Aquaculture Waste Environmental Impact Monitoring and Proposed Ameliorative Action Subject to Further Research (revised)

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1.0 Purpose of Report

The purpose of this report is to research the government guidelines for aquaculture discharge and to compare that against what is actually discharged from the system.

The environmental impact of other inputs such as power is also considered. In addition recommendations are also made to reduce the waste in water discharge so as to build a safety buffer against legislative change and also to increase the efficiency of the operation.

2.0 Executive Summary

The aquaculture operation on the Great Southern Institute of Technology campus had its discharge water tested over a week. These results were compared against guidelines for aquaculture, release into waterways, release onto land and release into sewerage. Apart from release into sewerage it was found that nutrients breached guidelines.

The operation is in the fortunate position of having scheme sewerage facilities available for disposal, which makes the endeavor a lot more sustainable than it would be if it were a stand alone operation.

Eliminating cadmium at source and empirically researching the effectiveness of vermifiltration are suggested so that sustainable expertise can be passed on to stand alone operations in order to enable them to achieve discharge compliance with greater fiscal economy.

3.0 Introduction

3.1 The Issue

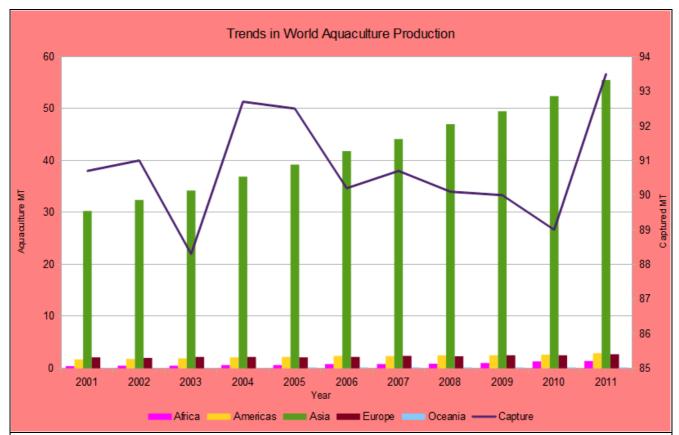
The aquaculture industry has a bad reputation for being its nutrient levels in its discharges, overuse of antibiotics, and fish escaping into the environment, especially those which have been genetically modified.

General impacts on the environment include:

- a. Habitat destruction
- b. Conflicts with predators
- c. Antimicrobial agents being discharged into the water
- d. High nutrient levels being discharged into the water
- e. Eutrophication of natural water bodies.

Compounding these problems is the fact that aquaculture supplies almost half the fish that is consumed worldwide. This means that the industry cannot be whittled away by legislation to an "acceptable level" otherwise people will go hungry.

"More than 85 percent of the world's fisheries have been pushed to or beyond their biological limits and are in need of strict management plans to restore them." (Overfishing). The reasonable expectation is that the quantity of captured fish are likely to diminish in the future while the worlds population continues to rise thereby placing further strain on other food production industries.



Graph 1. - plotted from data (FAO Fisheries, 2013). The bars represent aquaculture production in millions of tonnes per annum. The blue line is millions of tonnes captured. Asia is a clear leader, however other continents of the world are likely to increase as the supply from the ocean fisheries become more erratic and begin to trend downwards.

While it is unknown if future legislation will keep abreast with expected increases in production, any increases in the amount of nutrients/pollution discharged will adversely affect the environment and therefore, indirectly the economy.

Aside from the pollution aquaculture also draws upon fresh water from the environment. In Asia the Trans-Pacific Partnership Agreement will effectively stop signatories from standing in the way of corporate profits from fracking (Sierra Club, 2013). Since fracking is a major water polluter it is prudent to assume less available fresh water when considering expansion of aquaculture.

Any research into aquaculture systems would be incomplete without surpassing the current legislation. Additionally any discharge in the water, indeed the water itself, is a resource which should be recycled, if not into the aquaculture then into some other activity for economic benefit.

Fish pellets are also a potential source of environmental impact. They are made from fishmeal, vegetable proteins and wheat as a binder. While aquaculture does solve one aspect of its own pollution problem by using fishmeal as an input there is still an issue with the carbon footprint associated with producing pellets. Although to quantify this beyond the scope of this report it is self evident reduced pellet requirements per se translates to a reduced carbon footprint.

3.2 The study area

Albany is situated on the South-West coast of Western Australia having a mediterranean climate with warm summers and cool wet winters. Most of the rain occurs between May and September (Wikepedia). The Great Southern Institute of Technology is located within Albany on Anson Road.

The aquaculture shed is located in R Block on Campus and shares a building with the wool harvesting.

3.3 Methods and approach

The aquaculture team routinely take measurements from the fish tanks of, among other parameters, temperature, pH and electrical conductivity. These are recorded on paper forms. The aquaculture team were asked to copy this data on to a form supplied by the environmental monitoring team.

In addition, for the purposes of this project, two samples of water were taken each day at the same time. One sample was from the fish tanks and the other from the discharge holding tank located outside adjacent to the artificial drain close to the passionfruit vine. The contents of the discharge tank were stirred vigorously with a garden hoe in order to homogenize the sludge within the water.

In both cases the water was put into separate labeled sample bottles which were then refrigerated. The sampling period ran from 21-27 October 2013.

Nutrient and heavy metal testing was performed on the tank (clear) sample water. This was done with filtered sample water using the Spectroguant Nova 60 using standard testing procedures.

