate, biosecure room) whose purpose was to isolate and rear new smolts for the first four months to ensure no disease was introduced into the main facility and fish. The quarantine RAS system was a miniature version of the main RAS systems, albeit with a reduced level of redundancy.

The capital cost for the installed equipment was about $18/mt of annual production.

Opportunity for reducing costs:

- Eliminate the need for a quarantine facility (separate RAS system) through the use of an on-site hatchery or access to appropriately certified disease-free stocks. Small RAS systems, such as that for the quarantine facility used here, are expensive. However, the main production system would need to be larger and have one additional tank to support the same total production.

Purge Facility

The purge facility (installed equipment) represented about 5% of total RAS system costs.

Opportunity for reducing costs:

- A larger production facility or additional modular facilities would still only require one purge facility, with fish pumped to a central location for purge and harvesting. However, two tanks would be more optimal so that a weekly harvest schedule and up to 14 days of purge (if required) could be used The current system is designed to deliver purged fish every two weeks.

RAS components

Tanks

Size	500m3	250m3
$/tank	$104,549	$73,236
$/volume	$194/m3[1]	$267/m3
Fiberglass Sides	$413/m2[1]	
Concrete Base	$161/m2	
Cost Breakdown (All tanks combined)		
Tank sides & equipment	49%	
Concrete Base	25%	
Compact fill	13%	
Assembly	9%	
Other	4%	

[1] Traditional 8" concrete wall cost about $388/m2, Stay in place formed walls about $334/m2

Tanks represented about 13% of RAS system cost and 7.5% of total costs.

Tank costs included fiberglass sides, side boxes, mort recovery system, associated plumbing, concrete bases, under tank fill and assembly. While the tank base unit area cost less than tanks walls and equipment, changes in tank base area impacts building costs (e.g. $161/m^2 base cost+ $312/m^2 building cost = $473/m^2 effective cost of area increase). Therefore, increasing tank widths strongly impacts total costs.

Tank equipment made up almost 50% of the tank costs. Equipment cost included tank wall (55%), inlet structure (13%), jump screen (13%), bottom drain and mort recovery (11%) and side box (9%). The assembled fiberglass tank sides cost slightly more than if they were built in concrete (8" thick) using a modular forming process such as Octaform (www.octaform.com). This cost differential would be greater if the project were located near a major center with lower concrete costs or if the tanks were larger.

Opportunities for cost savings:

- Use larger (fewer) and deeper tanks to: (1) reduce capital costs (including tank cost, building size, required working area/walkways, monitoring and controls, etc.), (2) reduce operating cost (labour), and (3) Improve fish performance. Use of deeper

tanks (smaller diameter to depth ratio) will require some research to confirm hydraulics will be effective to provide minimal water quality variation (ensure there are no water quality hot spots) and self-cleaning. Increased use of center drain flows to support self-cleaning attributes would probably be required. As tank size increases, use of tank-centric water treatment and control systems may be more cost efficient (e.g. CO^2 stripping and oxygen addition) due to the large volumes of water that have to be moved through treatment

- Use modular forming or precast concrete for the construction of large tanks (>500m3).

Biofiltration

Biofilter costs (excluding concrete)

Equipment	66%
Media (Sand)	21%
Plumbing	13%
Total Cost	$259,538
$/kg TAN/Day	$4,576[1]
Approximation since treatment system also include structures for CO2 stripper, drum filter, header tank and pump sump.	
[1] 56.7kg TAN /day (1418kg feed/day)	

Biofilter costs (Including concrete)

Concrete	52%
Equipment	32%
Media (Sand)	10%
Plumbing	6%
Total Cost	$539,760
$/kg TAN/Day	$9,516[1]
Approximation since treatment system also include structures for CO2 stripper, drum filter, header tank and pump sump.	
[1] 56.7kg TAN /day (1418kg feed/day)	

The biofilter equipment alone represented about 4% of total RAS system costs. Fluidized sand biofilters (nitrification biofilters) were designed and constructed as part of a multi-function concrete treatment system that included CO_2 strippers, pump sump, header tank and drum filters. The main biofilter was made of five 16'x16'x12.5' cells.

Concrete was a major cost component. Sharing concrete walls with other water treatment components reduced overall costs and footprint of the central treatment area, but made concrete forms complicated and therefore formwork more expensive. Unfortunately, the concrete slab and wall costs could not easily be separated out for each treatment process in the main treatment systems. However, based on the use of approximate wall and slab volumes, approximately 60% of the treatment system concrete costs could be assigned to biofiltration. Note: Concrete was not included with other RAS components in the cost analysis.

Opportunities for cost savings:

- Reduce complexity of the biofilter design to reduce concrete formwork cost. This would allow for the use of more cost-efficient concrete construction approaches. See Opportunities for Concrete Construction.
- Add oxygen to the sand biofilters ("turbo charge") to increase biological efficiency and reduce total volume requirements.

Recirculating pumps

	$/pump	$/USGPM	Capacity
Growout pumps* (3)	$40,603	$5	8018 gpm, 16' TDH
Quarantine pumps* (2)	$25,275	$11	2268 gpm, 15' TDH
Purge pump (1)	$31,900	$21	1500 gpm, 15' TDH
*Vertical shaft, wet pit axial flow style			

Axial flow style pumps (vertical turbine, shaft drive) provided recirculating water flow., and were chosen for their energy efficiency (80%) and historic reliability. These represented about 4% of RAS system costs. Given their critical life support function and impact on total power cost , the use of high quality (reliable and efficient) pumps is well justified.

Three pumps were used for the grow-out system to provide reasonable redundancy in case of pump failure. Note: Only one pump is required to keep sand filter fluidized. Two pumps were used for the quarantine system, and one for the purge system.

Pump materials: HDPE pumps were rejected because of limited choice of configuration and price. Stainless pumps were rejected because of price (3x regular carbon steel). Epoxy coated carbon steel was the final choice. Agricultural grade pumps rather than industrial grade were chosen for their cost, although quality/ reliability was not as good.

Note: There were warranty issues with the first pumps received and the system supplier replaced them. Through the process of resolving the issues, the following lessons were learned:

- Ensure all pumps are in-place and tested well before delivery of fish. A back-up plan needs to be in place in case of failure at start up.
- Ensure transport and installation procedures are clearly communicated and there is a clear chain of custody and responsibility for this work. Note: These types of pumps can easily go out of alignment if jarred during transport.
- Start up and early running of the pumps and conditions (e.g. sump water depth) should be closely monitored and recorded to ensure performance meets specifications.
- Clearly understand the warranty terms and reputation of the vendors and products prior to purchasing.
- Ensure the facility design and pump characteristics are exactly harmonized (e.g. pump sump wall clearances, depth over suction point, dynamic head, etc.)

Opportunities for pump cost savings:

- Pump redundancy is essential but very expensive: use of several small pumps will be more expensive than a few large pumps (risk vs. cost decision). Therefore employing the minimum number of pumps to ensure adequate redundancy and risk mitigation should be the goal. Risk can also be minimized by ensuring quality and reliability are high. Try to select "industrial" grade as opposed to "agricultural" grade pumps from reputable manufacturers.
- Maximize energy efficiency by minimizing the time pumps are spend outside their efficient rpm range by: 1) Use of a bioplan where loading and therefore recirculation flow needs are relatively constant. 2) Have some pumps turn off rather than turn down during extended low load periods.

Suspended solids removal (drum filters)

	$/filter	Unit cost	Capacity
Growout Drum Filters(3)	$56,863	$10/usgpm	5,826 gpm @25mg/l TSS, 80 micron screen
Quarantine Drum Filter	$36,800	$13/usgpm	2,796 gpm @25mg/l TSS, 80 micron screen

Drum filters (rotary style) alone represented 4% of RAS system cost. However, this did not include controls to manage the backwash function, concrete basin or installation. Three drum filters were used for the grow-out system and one for the quarantine system.