Coliform testing was done using standard testing procedures with 3M petrifilm for Friday and Sunday. Counting was performed by two students.

The following method was used for determining the percentage of sludge from the sample water taken from the discharge tank.

- Thoroughly cleaned and dried sampling bottles were labeled, then weighed to determine tare weight
- Once the sample bottles were filled they were weighed again to determine gross weight.
- The weight of the water was determined by gross weight less tare weight
- · Thoroughly cleaned and dried cooking pans were labelled, then weighed to determine tare weight
- Each bottle of sample water was poured into its respective pan and each pan was placed in the oven at 90°C to dry.
- Once the pans were dried they were weighed to determine gross weight.
- The weight of the dried sludge was determined by subtracting the tare weight of each pan from its respective gross weight.
- The weight of the sludge was divided by the weight of the water to reach a percentage of sludge.

4.0 Waste water guidelines

4.1 Aquaculture in general for culture

ANZECC guidelines are used for determining water quality. Intensive fish farming using high quality feed will always have to manage sludge if the environment is to be protected.

The significant water quality parameters associated with aquaculture are:

- 1. Cadmium an extremely toxic heavy metal which the fish pellet manufacturer has to include in the pellets to match the cadmium in the sea water.
- 2. Ammonia more toxic than nitrites and nitrates this form of nitrogen has to be kept low both for the sake of the livestock and the environment
- 3. Nitrites are also quite toxic. Nitrites are converted to Nitrates by denitrification bacteria.
- 4. Nitrates are the least toxic form of nitrogen. Apart from being a pollutant all forms of nitrogen can be used by other biological processes rather than being disgarded, this opens the possibility of increasing revenue by producing byproducts.
- 5. Phosphorous is a crucial element for all life. However too much can disrupt an ecosystem, especially in Australia where much of the flora has adapted to decreased levels of phosphorous.
- 6. Coliform bacteria are symbiotic bacteria which help the fish to digest their food and are resident in the gut of the fish. While most of the bacteria within the fish are good for the fish, they can be disruptive of other ecological processes once discharged. In addition to this there is always the possibility of pathogenic bacteria entering the system and killing off the livestock

The following two tables are the recommended ANZECC guidelines for productive aquaculture.

Measured parameter	Recommended guidelines (mg/L) Freshwater production
Alkalinity mg/L CaCO ₃	≥20
Biochemical oxygen demand (BOD)	<15
Chemical oxygen demand (COD)	<40
Carbon dioxide	<10
Colour and appearance of water	30-40 (Pt-Co units)
Dissolved oxygen	>5
Gas supersaturation	<100%
Hardness (CaCO ₃)	20-100
рН	5.0-9.0
Salinity (total dissolved solids)	<3000
Suspended solids	<40
Temperature	<Δ2.0°C/hr
Table 1 Physico-chemical stressor guidelines so	ourced from Table 4.4.2 ANZECC

Measured parameter	Guideline (µg/L) Freshwater production			
Ammonia (un-ionised)	<20			
Cadmium	<0.2-1.8			
Nitrate (NO ₃)	<50000			
Nitrite (NO ₂)	<100			
Phosphates	<100			
Total available nitrogen (TAN)	<1000			
Table 2 Selection of inorganic toxicants sourced from Table 4.4.3 ANZECC				

4.2 For release on land

These guidelines are also produced by ANZECC. On campus there is considerable scope for dealing with discharge water as these can be fed through a hydroponics system before final discharge.

ANZECC Table	Parameter	Long Term	Short Term			
4.2.10.1	рН	6-9	6-9			
4.2.4 (average of 1900 and 4500)	Electrical Conductivity µS	3200	3200			
4.2.5.1	Hardness	n/a	n/a			
4.2.10	Aluminium mg/L	5	20			
4.2.10	Arsenic mg/L	0.1	2			
4.2.10	Berylium mg/L	0.1	0.5			
4.2.10	Cadmium mg/L	0.01	0.05			
4.2.10	Iron mg/L	0.2	10			
4.2.10	Zinc mg/L	2	5			
4.2.11	Nitrogen mg/L	5	25-125			
4.2.11	Phosphorous mg/L	0.05	0.8-12			
Table 3 Long and short term trigger values for release of water on to land.						

Consideration must also be given to the impact of harmful flora and contamination of waterways. (Dept. of Water, 2009, p. 15).

4.3 For release into sewerage

Once again these values are lenient, for the good reason that the discharged water is being mixed in with sewage anyway and the infrastructure is already in place for the sludge to be stabilized.

There are two tables for this, the first dealing with heavy metals.

Metal	Lower Mass Alarm Limit (g/d)		
arsenic	1	5	40
cadmium	1	5	15
chromium	30	10	1000
copper	30	5	120
lead	30	10	300
mercury	0.1	0.05	1
molybdenum	1	10	20
nickel	6	10	150
selenium	1	5	20
silver	2	5	10
zinc	50	10	500

Table 4 Selected heavy metals for release into sewerage. If discharge is below the lower man alarm limit you are permitted without restraint. Between the lower and the upper limits you are limited to a concentration given in the second column of figures. Discharging above the upper mass alarm limit is not permitted. (Water Corporation, 2008, p. 7)

Waste Component	Criterion							
	1. 200 mg/L as nitrogen when pH is not greater than 8							
A	2. Case-by-case limits if pH above 8.							
Ammonia	3. Case-by-case limits on pH if amonia above 200 mg/L							
	Mass limits determined by system capacity.							
	Mass limits determined by system capacity							
Biochemical oxygen	Mass alarm limit for Woodman Point WWTP	200 kg/d 300 kg/d						
demand (BOD ₅)	Maximum concentration 3000 mg/L							
	Discharge not to change overall C:N:P ratio of system							
	Mass limits determined by system capacity							
Chemical oxygen	Mass alarm limits for Subiaco and Beenyup WWTPs	300 kg/d						
demand (COD)	Mass alarm limit for Woodman Point WWTP	400 kg/d						
(Maximum concentration 6000 mg/L	roo ng, a						
	1. 100 mg/L for mass discharge less than 700 g/d							
Iron	2. Concentration limits set case-by-case for mass discharge greater than 700 g/d							
	Mass limit determined by capacity of the system							
Kjeldahl nitrogen								
I goldarii fiiti ogori	Mass alarm limit for Woodman Point WWTP	30 kg/d 50 kg/d						
pH	6-10	50 kg/a						
рп	Mass limit determined by system capacity							
Phosphorus	Mass alarm limit for Subiaco, Beenyup and Woodman Point WWTPs 10 kg/d							
	No readily settleable solids which are likely to accumulate in the wastewater col	loction system						
		lection system						
Suspended solids	Mass limits determined by system capacity Mass alarm limits for Subiaco and Beenyup WWTPs							
Suspended solids	Mass alarm limit for Woodman Point WWTP	200 kg/d 300 kg/d						
	Maximum concentration is 1500 mg/L	300 kg/u						
Townsaudtina	-							
Temperature	Maximum 38°C							
	1. 20,000 mg/L							
	Mass limits determined by system capacity							
	Mass limits for large metropolitan WWTPs							
	Mass limits for Beenyup WWTP	400 kg/d						
Total dissolved solids	Mass limit for Subiaco WWTP	220 kg/d						
	Mass limit for Woodman Point WWTP	450 kg/d						
	IVIASS IIITIIL TOI VVOOUTTAIT FOITIL VVVVTF	450 kg/u						
	Mass loads associated with the first 600 mg/L of concentration will be excluded in c	letermining a						
	customer's compliance with the mass limit.							
	Mass limits for other WWTPs determined on a case-by-case basis.							
Table 5 Waste guidel	ines for aquaculture (Water Corporation, 2008, p. 6) The permissible amount is often	n datarminad by						

Table 5 Waste guidelines for aquaculture. (Water Corporation, 2008, p. 6) The permissible amount is often determined by the specific waste water treatment plant. This is source of uncertainty raising the need for close liaison with the authorities during the planning phase.

4.4 For release into waterways

The table below lists the constraints for small scale aquaculture being defined as 5,000 litres a day of discharge or less. (Dept. of Water, 2009, p.7)

Wastewater discharge criteria					
Description of management/effluent quality	Maximum effluent concentration or impact on receiving waters				
Physical parameters					
Algae, colour, floating matter, odour, sediment	No discernible quality change to the water resource				
Temperature	less than two degrees Celsius change to ambient water resource temperature				
рН	Effluent with pH range 5 to 9				
Suspended solids	Up to 100 milligrams/litres in effluent				
Chemical parameters					
Salinity (measured as electrical conductivity)	Up to 100 milligrams/litre in effluent				
Unstable organic waste measured as five-day biochemical oxygen demand	Up to 50 milligrams/litre in effluent				
Nitrogen as ammonia	Up to ten milligrams/litre in effluent				
Nitrogen as nitrate	Up to 50 milligrams/litre in effluent				
Total phosphorus	Up to one milligram/litre in effluent				
All other contaminates that may potentially harm aquatic ecosystems	Effluent concentration up to 10 times aquatic ecosystems guideline value (ANZECC table 3.4.1, 95% of species)				
Microbiological parameters (pathogens)					
Bacteria, virus, parasite control using effective disinfection that may include irradiation, filtration, chemical treatment and/or long-term detention	In waters that may be used for animal water supplies or direct contact recreation, up to 100 thermo-tolerant coliforms per 100 millilitres in effluent				
ANECC 3.4.1 times 10 values μg/L					
Cadmium	2				
Table 6. Waste water guidelines for discharge into water ways	S				

The above guidelines generously lenient enough and fish health would be a concern should these guidelines be not met.

Large scale aquaculture does not have defined limits but refers to the impact on a site caused by the release of the discharge water. Different types of vegetation of different nutritional requirements and these are subject to seasonal changes.

5.0 Results of Trial

5.1 Parameter results

	October, 2013								
Parameter	21	22	23	24	25	26	27		
Coliforms per 100 ml					3		0		
Conductivity µS	1,215	1,208	1,158	1,203	1,248	1,268	1,355		
Discharged Litres	998.2	1020.9	1009.6	998.23	901.21	964	1080		
Dissolved Oxygen %SAT	110.3	88.4	88.4	88	85	86			
Dissolved Oxygen ppm	9.46	9.21	8.98	9.21	8.99	9.47			
рН	8.04	7.77	7.54	8.08	7.26	7.79	7.89		
Phosphorous (P) mg/L	5.4	4.5	4.9	4.76	4.46	4.68	4.64		
Sludge %age	0.11	0.09	0.09	-0.11	-0.10	-0.15	0.00		
Temperature °C	12.6	13.1	14	15	16.8	16.9	16.9		
Turbidity NTU	62	55	75	51	52	60	140		
Nitrates (NO ₃) mg/L	56.3	18.8	48.1	0.2	1.31	0.26	0.95		
Nitrites (NO ₂) mg/L	0.4	0.61	0.13	0.936	0.96	0.404	0.384		
Ammonia (NH ₄) mg/L	0.42	0.51	0.7	0.22	1.02	0.05	1.69		
Total Nitrogen mg/L	57.12	19.92	48.93	1.356	3.29	0.714	3.024		
Table7 Aquaculture water parameters with	Table7 Aquaculture water parameters with sharp changes highlighted in yellow.								