Note: The drum filters were sized and plumbed to receive both bottom and side drain flows from the culture tanks. Screen size (80 micron) was larger than used on other RAS salmon installations but represented an optimal size based on recent published research findings.

Opportunities for cost savings:

- If available, use larger, fewer drum filters to reduce costs. However, there should be at least two in any system to provide appropriate redundancy.
- Reduce drum filter capacity requirements by directing only bottom drain flows through the drum filters (don't filter the side drain flow).

Ozone system (dissolved and ultrafine solids removal)

Component		
Generator	55%	1200 gm/hr, water cooled, central generator with distributed dosing, air O3 sensors and alarm, PLC control.
Automated dosing in LHO	21%	Manual dosing is about 20k less
Installation- local contractors	11%	Install equipment, provide water, data and oxygen lines
ORP Probes	6%	Digital, high quality (eg Rosemount)
Installation- supplier	7%	Connect water, data and power, Run O3 lines, test
Total Cost	$182,000	

Note: An ozone system representing about 4% of RAS system costs, has just been installed. The system utilizes a central bank of generators with tank based monitoring, control and ozone injection system. ORP probes at each tank inlet provide the basis for feedback and control of dosing.

Ozone (and oxygen) is dosed into the Low Head Oxygenators (LHOs) just prior to the tanks. Locating the contact point at the LHOs will provide the benefit of conserving the oxygen produced from ozone break down. Tank inlet ORP probes are used to regulate O_3 delivery (on/off control) to each tank. Product concentration will be manually set. Since the ORP probes are relatively small cost components but provide a very critical function, they should be of high quality and from a proven manufacturer.
Note: ORP probe measurements are affected by any changes in water chemistry that affect redox potential. They are also reported to be sensitive to grounding issues (e.g. induced voltage charges in the water). Hence accuracy may be be low and therefore need to be confirmed if these probes are used to control ozone dosing.

Opportunities for cost savings:

- Requirements for ozone may be less or negated if dissolved solids or ultrafine particles were removed by other means (e.g. fixed bed biofilter system, foam fractionation {in saltwater}, etc.)
- Ozone may also be used as a method to reduce metal accumulation in highly recirculated systems if they accumulate (e.g. systems employing de-nitrification biofilters where water use is less than a few percent per day).

Oxygen generators

	Generators*	Liquid Oxygen**	
Capital (Total $)	$151,559		
Capital ($/kg total production)	$0.48		
Operating ($/kg oxygen)	$0.024	$0.35	

* Three generators (1/2 Ton/day, 250lpm, VSA technology), 2 compressors, 1 product tank.
** Cost pf product delivered to Port McNeil + equipment rental

These represented 3% of RAS system cost. Given their critical, life support function and impact on total power cost, the use of high quality (reliable and efficient) generators is well justified. Two generators have been purchased. A third is planned/ budgeted. In addition, a liquid oxygen (LOX) system has recently been installed to provide additional supply security. Note: liquid oxygen costs substantially more than generated oxygen at this location (see above) so its use as a primary oxygen source was not justified.

Opportunities for cost savings:

- The use of LOX to offset peak demand loads and consequently allow the use of a smaller generated supply system.

Monitoring and controls

MCAS Control Panel	52%	48% hardware, 52% design and programming	PLC's, SCADA, HMI software, commissioning
Motor Control Panel	28%	69% hardware, 31% design, 49 motor controls	Variable Frequency Drives, Panels, switches
MCAS Instruments	17%	100% hardware, 45 switches and sensors, 38 alarms	Probes, float switches, self actuated valves, solenoids
Power Use Monitoring	3%		Power monitors, panels, installation, programming
Total	$344,294		
Features: Totally custom solution, Industrial quality, Maximum flexibility, Local parts and service. Servicing three separate RAS systems			

Monitoring and Controls represented 7% of RAS system cost. This included: instrumentation, motor controls, computing hardware, software and programming, and power use-monitoring equipment.

The system was designed to meet the following requirements: use of "industrial grade/ high quality" components; use of standard components where locally available and serviced (including programming); meeting all facility needs including a moderate degree of automation, and capacity for easy modification and expansion. A fully customized solution was therefore developed, and the cost was higher than many of the available more standardized, off-the-shelf control solutions.

The system included 49 motor controls, 45 switches and sensors, and 38 alarms. While the extensive use of industrial quality components (e.g. Allen Bradley) resulted in high initial costs, the system should provide long-term reliability.

A Modbus system for data communication was employed (power and signal carried in the same cable), but an Ethernet-based system (signal only, multiple controls through one cable) may have been a more cost-efficient option.

Opportunities for cost savings:

- Reduce level of automation to improve reliability, reduce management complexity, and reduce capital cost. This would also force staff to be more alert to ongoing changes to the system, as they, rather than "the machine", would be making the adjustments. With this approach, the monitoring and manual controls systems would still need to be very reliable and easy to use.

- Match the quality of the components to project needs (also see engineering and design comments). For example, employ “industrial quality” (high cost) components only for critical or high-duty cycle functions and use lower, appropriate component grades for functions that are less critical.
- Reduce or eliminate the use of VFD for controlling recirculation pumps (see recirculating pumps, above). Use a series of pumps that are either on or off. This would reduce the complexity and cost of controls and may improve energy efficiency, since the pumps would only be operating at optimal flow. Use of more pumps would also improve redundancy/reduce risk. The negative aspect of this would be that total pump costs would be higher and there would be less flexibility for decreasing energy use when the system is lightly loaded. Note: In this project, the recirculation pumps cost less than the control systems. VFDs alone were about 50% of pump cost.
- Use one of the lower cost, off-the-shelf, modular systems. These are becoming more sophisticated in terms of customization and flexibility, and costs are dropping as the number of systems in use increases. The sacrifice in flexibility may be more than offset in the capital cost savings.

Gas Transfer (CO_2 stripper and LHO)

Component		
Low head oxygenators (LHO) (1/tank)	35%	Fiberglass components. Excludes concrete bases and connected plumbing
CO2 Stripper Blowers	25%	Large scaling opportunity (see below)[1]
CO2 Stripper Other Equipment	17%	Includes flat orifice plates with crown nozzles (57m2 area for main CO2 stripper). Excludes concrete.
Oxygen control	12%	Tank Diffusers, oxygen solenoids/ control panel, blower install
Installation	11%	
Total	$375,288	
[1]Blowers - Growout	$2 /cfm	
Blowers - Quarantine	$6 /cfm	
Blowers - Purge	$8 /cfm	

Gas transfer equipment represented 7% of RAS system cost. For each tank, oxygen was added through use of a single fiberglass, Low Head Oxygenator (LHO). Within the main treatment facilities, CO_2 stripping (and some oxygen addition) was accomplished using a flat orifice plate with crown nozzles (to break up water). The water passes through the crown nozzles and falls as a dispersed stream to the pump sump below. Blowers draw air under the orifice plate where it contacts the falling water and gas exchange takes place. The equipment cost did not include the concrete structures that were integral to the CO_2 strippers. These were part of the whole concrete treatment facility that included the pump sumps, header tanks and biofilter, and the costs could not be separated out.

Opportunities for cost savings:

- Employ a centralized the LHO facility (part of the main treatment system) with individually controlled subsections devoted to each tank. This would lower construction cost, although it would then require piping from the LHO to individual tanks rather than use of a common distribution line and manifold.
- Use fewer, larger blowers since blower cost efficiency ($/cfm) was very dependent on scale (as long as some equipment redundancy is maintained).
- Use in-tank de-gassing and/or oxygenation in “deep” tanks to reduce volume of required recirculation flows and external (to tank) oxygenation systems. This would reduce both capital and pumping costs although some sacrifice in oxygen transfer efficiency would result.
- Use main (deep) header tank for primary oxygen injection (raise to 100% saturation) then top up oxygen at the tanks using a smaller side stream LHO at each tank.