Aggregate Statistics on the above table follow:

Parameter	Min	Max	Mean	Standard Deviation	Coeff of Var.		
Coliforms per 100 ml	0	3	1.50	2.12	1.41		
Conductivity µS	1158	1355	1236.43	62.88	0.05		
Discharged Litres	901.21	1080	996.02	54.59	0.055		
Dissolved Oxygen %SAT	85	110.3	91.02	9.55	0.10		
Dissolved Oxygen ppm	8.98	9.47	9.22	0.21	0.02		
рН	7.26	8.08	7.77	0.29	0.04		
Phosphorous (P) mg/L	4.46	5.4	4.76	0.32	0.07		
Sludge %age	0.09	0.11	0.10	0.02	0.16		
Temperature °C	12.6	16.9	15.04	1.86	0.12		
Turbidity NTU	51	140	70.71	31.61	0.45		
Nitrates (NO ₃) mg/L	0.2	56.3	17.99	24.41	1.36		
Nitrites (NO ₂) mg/L	0.13	0.96	0.55	0.31	0.56		
Ammonia (NH ₄) mg/L	0.05	1.69	0.66	0.55	0.84		
Total Nitrogen mg/L	0.714	57.12	19.19	24.14	1.26		
Table 8 Aggregate statistics of measured parameters.							

A correlation coefficient grid was also done between parameters in order to highlight possible relationships between parameters.

Correlation Coeffici	ent % grid									
	μS	DO %SAT		рН	Р	°C	NTU	NO ₃	NO ₂	NH ₄
DO %SAT	-14									
DO ppm	48	53								
рН	10	53	72							
Р	-31	91	47	51						
°C	70	-67	-13	-33	-59					
NTU	72	21	-12	15	-5	35				
NO ₃	-58	74	6	10	79	-81	-12			
NO ₂	2	-31	-20	-11	-45	24	-46	-59		
NH ₄	61	-13	-80	-30	-28	37	80	-16	-9	
TN	-58	74	4	9	79	-80	-11	100	-59	-14
Table 9 Correlation	Coefficient of	grid to highlight	possible r	elationsh	nips betw	een par	ameters.			

5.2 Significant figures

Significance without reference to the guidelines (covered in section 6.1) would take the form of:

- Sharp changes in a parameter over time
- · Parameters with high coefficient of variation
- Significant correlations between two parameters

Cadmium, which is a highly toxic heavy metal, was not measurable for five of the days. This was due to the low concentration being out of the range of the test equipment. The lowest concentration testable on the Spectroquant Nova 60 is 25ppb.

Nitrates also showed a sharp drop from the 23rd to 24th October. Apart from coliforms, which only has a sample size of 2, nitrates also have the highest coefficient of variation.

Significant correlations are between nitrates and temperature, nitrates and phosphorous, and cadmium and conductivity.

A negative percentage weight for sludge is not possible and this anomaly is discussed in section 6.2.

In all cases a larger dataset would be ideal in order to eliminate statistical anomalies and possible error in the testing procedures.

6.0 Discussion of results

6.1 Compared against guidelines

6.1.1 Aquaculture guidelines

The following table compares aggregate statistics of parameters against aquaculture guidelines.

Parameter	Min	Max	Mean	Aquaculture		
Dissolved Oxygen %SAT	85	110.3	91.02	<100		
Dissolved Oxygen ppm	8.98	9.47	9.22	>5		
рН	7.26	8.08	7.77	5.0-9.0		
Phosphorous (P) mg/L	4.46	5.4	4.76	<0.1		
Nitrates (NO ₃) mg/L	0.2	56.3	17.99	<50		
Nitrites (NO ₂) mg/L	0.13	0.96	0.55	<0.1		
Ammonia (NH ₄) mg/L	0.05	1.69	0.66	<0.002		
Total Nitrogen mg/L	0.714	57.12	19.19	<1		
Table 10 showing aggregate parameters against aquaculture guidelines. Cells highlighted in yellow have been breached.						

Values highlighted in yellow show where the aquaculture guidelines have been breached. Cadmium is a particularly worrisome parameter, not only by the extent of the breach, but also by the toxicity of the metal.

The saturation of the dissolved oxygen was only exceeded on one day and rectification of this is straightforward since oxygen levels are maintained by a pump.

Phosphorous, nitrites and ammonia were breached on every day. Nitrates were exceeded on one day. This provides a less than ideal environment for the fish.

6.1.2 Wastewater discharge criteria (Into waterways)

The table below shows aggregate statistical data of the parameters compared to that of waste water discharge criteria. The official guidelines express salinity as mg/L. This forms part of Total Dissolved Solids (TDS). The other dissolved solid is phosphorous. TDS can be converted into micro Siemens by dividing by 0.64 (Ponce, V.)