Heating and cooling

Component		
System install[1]	~ $461,019	67%
Tank Base Heating Coils	$67,840	10%
Engineering	$51,528	8%
Heat Pumps (2)+ heat exchanger	$42,000	6%
Geothermal wells and connections	$37,300	5%
Air Ducting	$24,600	4%
Air Heat Recovery System (ERV's [2])- Postponed		
Total	$684,287	100%
[1] Air heaters, insulated lines, electrical connection and controls. [2] ERV's estimated to be $327,000		

Heating and Cooling represented 13% of RAS system cost. The current system represents the most efficient result after a long line of previous draft solutions. The complexity of the engineering and uncertainty around heating loads and losses (uncertainty around final costs) contributed to the long and involved design process. The current solution is a relatively simple one compared with previous iterations, and was meant as a starting point for the facility. Further upgrades may be required if heating or cooling needs are greater than estimated.

General Description: Two heat pumps use water from a separate freshwater well as a heat sink and source. Heat is transferred to and from culture water and building air through glycol lines that supply under-tank heating coils and air heat exchangers. Evaporative heat loss in CO_2 strippers, condensation and building CO_2 levels are controlled through building ventilation and CO_2 stripper blower speeds. Unfortunately, some of these functions work in opposition and therefore balancing is required. For example, venting the CO_2 strippers into the room rather than directly outside will reduce heat loss in winter. However, this will cause CO_2 and water vapour concentrations in the building to increase. This in turn will reduce CO_2 stripping efficiency, may result in a health risk (from high CO_2), and will increase the risk of water condensation on both building and equipment.

The main cost was for the heating and cooling system was installation, given that it included a lot of insulated plumbing, electronic control valves, a control system and buffer tanks.

The design included provisioning for the installation of energy recovery ventilators (ERVs) if required in the future.

Opportunities for cost savings:

- Use de-nitrification to reduce heating losses from new water supply and effluent discharge. This option would have to be weighed against the cost of cooling in the summer months, as the de-nitrification process would add heat to the system.
- Optimize water quality to reduce new water requirements. For example, if CO_2 limits could be increased, this would reduce CO_2 stripping needs and therefore heat losses in winter.
- Develop an efficient air ducting system to maximize the use of the CO_2 stripper as an evaporative cooling unit and to utilize mechanical room heat in the winter.
- Allow larger seasonal variation in water temperature, allowing fish growth rates to vary seasonally rather than providing optimal conditions year round. Savings in heating system capital and operating costs may offset the potential increase in production cycle time. For example, the design of the 'Namgis FN heating and cooling system was based on relatively tight temperature range criteria. In this case, the capital cost required to meet these criteria (and maintain optimal growth through the winter) may have outweighed the cost of additional rearing space required if growth rates were slightly slower. Due to the relatively high capital costs, this design aspect should be thoroughly investigated in the early design stages of new projects.
- Add effluent heat recovery and/or air heat recovery if potential financial returns (capital + operating/maintenance costs) warrant.
  Note: Cooling requirements should be treated with as much importance as heating needs in the design process.

Main building

Cost breakdown		Unit Cost		
Building Structure	48%	Building structure	$20/sq ft	$215/m2
Foundation	22%	Foundation	$9/sq ft	$97/m2
Interior structures & Finishing	13%	Total Building + Foundation	$29/sq ft	$312/m2
Concrete Floor	12%	Concrete Floor	$10/sq ft	$109/m2
Overtank lifting beams	4%			
Total Cost	$1,310,672			
Total areas (117' x 271' x 13'): 31,823 sq ft (2956m2), Floor area 15,774 (1465m2) Building roof is not clear span. There are support post throughout.				

Building Area Use	
Tanks	35%
Grow-out and Quarantine Treatment facilities	16%
Other equipment, walkways, lab etc	49%
	100%

The main building, complete with foundation, floor and interior finishings, represented 15% of total facility development costs. The building structure and foundation alone represented 10% of total facility cost.

Building Description: pre-engineered steel building, 117'x 271'x 13' with galvanized beams, 26 galvanized steel cladding and roof, insulated (4"/R20 roof, 3"/R10 wall), 4-overhead doors, 6-man-doors, ridge vents and several wall louvers, roof support posts throughout the building (trusses are not clear span). Galvanized beams were chosen as the best option for dealing with corrosion in the moist saline environment. However, the use of galvanized surfaces requires that condensation is strictly controlled to ensure culture water is not contaminated.

The high seismic rating for the area added about 1% to building structure cost and, in the opinion of the builder, a substantial increase to the foundation cost. Building erection during winter conditions added $24,000 to cost.

The culture tanks occupied 18% and 13% of the culture area in the quarantine and grow out systems, respectively. The water treatment systems occupied 80% and 33% of the culture tank areas for the quarantine and grow out systems respectively. The water treatment systems were relatively compact, as they were constructed as one unit with shared walls and minimal connecting channels, and fluidized sand biofilters provided high treatment efficiencies in relatively small footprints because of the high media specific surface areas (>10,000 m^2/m^3). However, the CO_2 stripper plates occupied a considerable area compared with more vertically oriented designs. There was also a substantial volume of unoccupied, non-functioning space above the treatment systems.

Opportunities for savings:

- Incorporate building optimization (cost minimization) recommendations from building suppliers when developing facility layout (see Local Recommendations in Appendix), e.g., positioning of vertical support posts and sidewall heights for steel buildings.
- Consider use of fabric on frame (FoF) structures. These are very economical up to about 100' widths and may be economical at widths over 100' provided total building size is large enough to economically justify large crane mobilization costs. FoF structures may not be suitable for climates with more extremes in temperature environments although they can be insulated to at least R21.
- Move mechanical and water treatment systems outside the main building(s) to reduce main building size. Mechanical and treatment system enclosure could be built more appropriate to the structure e.g. closer spacing of roof supports, insulated hatches over CO_2 stripper and biofilter cells. Ducting of air to or from the culture facility as required would be simpler.
- Reduce walkway area around tanks. However, space required for fish handling needs should be well understood prior to defining walkway areas.
- Integrate building foundation with other concrete elements so structures reinforce each other (share stress loads), allowing the total size of concrete structures to be reduced, as well as formwork complexity. For example, everything could be built off a single large slab (floor, building foundation, tank bases, equipment mountings, building support posts, etc.).
- Investigate use of inflatable buildings, which could utilize existing blowers to supply the required air pressure. Note: 50 lbs./sq. ft. support only requires 0.3psi air pressure.
- With very large tanks, it may be more cost effective to employ individual tank buildings (covers) rather than enclose everything in one building. However, heat/cooling implications would have to also be considered in the evaluation.
- Utilize unused space above the treatment facilities (e.g., one Norwegian facility visited by the author included an entire floor with RAS equipment built on top of the biofilters).

Civil works

Site preparation

Component				
Fill	67%	Mainly Excavating, sorting and screening on-site material.		
Overburden removal	18%	Mainly Chipping stumps & slash (150 truck loads)		
Other	11%	Site grading/ compacting,		
Clean Up	4%			
Timber removal	0%	Timber removal offset by log sales		
Total	$341,336			

Site preparation represented about 4% of total design and construction cost. Developing the access road and site to the safe flood plain elevation was the largest cost, requiring replacing elevation lost from overburden removal, then adding up to 1.3 meters on top. This was considerably lower than it could have been if the fill had not been sourced on the same property.

Opportunities for cost savings:

- Build tanks above ground and supply raised walkways or a raised floor/mezzanine. Extra cost of adding height and walkways may be less than the cost of the fill, depending on the location of the nearest source of structural fill.
- Consider use of geofoam blocks as a potentially lower-cost alternative source for fill between tanks. (This would also reduce side loading on fiberglass tanks.)
- Avoid building on a floodplain.

Effluent treatment

Infiltration Basin*	39%	Mainly excavation costs. Cost offset by use of excavated fill for the main facility.
Solids settlement cones	26%	3x 9' Fiberglass cones installed with plumbing and pumps
Solids Storage and Handling	18%	Storage tank, trash pump, transport tanker, raised platform for tank and loading area.
Effluent Disinfection	13%	Chlorination/ de-chlorination system. Not a legal requirement
Domestic sewage treatment	3%	
Misc Plumbing	1%	
Total	$282,896	
*Infiltration basin area: 3600m2, Main building footprint: 2900m2 : Land use impact is high !		

Effluent Treatment represented about 3% of total development cost. Most of this was divided among the infiltration basins and gravity thickening cones used for drum filter backwash sludge.

The infiltration basin development cost was lower than it could have been because the material removed to create the basins was used as structural fill to raise the elevation of the access road and main facility. In addition, the area consumed by the basins (land cost) was not accounted for in this project. The basin area was about the same size as the rest of the facility and would have been larger if the soil permeability had not been extremely good. Therefore if land value had been accounted for, the true/effective cost of the infiltration basins would have been substantially higher.

To reduce sludge transport costs, a storage facility was built, so that economical full loads were shipped.

Disinfection of effluent was a stakeholder decision, rather than a legal requirement, and was based on the facility's proximity to a salmon-bearing stream. There was no legal requirement for further treatment of effluent or sludge (e.g. to reduce BOD, phosphorous, etc.).

Opportunities for cost savings:

- Land area reduction: investigate the feasibility of injection well discharge of effluents as a means of reducing land use/cost. This would require considerable pre-treatment to remove suspended and dissolved solids that could plug injection wells.
- Reduce total waste volumes, and therefore sludge disposal costs, by using additional technologies (e.g. belt filter) to further concentrate sludge.
- Use denitrification to reduce effluent discharge volumes.

- Value-add and sell waste products (e.g. as organic fertilizer products).

Influent UV disinfection

Capital (Total $)	$31,752	2 units in parallel (each 60mj/cm2 @ 135gpm & 90% Transmissivity, Aquafine, no wipers) mounted in parallel.
Capital ($/unit flow)	$62/lpm	

UV disinfection represented less than 0.4% of total development cost. However, it had an extremely high functional value in terms of its role in keeping pathogens out of the facility.

System description: Water is supplied from groundwater wells with about 90% transmissivity, so UV treatment was the appropriate solution. The project is located next to a very productive salmon-bearing river, the aquifer is known to be highly permeable, and the seasonal variation in transmissivity was unknown, so a much higher than normal dosage and redundancy were used in the design. For example, each UV unit was capable of handling 100% of maximum flows at 2x the required end of life dosage (30mj/cm^2) for targeted pathogen inactivation. As the units are mounted in parallel, the dosage was effectively 4x the required dosage (i.e., capacity is 4x maximum requirements)

This extra capacity will allow the simultaneous disinfection of both purge and RAS facilities if needed. Water discharged from the purge facility normally supplies the two RAS facilities. If required, purge water could be directly discharged and the RAS facilities directly supplied with new water.

Opportunities for cost savings:
- Ozone may provide a more cost effective (albeit riskier) disinfection system for dirtier water sources, as well as improving supply water quality and boosting oxygen.

Other civil works

Component			
Other Buildings & Structures	$205,877	25%	Harvest area, Office, LOX facility, fencing, lighting,
Back Up Power	$167,191	21%	1x 300KVA, 600V, transfer switch, installation, fuel storage
Water Supply	$187,772	23%	3 production wells (8" and 12"), plumbing , electrical
On Site Management	$158,021	20%	
Main Power	$63,766	8%	Pole and transformer
Misc	$27,015	3%	Accounting, labour mobilization and LOA
Total	$809,642	100%	

Other civil works made up about 9.5% of total development costs.

Opportunities for cost savings:

- Management costs could be considerably reduced through use of a tendering process that included more fixed price contracts. Project interruptions and design changes also increased costs. (See Engineering: Tendering and Planning section, below.)
- Total water supply system needs and costs could be reduced by increasing water recycling (e.g. through use of denitrification biofiltration).
- Back-up power capacity was sized to account for some equipment loads that had not been designed and/or or added to the system. Knowing these requirements earlier might have allowed purchase of a smaller generator. Conversely, the generator was sized to maintain all fish culture related functions. If sized only for critical functions, it would be smaller.

Equipment

Aquaculture equipment

Fish handling	39%	12" fish pump & Piping (60%), grader, counter, fish Crowder, moveable grading station.
Feeding	22%	Central feed systems, hoppers, bulk feed lifting, etc
Harvesting	18%	Percussion stunners, chutes, etc
Other	17%	Primarily a contingency for fish handling + nets, scales, mort storage.
Lab	2%	WQ instruments etc.
Cameras	1%	
Biomass Scanner	0	Biomass scanner leased. (30k to purchase)
Total	$852,994	

Aquaculture equipment made up 10% of RAS system costs.

The fish handling systems were the most expensive and challenging. While systems for gently pumping and grading fish are relatively proven, systems for easily setting up and moving equipment designed for large fish within a land-based facility (especially large pipes and pumps), have not been developed. In addition, methods for crowding fish and removing fish from large tanks are not well refined. (For instance, large clamshell style mechanical crowders require substantial overhead clearance and overhead lifting systems.)

Fish handling equipment was also the most expensive non-RAS equipment purchased. The final solution consisted of a 12" fish pump (sized for large fish >12lbs.), aluminum piping, movable intake nozzle, and movable grading station with grader and fish counters. All of these were designed to be movable, so the equipment could be shared among future modules. The use of passive swim ways between tanks and in-tank grading were also considered. However, the fish pump approach became the only real alternative because the list of needs included 1) removing early maturing fish (grilse) by hand, 2) harvesting, 3) size grading, and 4) avoiding the use of unproven technologies.
Other fish handling related costs that were not accounted for in this summary included the afore-mentioned overhead/over tank lifting beams ($56,000) and additional building height required to accommodate handling of a large fish crowder.

Opportunities for cost savings:

- Reduce the floor space and height clearances devoted to fish handling once actual needs are well defined. During the design process for this project, the space set aside was a reflection of the uncertainty of these needs. ?
- Most of this equipment can be shared among other modules, so increasing scale will greatly improve return on these investments.

Other equipment

Maintenance	32%	Tools and spares
Lifting & Forklift	31%	Hoists, pallet jack, etc.
Safety & Security	23%	Fire suppression, first aid, security
Office, IT, Communications	11%	
Vehicle	4%	Older model truck
Total	$78,590	

This was a relatively minor cost category (about 1% of total costs) but probably should be higher because the investment in spare parts and components is probably below "safe" requirements at this stage.

Broad spectrum cost factors

Construction

Concrete

Formwork	34%	RAS Treatment System	42%
Concrete	23%	Building Foundation	25%
Management & Safety	19%	Tank Bases	15%
Rebar	16%	Building Floor	11%
Placement and Finishing	8%	Other	6%
Total	$1,131,402	Basic concrete mix	$215/m3
Typical 8" Finished Wall Cost[1]	$388/m2	Concrete additives[2]	$103/m3
		Average concrete cost	$318/m3

[1]Assembled fiberglass tank walls cost $413/m2. Stay in place formed walls would probably cost $334/m2.
[2] Concrete Water proofing cost $48/m3

Concrete represented about 13% of total design and construction costs ($1,131,000 total). This included tank bases, treatment systems and building foundations and floors. Standard (custom) construction forming methods were used throughout. This is the slowest and most costly method of developing concrete structures but the only realistic choice, given the complex and non-repeating nature of the structures.