Parameter	Mir	Max	Mean	Waste water			
Coliforms per 100 ml	C	3	1.50	100			
Conductivity µS	1158	1355	1236.43	156.25			
Conductivity µS adjusted for average Phosphorous	1150	1347	1229	156.25			
рН	7.26	8.08	7.77	5-9			
Phosphorous (P) mg/L	4.46	5.4	4.76	1			
Sludge %age	0.09	0.11	0.10	0.01			
Nitrites (NO ₂) mg/L	0.13	0.96	0.55	50			
Ammonia (NH ₄) mg/L	0.05	1.69	0.66	10			
Table 11 showing comparison against wastewater discharge criteria. Parameters of concern have been highlighted in							

Table 11 showing comparison against wastewater discharge criteria. Parameters of concern have been highlighted in yellow.

Cadmium is a concern as this accumulated through trophic levels in the ecosystem and is highly toxic.

The salinity is also too high, although there are large parts of Western Australia where there is a greater level of salinity occurring naturally in the waterways and so the impact of this level of salinity in the discharge stream should not be problematic.

Phosphorous along with nitrates, nitrites and ammonia are plant nutrients which when released into the environment can give rise to eutrophication events in waterways through the excess growth of algae and plants. Phosphorous is often the limiting nutrient for plant growth in Australia, making the ecosystem especially sensitive to its presence.

6.1.3 For release on to land

A table showing common parameters for both long and short term follows

Parameter	Min	Max	Mean	Long Term	Short Term	
рН	7.26	8.08	7.77	6-9	6-9	
Electrical Conductivity µS	1158	1355	1236	3200	3200	
Nitrogen mg/L	0.714	57.12	19.19	5	25-125	
Phosphorous mg/L	4.46	5.4	4.76	0.05	0.8-12	
Table 12. Measured parameters compared to long and short term trigger values for release on to land.						

While the guidelines for land also allow the land usage to be taken into account, thus implying that larger nutrients are allowed for agriculture, the level of cadmium excludes this possibility both in the long and short term, although more sophisticated testing could allow cadmium in the short term as the average is likely to be in range. Both pH and electrical conductivity are good for long and short term, care would have to be taken with nitrogen and phosphorous, liaising with authorities as release shifts into long term.

6.1.4 For release into sewerage

The guidelines for release into sewerage are, from an aquaculture perspective, extremely lenient for an operation of this size. Water can be discharged without legal impediment.

This is illustrated in the table below the grams per day was determined by multiplying the concentrations by the average discharged litres per day (996.02):

Parameter	Estimated daily discharge g/d	Sewerage g/d
Phosphorous (P)	4.74	Determined by system capacity
Sludge	179	200,000
Ammonia (NH ₄)	0.66	Determined by system capacity
Total Nitrogen	19.11	24.14
Table 13 showing estimate	ed daily discharge against sewerage guidelines	•

6.2 Possible causes for significant figures

6.2.1 Cadmium

The single most significant parameter, for this operation, is cadmium, both from a legal and an environmental perspective. The other problem parameters are, at least, nutrients which are too concentrated. However a high nutrient load can be stripped from water with various species that make demanding use of them before the water gets released into the environment. Unfortunately this is not the case with cadmium which is a toxic metal.

Cadmium is present in the feed pellets due to biological accumulation The figures suggest that there may be too much cadmium in the pellets so these should be measured independently along with the water coming into the system. Cadmium is also used in brake linings of vehicles. There is a possibility that the dust could be settling on the roof and being washed into the rain tanks. Additional testing was performed on the rain water and this was below the measurement range of the testing procedure.

If most of the cadmium is coming from the pellets then this feed will need to be diluted with cadmium free food until the right balance is found.

Since the GSIT is providing advice to other operators it is important to document the sources of this contaminant. In addition it is also important to determine what form the cadmium is in.

6.2.2 Nutrients - Phosphorous and Nitrogen

The source of these is in the feed. This can either come from uneaten feed or waste produced by the fish. The aquaculture system has several technologies in place for removing nutrients. These include swirl separators, filter pads, biological filters, sand filters and protein skimmers.

Throughout the sample period approximately 1,000 litres of water was discharged each day. Rain water is brought in to replace that which has been discharged. Two obvious causes for the nutrients present themselves, either the system is overstocked with fish or the system is under serviced with water filtration equipment.

The maximum stocking rate of a basic system is $30-40 \text{kg/m}^3$. On November 4, 2013 the grow out area had 139.4 kg fish in approximately 9m^3 of giving a stocking rate of 15.5kg/m^3 .

6.3 Environmental impact assessment

Western Australia has extremely old and poor soils with native flora and fauna adapted to a low nutrient environment, especially for phosphorous. Cadmium is toxic both to native and exotic species especially aquatic.

Presently discharge water is being released into the sewer where it is processed by Water Corporation. Due to this water being mixed in with the rest of the city's discharge water it is impossible to assess the impact of this operation specifically.

In addition to the sewer discharge the protein skimmer also discharges low volume sludge within the root zone of a *Passiflora edulis* (passion fruit vine) and some *Ipomoea batatas* (sweet potato). Both these plants are demanding in their nutrient requirements. It is doubtful that these plants can absorb all the nutrients since the fish are at least one trophic level higher than the plants yet the fish have the higher biomass. In order to verify the degree to which the plants are absorbing the nutrients testing would have to be performed under the root zone of the plants.