Formwork was the largest cost component for concrete structures and was directly related to labour cost and formwork complexity. The remote location was also a significant factor, as living costs for imported workers added 40-50% to labour costs. The supplier estimated that labour was 30% higher compared with the closest "large" town (Campbell River). In addition basic concrete mixes ran about $22% higher than Vancouver area pricing. The formwork cost breakdown was 69% for walls and 31% floors, footings, etc. Rebar cost was made up of 57% material and 43% labour.

Water treatment systems were the most expensive concrete components at 42% of total concrete cost. Management and safety costs were unexpectedly high at almost 20% of total. Superintendent and safety coordinators (including living out allowances) accounted for 72% of management and safety.

Opportunities for cost savings:

- Reduce formwork costs by reducing geometrical complexity of structures. This would 1) reduce labour costs, 2) open the door to more cost efficient forming processes such as modular, stay in place formwork (e.g. Octaform) or gang-style forming, and 3) potentially open the door to the use of pre-cast structures.
- Build tank walls out of concrete: Fiberglass tank walls cost $\$413/m^2$ installed, while "normal" concrete formwork walls cost $\$388/m^2$ on average for this project. It was estimated that using a concrete stay in place forming process (e.g. Octaform) for the tanks would have cost about $\$334/m^2$ at this location.
- Avoid building far from major supply centers, which incur extra costs for imported workers and potentially higher concrete costs compared with larger centers. Setting up an on-site concrete batch plant may be one way of mitigating high local concrete mix costs.
- Use lower cost methods of waterproofing (e.g. in-concrete or external waterproofing alternatives).
- In some cases, building "thick" walls may have been less expensive than "thin" walls, due to the reduction in additives required to increase strength and improved flow through tight spaces and the reduction in rebar requirements.
- Develop the whole facility on a single concrete slab, integrating all structural elements into the slab and therefore reducing total structural needs. Tie all components into the slab (build facility upwards). This would require integrated engineering and design processes (RAS and structural). This may also reduce the seismic loads (= sizing) for the components built on the slab, since it could be sized to insulate the components.

Electrical

RAS General		52%	
	17%		Underground main electrical
	8%		Motor Control Center wiring/ cables, conduit
	27%		Install and terminate electrical devices: Connect other electrical equipment (other MCAS, lights, etc.)
Main supply		18%	Pole and Transformer
Building Misc.		13%	
Heat/Cool system		10%	
Supply Wells		7%	
Total		$354,324	
Materials		58%	
Labour		42%	Local Electrician- $70/hr, Apprentice- $55/hr

Electrical (wiring) costs represented 4% of total design and construction costs. Labour was about 42% of this cost.
Ongoing changes and uncertainties during design and construction significantly impacted costs (re-wiring, redundant wiring). Ongoing interruptions also added to labour cost.

Opportunities for cost savings:

- Use wireless controls and communications systems where appropriate.
- Avoid interruptions, design changes (change orders), and material overage (wastage), by starting tendering and construction after the design and construction drawings are completed and funding is in place.
- Reduce wiring costs by simplifying the monitoring and control systems. (See monitoring and controls opportunities.)
- Reduce per-unit electrical costs by increasing the scale of the facility (especially tank size) since many of the electrical costs are relatively fixed.

Plumbing

Pipe	36%	RAS general plumbing (large dia.), Primarily PVC	53%
Valves	31%	RAS final connections (small dia.)	16%
Pipe Fittings	15%	Tanks & Treatment System (large dia,)	10%
Flanges	15%	Heating and Cooling System	5%
Couplers	3%	Water Supply (HDPE pipe)	4%
Total Cost	$561,986	Effluent (infiltration basin)	9%
Materials[1]	71%	Other (floor drains, etc)	3%
Installation	29%		100%
[1] 85% of cost is for materials >18"			

Plumbing represented about 6% of total design and construction costs. Material costs accounted for about 71% of this. About 85% of material costs came from pipe, fittings, etc. that were greater than 18" diameter.

Opportunities for cost savings:

- Include consideration of best overall return on component investment (operating and capital investment costs) in the design process. In some cases, the use of smaller (or larger) diameter plumbing with higher (or lower) energy cost may provide a better

return than what normal design approaches would suggest. While, for a given flow hydraulic head (energy cost) increases exponentially with smaller pipe diameters, pipe and valve costs increase exponentially with larger diameters. All functional implications would still need to be considered in these analyses. For example, reducing pipe diameters in gravity flow (low pressure) systems would substantially increase header tank requirements. Conversely, increasing pipe diameters can lead to increased sedimentation from a reduction in flow scouring. There are also price thresholds in pipe and valve pricing for certain diameters that should be considered.

- Investigate opportunities for use of open channels and gates as an alternative to large diameter pipes and valves.
- Investigate the installed cost of alternative large diameter pipe materials in the design process (e.g. concrete, fiberglass, HDPE). HDPE seems to be the material of choice in Europe. Does this make sense in North America? What are the practical limitations (e.g. availability of local skilled installers)?

Planning, Engineering and Design

Engineering

RAS Engineering	50%	Schematic design(7%), Process & Layout (17%), Construction Drawings (27%)
RAS Commissioning, & Support	17%	Research (options assessments), inspections, training, drawing updates.
Misc	11%	Front end engineering, structural inspections
Heating and Cooling	10%	
Hydrological	8%	Flood risk (2 studies), Groundwater flow (2 studies)
Geotechnical	2%	
Effluent	2%	Infiltration basin design
Total	$714,384	

Engineering processes represented 8% of total project costs. RAS engineering represented about 7% of RAS systems cost. Note: front end engineering processes (concept designs) and research were included in this total cost. While these seem like relatively high costs, the indirect cost impacts are higher. For example, the impact of engineering decisions probably accounts for a major portion of potential cost variation.

Opportunities for cost savings:

- Invest in quality engineering processes. Given the strong relation with overall project cost efficiency, this should provide very solid financial returns.

General Planning and Design

Opportunities for cost savings:

- Increased production scale: As presented throughout this document, there are numerous opportunities for improved capital and operating costs, as well as reduced risk (increased redundancy), with increasing production and facility component scale. The following table summarizes some examples from this project.

	Unit cost Reduction	"Large Scale" (Grow out facility, 420mt/yr)	"Small Scale" (Quarantine Facility, 50mt/yr)	(Purge Facility)
Tanks		500m3	250m3	
	27%	$194/m3	$267/m3	
Recirc Pumps		8000 gpm	2300 gpm	1500 gpm
	55%	$5/gpm	$11/gpm	$21/gpm
Blowers		16,000 cfm	2,300 cfm	
	66%	$2/cfm	$6/cfm	
RAS Systems		421mt/yr	50mt/yr	
	58%	$8/kg	$19/kg	
Drum Filters		5800 gpm	2800 gpm	
	23%	$10/gpm	$13/gpm	

Rearing density optimization (fish performance/operating costs vs. capital cost): The main capital cost variables associated with changing rearing densities for a given production tonnage are tank and building costs. Given the relatively minor impact on total capital of changing tank volume, the cost of reducing rearing densities may be less than the operating cost benefits. For example, decreasing design densities from 100 to 75 kg/m^3 in the design process for the 'Namgis FN project (33% increased volume needs with no change in total production) would have increased total facility cost by about 3.5% or $309,000 (see below). If feed conversion could be improved by 8% for a $62,000/year savings, this capital investment would provide a 20% annual return on capital.

Other potential benefits to lowering densities include:

- reduced risk of fish loss during power outages (longer fish survival time with lower densities)
- reduced oxygenation costs: less degree of oxygen super saturation required in tank supply water. This would allow a greater use of aeration to supply oxygen.

- better "animal welfare" (meeting Organic label requirements = potentially better market returns)

Therefore, in the design process, the cost of increasing rearing densities and the potential impacts of fish performance should be carefully weighed against savings in capital.

Reduce densities from 100 to 75kg/m3 (25%)	Facility Cost Increase	
Increased Tank cost	2.5%	33% more volume/tank cost
Increased Building cost (roof, wall, foundation)	1.0%	7% increase in building area/cost
Increased Treatment system cost	0.0%	No change in total biomass
Total Increase in Capital Cost	**3.5%**	

- Employ optimized water quality parameters in design processes. Create designs that are based on providing water quality that balances capital costs with operating costs and fish performance. Given the uncertainty regarding the relations between fish performance and various water quality parameters, this approach is difficult at this time. Consequently, a conservative approach is probably the best approach today.
- Develop a code of Standard Engineering Practices and Assumptions for RAS facilities rather than re-examining the suitability of engineering assumptions for each project (re-inventing the wheel), or defaulting to potentially inappropriate standard assumptions. These would provide the pathway for more cost efficient RAS design development. . Developing these would include balancing risk vs. cost, longevity vs. technical depreciation, etc. While, for this project, it would have been prohibitively expensive and time consuming to re-examine all engineering assumptions in the final design process, the reliance on general (but safe) industrial standards probably had a significant impact on costs. In summary, a set of design standards should be developed that:
    - include structural engineering variances (variances from industrial design practice) that are appropriate for fish farms.
    - are based on lifespans that are appropriate for nature of the industry. (In the author's experience, aquaculture technologies are frequently obsolete within 5-10 years.)
    - include functional criteria that minimize unnecessary capacity or features, e.g. concrete structural specifications for crack controls in tanks.
- Creation of modular, "off the shelf" RAS treatment system designs (e.g. 500mt/yr feed): as the engineering costs would be amortized over multiple units, these could be

highly refined and highly cost efficient. They may also open the door for the use of more modular, off-the-shelf, integrated, third party components, as well as helping benchmark these systems and increase design competitiveness.

- Denitrification biofiltration: Depending on costs, complexity and reliability, this offers the potential to
  - reduce heating costs (although it would also increase cooling requirements in the summer months)
  - reduce water supply and treatment costs: Supply water pumping and disinfection, water hardness, PH and salinity control.
  - reduce effluent treatment volumes, costs and environmental impact.
  - open the door to more customized water quality options.

  However, a track record of stable performance, practical management solutions and proven economics is required to open the door to widespread use in RAS systems. The accumulation of potentially harmful metabolites would also have to be considered in these types of highly recirculated systems.
- Choose engineering companies carefully. Quality, experience, and design flexibility (the willingness to re-examine approaches) vary considerably. Final capital and operating costs will depend much more on the quality of the engineering than the fees charged.

Tendering, planning and budgeting

As with many leading edge technology projects, the 'Namgis FN facility design and development process took longer than anticipated. The regular uncovering of new challenges, adding of new costs (and new funding needs) resulted in a considerable number of delays in the project. At the same time there was a need to keep development moving forward. This resulted in significant overlap and recasting of funding, design and construction processes, which had a major impact on total costs. For example:

- Proceeding with construction before completion of final engineering meant that use of fixed-price tendering was not a suitable approach for many development tasks; the potential number of change orders would have probably resulted in higher final costs. The often chosen time-and-charges approach to contracting was more cost efficient given this situation, but required more management time.
- Uncertainty during construction resulted in some re-construction and some over-construction to handle potential changes to the final design.
- Rushed tendering processes in general reduced the opportunity for competitive contracting.
- Interruptions in funding resulted in interruptions in construction and consequential cost increases.

The unique funding processes and research orientation of this pilot project also required that significant resources be devoted to ongoing inquiries, information tracking, analysis, and reporting and meetings.

One of the key drivers in the design process was the need for the business to generate a positive cash flow. As new information regarding operating costs was discovered, there was a frequent need to change facility scale and/or the production plan to ensure that a positive cash flow could be maintained while minimizing capital costs.

The following provides a high-level summary of the evolution of scope and total capital costs for the project.

Date	Budget (millions)	Production (mt/yr)	Key Design and Technology Changes
Sept 2010	3.0	175	Two species , 135m3 tanks, Two buildings, Two RAS systems
Dec 2010	5.0	315	One species, 500 M3 tanks, 6 tanks, Two temperatures, Two RAS systems, Purge system, One building
May 2011	6.5	315	First detailed installation estimate
Sept 2011	6.0	390	One temperature, Quarantine facility, 5 tanks, Propane heating
Dec 2011	6.9	390	Construction Starts. First estimate of new heating solution cost
Aug 2012	6.6	461	Maximum rearing densities increased from 50 to 90kg/m3, Cost reduction initiatives vs discoveries of new costs.
Dec 2012	7.6	461	New heating solutions, Effluent disinfection, Harvest equipment addition, Additional oxygen generator.
June 2013	7.6[1]	377	Increased grilse estimate, Irregular smolt intake, Ongoing cost reduction vs cost discoveries.
Aug 2013		470	Optimized system expectation (long term)

[1]Final budget does not include delayed but planned future expenditures (eg ERV).

Opportunities for cost savings:

- Minimize total costs by minimizing the overlap in processes that should proceed sequentially (permitting, funding, design and construction). For example: complete detailed engineering drawings before the start of construction, to allow for effective tendering and contracting processes. Rushed tendering can restrict the number of potential bidders and therefore competitiveness and quality of bids. Permitting and funding should take place in advance of planned development, to avoid interruptions. If public lands are involved, greatly increase the budgeted time for permitting (plan on one year). While overlapping these processes will decrease time to first harvest (and first cash flow), the cost penalties could be devastating.
- Public land and public money are expensive. Significant time and resources need to be budgeted if either are an ingredient in the development process. A significant portion of the received fund (e.g. 5%) should be budgeted for any funding application process.

- Tendering process: where there are significant unknowns and innovation is a significant element in the design and/or development process, time and charges may be the best approach to contracting. However, budgets should then contain significant contingencies for uncertainties and cost overruns.
- Tendering for RAS engineering: if bio-programming and the other major design assumptions are well established (e.g. specifications for water quality, fish growth, feeding, fish movements, and tanks), RAS engineering should be contracted on a fixed cost (rather than time and charges) basis. Where the choice of engineering company also locks in the major equipment supply choice, the agreement should include both equipment supply and engineering pricing. It may be worth paying for two preliminary design and quotation processes to ensure competitive pricing, to gain the benefit from two sets of design opinions, and ultimately to ensure the best value solution is chosen.

Site selection

Site criteria met in this project were that it**:**

- was on 'Namgis First Nation Lands and met the approval of 'Namgis community
- was close to local services and labor resources
- met total area requirements for the project with room to grow
- had abundant and high quality water resources

Positive site attributes:

- High quality groundwater supply: ample fresh and brackish water, no deleterious substances, at shallow depth. Note: while there is some salinity, it may not be sufficient for optimal Atlantic salmon growth.
- Level land that is highly permeable (to allow effluent return to ground) and offering an on-site source of soil suitable for use as compact fill.
- Three-phase power close to site
- Next to Vancouver Island Highway and major power lines
- Minimal residential development in adjacent land
- Low power cost: $0.07 - $0.08/kwh
- Several local salmon processing facilities (farmed and wild) close by.
- 10-minute drive to closest small town (Port McNeil). Two-hour travel to closest medium supply center (Campbell River). One-day travel to Vancouver, the closest large center and market hub (transport cost of product to Vancouver is about $0.05/lb.)

Site challenges:

- The site is next to the Nimpkish River, a major wild salmon stream, which added significant costs related to:

    - flood risk assessment (hydrological investigation) used to determine required minimum flood risk elevations
    - fill required to raise the site to achieve flood risk elevation
    - biosecurity risk from wild salmon (groundwater contamination and animal /bird mediated site contamination)
    - additional environmental assessment and other public process costs related to proximity to salmon bearing waters
- Reserve lands: As previously mentioned, this increased the requirements for permitting, including environmental assessment, compared with private lands.
- Relatively remote location: This added costs, particularly during construction, because of living out allowances for many workers, freight, and higher local supply costs.