It is likely that the produce from these plants are contaminated with cadmium. Unless testing is done to prove that they are safe, it should be assumed that these plants are unfit for human consumption. Signage should be placed in front of these plants warning people of this until further testing can prove it safe.

Any fauna consuming these plants would also be exposed to cadmium and it is through this vector that the heavy metal would be spread into the ecosystem above ground. Some cadmium is likely to be entering the subsoil and contaminating ground water - possibly the irrigation bore.

7.0 Sustainability of venture

7.1. Overview of system

Rainbow Trout are farmed within the Recirculating Aquaculture System. This consists of a hatchery, nursery and grow out area. The hatchery and nursery are not always in operation for all times of the year. The grow out area consists of large tanks where the fish are fed Spectra FF commercial fish feed. The grow out tanks have approximately 100kg of fish. Fish feed is at a rate of 2% biomass per day.

Pumps provide circulation of water which travels through various cleansing stages such as UV sterilizers, swirl separators, a sump, protein skimmer, sand filter and a bacterial biofilter.

During the study period the total amount of water in the system was estimated at 13,000 litres. Approximately 1,000 litres per day is discharged.

Photovoltaic solar cells on the roof to supplement the scheme power.

Rainwater harvesting is collected from the roofs of the buildings and stored in tanks which feed into the aquaculture system as needed.

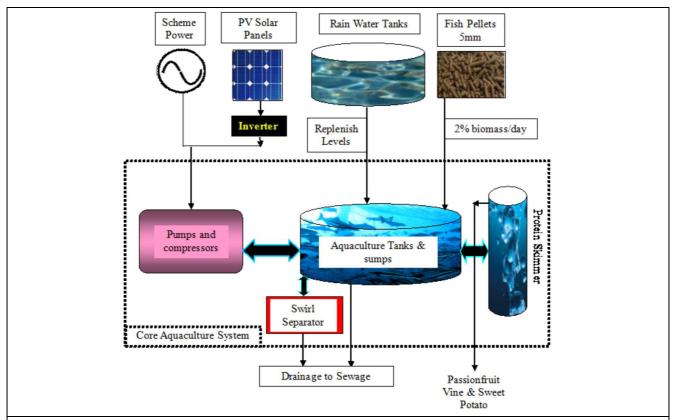


Diagram 1 shows a basic schematic of the aquaculture system. The PV solar cells on the roof assists in driving the pumps and compressors. Rain water is used as the chlorine in scheme water irritates the fish gills. Pellets are also added to feed the fish. Water and sludge are discharged.

7.2 Environmental assessment overall

Overall, as an individual operation the aquaculture system is not doing much harm to the environment. This is mainly because Water Corporation take the sludge that they get and this is either converted to biosolids (Water Corporation 2013) or are applied to the Albany Tree Farm along Gunn Rd.

The Water Corporation is under a legislative requirement to render wastewater safe and a trip by the EMT team earlier this year confirmed that extensive testing does take place.

All of the water used by the aquaculture system is untreated campus harvested rainwater so there are no ongoing carbon emissions in bring the water to the fish tanks.

Although the power consumption of the operation is quite high at 7675KWH over a 10 week period (Metcalfe, 2013, p. 6) this is partially offset by photovoltaic solar cells. There are plans to increase the number of solar panels in the future, thereby reducing the carbon emissions in the future.

Annually the, without assistance from the solar panels, the tonnes of CO₂ produced is 37.4 tonnes (Metcalfe, 2013).

Since the solar panels are connected to the grid there is no environmental impact from storage batteries, as there are none.

8.0 Management recommendations

8.1 Facility use

The facility should continue to be used for aquaculture. While it's true that there are some difficulties to be overcome, it is reasonable to assume that other operators have similar problems. So by overcoming problems on Campus their problems are also overcome.

As an educational institution the GSIT should continue to strive to be a leader in the endeavor of aquaculture. Due to the urban setting of the operation most of the potential environmental impact is avoided by the sewerage facilities provided by Water Corporation.

There is the potential for many aquaculture operations within the Great Southern region which would not have access to Water Corporations sewerage facilities and so therefore would have to strip the nutrients from the water before discharging it.

I believe it falls on the GSIT and other educational institutions to solve this, and other problems with solutions that are inexpensive to implement and operate.

8.2 Equipment

Some of the equipment, including tanks and swirl separators are manufactured on site using fibre glass. This is an inert material which does not leach contaminants into the water after an initial period. The same is true for the piping which is plastic.

There are times when there is a supersaturation of dissolved oxygen in the water. This undesirable state is expensive to produce as it relies on a blower to send bubbles through the water. One possible improvement would be to have a permanent dissolved oxygen sensor in the water and when the dissolved oxygen is to high then power is cut or reduced to the blower.

During the sampling period it was observed that the protein skimmer had algae growing in it. This was apparently utilising the nutrients in the sludge before it left the unit. It would be expected that the algae would inhibit the sludge from leaving the unit and so therefore this should be kept clean.

While not classified as "equipment" the passionfruit vine does provide a service in helping to keep the operation cool in the summer months. Presently this is fertilised by the output of the protein skimmer. In order to qualify more fully with the discharge guidelines it would be beneficial to have the vine in a large pot with the output from the base of the pot diverted away from the environment if the nutrient level is still too high.

8.3 Waste removal

Waste is defined as a failure to use. Most of the dissolved solids within waste water, especially nitrogen and phosphorous, have been paid for by good money. Even in an operation where the discharge is well within guidelines it makes sense to recycle those parameters that can be used by aquaculture and to extract and possibly sell those that cannot be utilised by the fish.

The waste water is also high in cadmium. This is not a plant nutrient and this is best addressed by reducing inputs of cadmium into the system to acceptable levels.

While endeavoring to do the above it is important to keep in mind the cost benefits of reducing waste removal. This is a question of fact specific to each operation. If the operation is close to the 5,000 litre limit and the operation cannot expand due to then you are losing a large opportunity cost. If however you are comfortably within the guidelines it would be difficult to justify a large expenditure. However technology continues to progress and the cost of waste reduction may become viable in the future.

The operation on campus is in an ideal environment for recycling of waste. Most of the sludge is full of nutrients used by horticulture and the institution also produces a lot of shredded paper.

Since one of the objectives of the aquaculture operation is to give advice to other aquaculture operations within the region it follows that various recycling and waste reduction technologies and techniques should be researched. Factors to consider are:

- 1. Difficulty of implementation
- 2. Cost of implementation (capital outlay)
- 3. On-going expenditure, including labour
- 4. How effective the implementation is
- 5. How flexible the implementation is.

Several universities around the world have used earthworms in vermicomposting and vermifiltering as a cost effective and low maintenance way of reducing sludge.

Vermicomposting is the use of earthworms to cold compost organic wastes. The species best used for this is *Eisenia fetida* as this has rapid reproduction, has a large appetite, can withstand a wide range of temperatures and can tolerate a high nutrient level.

Conceptually the diagram of the aquaculture set up would be adjusted to this.

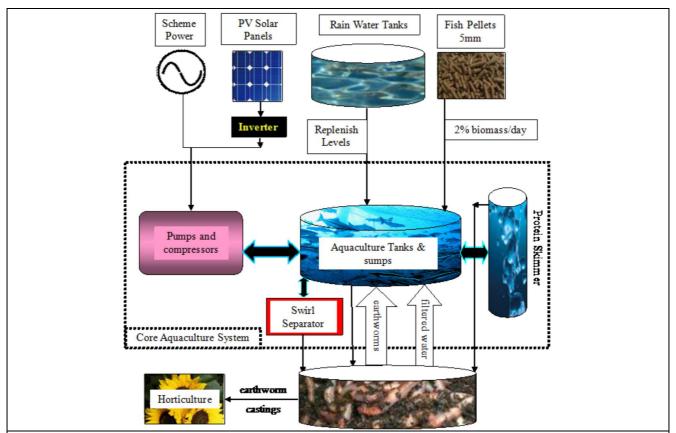
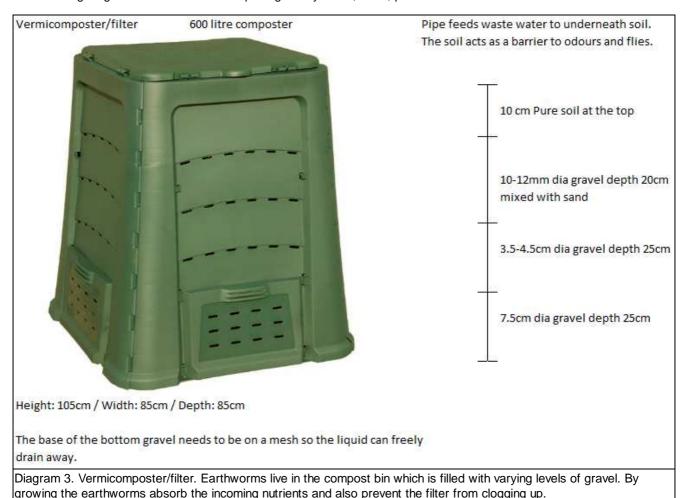


Diagram 2. Here the sludge and water is passed through a vermicomposting /vermifiltering process. The earthworm castings are used as an input to horticulture. The excess earthworms, being high in protein, and the filtered water is reused.

To begin putting this into practice is straight forward, low tech and inexpensive. The main components are compost bins, stones, sand, soil and an initial population of earthworms. Since the earthworms breed fast they will reach a stable population quite quickly and then some would be ready for harvesting.

The following diagram is based on a description given by Sinha, 2008, p. 5.



Once constructed the main objective with one of these biofilters is to test its capabilities to see how effective it is in processing water. Since the unit relies on earthworms for its operation sufficient time will have to be given for its

Once earthworms reach a certain density they stop breeding and at this point a certain number of worms will have to be removed along with their castings as these represent absorbed nutrients. Earthworms double their number every 60-70 days and that vermifiltration has been tested at 8,000 worms per cubic metre, (Sinha, 2008, p.5).

For general work place efficiency it would be best to remove excess worms and castings once a week.

performance to stabilise. Once this performance is known it can be scaled to the size of the operation.

Calculating a doubling every 65 days then the percentage of worms and castings to be removed each week would be $(2^{(7/65)-1}) \times 100 = 7.75\%$ or one thirteenth. This is not easy to judge. It would be a mistake to take out of fixed amount each week because if, for whatever reason, the earthworm numbers dropped they would be less able to produce that quantity of excess worms and castings for the following week. Once this cycle starts it would be difficult to break because the worse the problem gets the bigger the percentage of the total worms the fixed amount withdrawn represents.