Cost reduction vision

A casual projection of capital costs, based on the 'Namgis FN experience and characteristics and including estimated changes in key variables, suggests significant savings are possible.

Additional, optimized 470mt/year module, built at current location and using same technologies

- No quarantine facility. An on-site hatchery would eliminate the necessity.
- Exclude purge facility, which would be separate and shared between modules
- No special research-related monitoring equipment
- Land developed for new building footprint only
- Utilize current water supply system
- Using existing engineering design parameters Efficient tendering and construction rollout
- Concrete tanks
- Aquaculture and other equipment (e.g. fish pump) are shared with existing facility
- Administration and maintenance facilities are shared with existing facility

Projected Cost **$13/kg annual production**

Optimized 1500mt/year module at "ideal" location in Canada and using alternative technologies

- Located close to a major service and supply center
- Utilize scaled-up components, e.g. "Large" tanks (1000m^3)
- Optimize operating parameters. Components sized to match needs with minimal reserve capacity.
- Efficient design with respect to construction methods and costs.
- Efficient tendering processes.
- Idea site characteristics with respect to construction costs, resource supply, effluent discharge, etc.
- Excludes hatchery and land cost.

Projected Cost **$10/kg annual production**

Appendix 2: Taste of B.C. facility

Detailed breakdown of components and costs, with opportunities for cost savings





RAS components

Tanks

Tank Specification	Total Vol. (m^3)	Cost Summary	
1 x 10' diameter, 8m^3	8	Total Cost	**$162,170**
4 x 16' diameter, 25m^3	100	Unit Cost	**$231/$m^3$**
4 x 20' diameter, 40m^3	160		
4 x 26' diameter, 96m^3	384		
2 x 16' diameter, 25m^3 (purge)	50		
Total Volume:	702 m^3		
Cost includes sides, fiberglass bases, bottom screens, inlets structures. Labour for assembly included in general labour. There are no mort removal features.			

Tanks represented about 18% of RAS system cost.

The tanks are fiberglass sides and base, dual drain Cornel style. All discharge from the tanks, including side and bottom flows pass through a side drain box. Bottom drain flows enter the side drain box through a removable standpipe. Side and bottom drains flows merge after the side box. Weirs in the side box control water level. Tanks were mounted at ground level or partially buried to provide working height.

Opportunity found for cost savings: smaller tanks were purchased used.

Biofiltration

Biofilter Cost Summary (excluding concrete)	
Equipment	$40,149
Media	$21,999
Total biofilter	$62,148
kg TAN/day (based on1163kg feed/day)	47.4
$/kg TAN/day	$11,387

Biofilter equipment represented approximately 7% of RAS system cost.

A fluidized sand bed (FSB) filter is the main component of a multifunction treatment system. There are two biofilter cells each of approximately 15' x 10'x 12' deep. Total volume equals 3600 sq. ft. (102m^3). Note: concrete has been excluded from this cost summary.

Recirculation pumps

	$/pump	$/USGPM	Capacity
Main System Pumps (3)	$14,240	$5.7	Cast iron, Axial Flow, 2500 USGPM/pump @ 16" TDH
Purge System Pumps (2)	$2,055	$12.5	Cast iron, centrifugal, 165 USGPM/ pump @15' TDH
Total Cost	$51,756	$6.6	

Recirculating pumps represented about 6% of RAS system costs.

Main production system has three recirculating axial flow pumps, which supply a total flow of 6845 usgpm (26m^3/min) to the header tank. Each pump is capable of 2500 gpm at the design head. Type: Fairbanks Morse, 10", 2300 usgpm @ 21' TDH, cast iron.

The purge system uses two 165 usgpm centrifugal pumps, which supply 500 usgpm (1.9m^3/min) total flow. Type: TACO 165 usgpm @ 15' TDH Coast iron.

Suspended solids removal (drum filters)

	$/Unit	USGPM	$/USGPM	
Drum Filter	$44,175	3851	$11.5	54 Micron

Drum filters represent about 5% RAS system costs.

The main production facility uses a single 54-micron drum filter for solids removal (The design specified 80 micron but a 54-micron screen was delivered.) There is no solids removal equipment on the purge system.

Dissolved and ultrafine solids removal (Ozone)

A used ozone generator (15-year-old Del) was purchased but has not been installed, and the installation budget is not included in this analysis. Output is approximately 100gm/h. Update: Since the time of this analysis, a new ozone generator was purchased for the system. The original unit serves as a spare.

Oxygen Supply

	$/unit	LPM flow	$/lpm

Generator	$48,442	125	$388	OSI, VSA technology

The oxygen generator represents about 5% of RAS system cost.

An OSI 500 oxygen generator (VSA technology) supplies 250 lpm, 500lbs./day (227 kg/day) @ 92% purity. A leased liquid oxygen tank (capacity for one day supply) is used as back up and for supplementing the oxygen generator during peak demand periods.

Monitoring and controls

Component	Total Cost	
MCAS Control Panel	X	Monitoring package (point 4)
Motor Control Center	X	Variable Frequency Drives (VFDs), motor starters and panel for recirculation pumps, blowers and drum filter
MCAS Instruments	X	Power monitoring, DO, temperature (air and water), ORP, level switches, flow meters.
Other	X	Alkalinity dosing system, self-actuating valve for effluent control.
Total	$94,855	

Monitoring, controls and alarm systems (MCAS) represent about 10% of RAS system costs.

The MCAS system relies primarily on manual responses to manually monitored conditions, automated alarm signals from key equipment, and constantly monitored oxygen.

A motor control panel with variable frequency drives (VFDs) provides variable speed control for the recirculation pumps and CO_2 stripper blowers. The monitoring and control system provides automated control for drum filter functions, back up oxygen supply and a self-actuating valve for effluent discharge. In case of power failure, oxygen generator failure, drum filter failure or pump failure, back up oxygen from the liquid oxygen tank is automatically sent to diffusers in individual culture tanks. There are also automatic pump shutdowns in case of out of range (low or high) water levels, depending on the component. Effluent discharge flow is automatically controlled, based on head tank level and a self-actuating valve on the discharge line.

Oxygen generator, alkalinity dosing pump, influent water pump and purge blowers are manually controlled.

Monitoring instrumentation includes: oxygen, temperature, water level in sumps and influent supply water flow, ORP and Ph. CO_2 and other water quality parameters are manually monitored using hand held instruments or chemical testing.

Alarm outputs include sound and visual alarms and auto-dialer. All monitored signals are sent by Ethernet to an owner-supplied PC.

Header tank dissolved oxygen (DO) is continuously monitored while culture tank DO is manually monitored. DO in the tanks can be manually regulated by either tank water flow adjustment, LHO oxygen supply adjustment or adding oxygen diffusers connected to the back-up LOX supply.

Summary of key functions of the monitoring and controls system:

Parameter	How controlled
Recirculation pump speed (growout system)	Manual through VFD.
Recirculation pump speed (purge system)	Manual through VFD
Alarms and autodialer	Signals from main power panel, tank or header oxygen, UV, drum filter, pumps, water level in sumps
Alkalinity dosing pump	Manual (on/off or pump speed)
Oxygen generator	Manual based on measured DO
Back up oxygen supply	Automatic based on DO in the main header tank or trouble signal from the Oxygen generator, recirculation pump, power supply or drum filter
CO2 stripper blower speed	Manual through VFD
Drum filter motor and backwash cycle	Automatic based on sump water level
Influent water supply	Manual.
Effluent discharge valve	Automatic based on header tank level.

Gas exchange system

Component	Total cost	
LHO	$9,000	
Blowers and Connections	$14,768	Two blowers @4575 CFM = $2.5/cfm
CO_2 Stripper Other	$20,077	Diffusers plate, and misc.
Oxygen control and diffusers	$28,802	
Purge System gas exchange	$12,584	Oxytower (PRAqua Ltd.)
Total	**$85,402**	

The gas exchange equipment (for CO_2 stripping and oxygen addition) represents approximately 9% of RAS system costs.

CO_2 stripping and aeration for the main production system, is accomplished using a flat orifice plate (160 ft2) with crown nozzles (to break up water). The water passes through the crown nozzles and falls as a dispersed stream to the pump sump below. Blowers draw air under the orifice plate where it contacts the falling water and gas exchange takes place. Note: the equipment cost did not include the concrete structures that were integral to the CO_2 strippers. These were part of the whole concrete treatment facility that included the pump sumps, header tanks and biofilter, and the costs could not be separated out. Two blowers supply 4,575 CFM (@ 0.5 inches water gauge) to the CO_2 stripper. The design airflow rate is 7 times the water flow rate. This air is then discharged back into the building. Blower speeds can be manually controlled by variable frequency drives so that operators can optimize energy consumption while maintaining suitable water quality.

A low head oxygenator (LHO) is located adjacent to the header tank, and oxygenates water as it flows from the treatment system header tank on the way to the fish rearing tanks.

CO_2 stripping, aeration and oxygenation for the purge tanks are accomplished by a gas exchange column (Oxytower, PRAqua Inc.). Water is pumped to the top of the Oxytower where it flows onto the orifice plate containing crown nozzles. Influent/new supply water is also added to the top of the Oxytower. The water passes through the crown nozzles and falls as a dispersed stream to the water collection well below. Blowers draw air beneath the orifice plate where it can contact the falling water where oxygen is transferred into the water and carbon dioxide transferred out.

Main Water Treatment System

This is a concrete structure that includes biofilter cells, header tank, pump sump, LHO, and drum filter sump. Invoices were not broken down according to component, so no specific cost or cost analysis could be determined. The whole treatment system occupies a footprint of about 33'x30'x 12' (height of header tank).

Buildings

	Total	%	$/m2	$/sq ft	
Main building structure	$167,254	87%	$124	$12	Design-build
Foundation	$18,193	9%	$14	$1	
Floor	$7,144	4%	$5	$0.5	2400 sq. ft. concrete (remainder is gravel)
Total	**$192,601**	**100%**	**$143**	**$13**	

Buildings represent 13% of total development costs.

The main building is fabric covered steel structure (Megadome Structures). Dimensions: 207' x 70.4' x 28' (center height). Footprint: 14,572 sq. ft., 1354 m^2. Trusses are unsupported/clear span galvanized steel. Fabric is polyethylene membrane: 12oz./sq. yd., 15-year warranty. Note: the fabric is relatively light duty compared with other building options (e.g. 25-30oz./sq. yd.), but a 15-year warranty should assure reasonable longevity. There is one 14' x 14' roll up door and three 4'x4' vents. There is no insulation.

A used 20' steel storage container was also purchased ($2,636) and serves as the main electrical/ mechanical room.

Civil works

Component	Cost	
Site preparation and fill	$151,947	
Influent water supply- pump	$369	
Influent water supply - UV treatment	$7,531	
Effluent treatment and discharge		Included in some site preparation and plumbing costs. Infiltration ditches and pond were pre-existing.
Total	$159,847	

Site preparation

Because of the high water table and poor drainage, about 12' (3.6m) of surface material had to be removed and built back up with appropriate fill. Trees and debris removal are included in site preparation costs.

Influent supply water and treatment (UV)

The main water supply is a spring fed pond (artesian) located on site. A 1.75 hp (45 usgpm) pump, pumps the water through a pool type sand filter (manual backwash) and UV disinfection unit to the facility.

One UV disinfection unit capable of irradiating the design flow rate of 55 gpm was purchased, although two at 80gpm were recommended in the design.

Effluent treatment

Effluents flow untreated into a settling pond, then circulate through ditches to wetlands, and subsequently return to the source pond. Settle solids can be removed from the pond for disposal off site as required.

Filter solid wastes (drum filter backwash) flow into two holding/settlement tanks (1200 and 1500 gal.). The settled thickened solids that collect at the base of these tanks are pumped out as required to a transport truck. Further effluent treatment was planned but not initiated at the time of this analysis.
Update: Since this analysis, a gravity thickening (settlement cone) and sludge storage tank have been added to the system.

Equipment

Component	Cost	
Feeding	$1,253	By hand + some existing demand feeders (no cost)
Fish movement	$0	By hand (dip net)
Grading	$0	Existing grader on-site (no value assigned)
Harvesting	$30,000	Estimated - equipment not purchased
Lab	$11,000	Estimated total of purchased + existing water quality and fish health lab equipment
Total	$42,253	

Aquaculture equipment made up <1% of RAS system costs. It was only necessary to purchase a minimal amount of equipment, as there was some on site as part of the pre-existing smaller trout facility on site. Purchased equipment included: DO meter, Insitu "Smart Troll" meter, spectrophotometer, test kits, fish health lab.

Broad spectrum costs

Concrete

Component	Total Cost		
Formwork + Materials	$59,016	46%	Labour, management, materials
Concrete	$52,842	41%	Includes delivery
Placement & Finishing	$3,351	3%	Labour and management
Steel (Rebar)	$12,511	10%	
Total Concrete Developments	**$127,719**	**100%**	
Concrete Mix (26mpa)	$132/m^3	81%	Mix ranged from 10 to 32 mpa ($125-$145/m^3)
Concrete additives	$31/m^3	19%	Waterproofing (Xypex) $37.5/m^3 (when used)
Total Concrete Mix	**$163/m^3**	**100%**	

Concrete works accounted for 8% of total development costs.

Concrete construction included the building foundation (fabric on steel building), main treatment system and a partial concrete floor.

Plumbing

Component	Total Cost	Percent	
Materials	$70,695	57%	Pipe, valves, connectors etc.
Installation	$53,870	43%	Labour ($25-30/hr.), machine rental, supplies
Total	$124,564	100%	

Plumbing represents about 8% of total development costs. Plumbing labour includes tanks assembly and installation.

PVC pipe between 3" and 24" was used. Invoices were not broken down according to components, so only an aggregate summation of materials and installation could be resolved. All valves were manual with the exception of the effluent discharge valve, which was self-actuating.

Electrical and power supply

Component	Cost	
Connect RAS Components	$28,604	Connection of all electrical components to main supply panel (excludes electrical supply)
Power Supply	$20,287	BC Hydro permit and wiring to the main panel
Back Up Power	$0	There is no back-up power facility.
Total Electrical	**$28,604**	
Electrician rate	$60/hr.	

There was only sufficient information to delineate costs associated with providing power service to the facility (power supply) and connecting the electrical components to the main supply panel. Original equipment costs are not available.

The main supply is a 600amp, single-phase 480/600v service. (The motor control panel is 480v). There is no back-up power facility (generator). In case of power outage, it is assumed that a 2-day supply of liquid and gas oxygen on site should be sufficient to maintain the fish. CO_2 and other water quality parameters are also assumed to be manageable for that time period.
Update: Since the time of this analysis, a back-up generator has been added to the system.

Engineering, design and project management

Component	Total		
RAS Engineering & Commissioning	$130,749	93%	Schematic design, Process design, construction drawings, commissioning support
Electrical Eng.	$3,019	2%	
Structural Eng.	$6,256	4%	Treatment system concrete
Geotechnical Eng.	$225	0.2%	Site geotechnical assessment
Total	$140,249	100%	
Management & Administration	$150,150	100%	Accounting and administration services

Engineering represented 9% of development costs.

RAS engineering represented most of the engineering cost. There was no flood risk at this site. A full geotech report was not prepared "as it was not needed". Structural engineering services were only used in the treatment system concrete work design.

Steve and Janet Atkinson, owners of Taste of B.C., acted as general contractors and construction managers for the project and provided all administrative services.