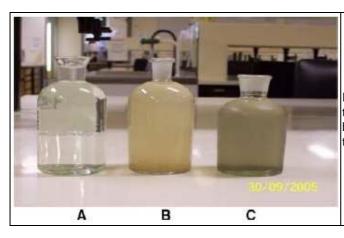
The best solution is to have a mark on the inside of the bin and material is only taken until this mark is reached and no lower. Another factor in favour of this approach is that earthworms do not breed consistently throughout the year.

The number of vermifilters required is as follows:

Parameter		Units	Label
Volume of vermifilter bin	600	litres	Α
Volume in CC (A x 1000)	600000	ml	В
Height	105	cm	С
Length/Width at base	85	cm	D
Divide by height to get mean area (B/C)	5714.286	sq cm	E
Square root to get the mean Length/width (E^0.5)	75.593	cm	F
Length/Width at top (lid) (F-(D-F))	66.186	cm	G
Difference in Length/Width over height of 105cm (D-G)	18.814	cm	Н
Difference in Length/Width over 70cm (cumulative height of the top of the sand over the base) (H x 70/C)	12.543	cm	ı

Length/Width of top of sand (D-I)	72.457		J
Area of top of sand (Length/Width squared) J ²	5250.045	cm ²	K
Area of top of sand (Length/Width squared) m ² (K/10000)	0.525	m^2	L
Prudent loading rate of discharge water m ³ /(m ² .d),(Sinha, 2008, p.3)	2	$m^3(m^2.d)-1$	М
Loading rate of one vermifilter (L x M)	1.050	cum/day	N
Loading rate in litres (N x 1000)	1050	litres / day	0
Estimated daily discharge from aqualculture system	1300	litres / day	Р
Number of vermifilters required (P/O)	1.238		
Rounding up (which leaves a good performance margin)	2		

The water cleansing effect of vermifiltration is beautifully illustrated in the following photograph taken from Sinha, 2008 p. 7.



Picture 1. - "Appearance of sewage before and after treatment. Bottle A, the clean vermifiltered sewage water; bottle B, the hazy water from the controlled kit; bottle C, the turbid and cloudy sewage water." (Sinha, 2008, p. 7)

Another approach is to focus on the protein skimmer. This has got a high level of biosolids with only 3-4 litres of water discharged per day. Earthworms have their highest growth rate when fed on a mixture of 50% cardboard and 50% sludge with an 80% moisture content (Mishra, 2003).

A lot of shredded paper is produced on campus and this should be investigated as a substitute for cardboard. If this is used to half fill one of the segments of a can-o-worms, until sludge fills the rest of the segment. This is then rotated with a second can-o-worms where the bulk of the vermicomposting take place. The following diagram illustrates this idea.

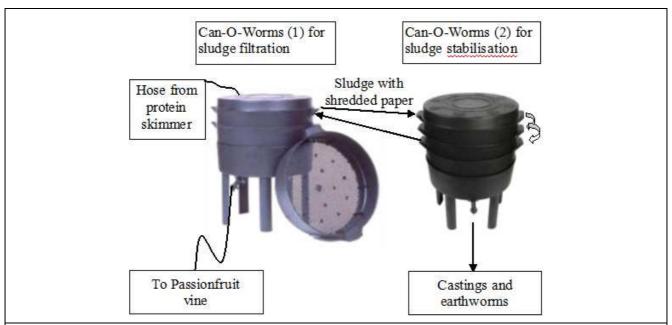


Diagram 4. Here there are two can-o-worms. #1 is fed from the output hose of the protein skimmer and the water, with most of the solids filtered out, flows through the passionfruit vine. Once the top segment fills with sludge (making half paper, half sludge) it is put into #2 where vermicomposting takes place.

As an idea this is also subject to much "fine tuning". It will probably be advantages for #1 to have a lower segment filled with shredded paper and some worms where they will be growing with lower levels of nutrients that is optimum for them. In which case they will be absorbing any dissolved nutrients to their fullest capability. Also it may take more then one '#2' can-o-worms to service the #1.

Furthermore there is nothing preventing these two ideas being combined. The output to the passionfruit vine could be fed

into the compost bin in diagram 3.

Once the optimum combination is found the output water can be reassessed and a decision made whether to recycle the water back into the aquaculture system or apply it to horticulture.

Careful note should also be made of the amount of shredded paper is used by this process and testing done to determine whether the paper is bringing undesirable contaminants into the process.

9.0 Conclusion

The Great Southern Institute of Technology has a great teaching tool in its aquaculture system. It is currently being used to teach Certificate III students.

While the environmental impact of the facilities discharge water is low, this good result is dependent upon scheme sewerage facilities. These facilities are not available on many farm locations. The discharge water is high in nutrients representing an opportunity for horticulture to cut fertiliser usage and therefore lower the environmental impact of the institute as a whole.

While the vermifiltration methods discussed in this report are yet to be confirmed as a viable solution they do represent a good avenue of investigation in the search of providing a cost effective approach toward sustainability.

The ideal situation is that discharge water can be sufficiently scrubbed of nutrients that it can be reused. While this may not be possible to achieve economically, sufficient nutrients can be extracted from the water to greatly reduce the impact of the water on the environment. The nutrients can also be in a form where they can be used elsewhere on a farm or sold to a neighbouring farm.

More research needs to be undertaken in reducing the power consumption of the operation. Fine bubble aeration should be investigated. Depending upon the performance of the vermifiltration is may be possible to dispense with other power consuming filtration.

In summary there are multiple paths to improve the efficiency of this operation and hence assume a leadership role in driving the development of aquaculture in the region.

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