Monitoring the Environmental Performance of the Intensive Recirculating Water Rearing System at the Fish Farm Taste of BC Aquafarms

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ABSTRACT

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The environmental effectiveness of the intensive freshwater recirculating rearing system for rainbow trout (*Oncorhynchus mykiss*) used by the Taste of BC fish farm in Nanaimo, British Columbia, was measured in 2016. Total phosphorus, suspended solids and total solids for all inputs and outputs were measured using 15 24-hour sampling periods, at the same time as fish production.

The amounts of waste excreted by fish was added to the waste introduced by new water. This was compared to the amounts measured in the two effluents in the growing system. Average recovery efficiency was 83% for total phosphorus. For total phosphorus, the total recovery efficiency for the facility could have varied between 63-79% if it used the techniques currently being used in Quebec. Global efficiency would then be superior to the 40% currently required by Quebec ministries for current non-intensive recirculation systems.

Taste of BC fish farm accurately represents the intensive recirculating system that the Quebec fish farming industry wishes to develop. Measuring the environmental effectiveness will provide evidence to determine their environmental impact and facilitate their establishment in the province.

RÉSUMÉ

Marcotte D., Wade, J., and Bibby, A. 2023. Monitoring the environmental performance of the intensive recirculating water rearing system at the fish farm Taste of BC Aquafarms. Can. Tech. Rep. Fish. Aquat. Sci. 3247: v + 25 p.

L’efficacité environnementale du système d’élevage de truite arc-en-ciel en recirculation intensive de l’eau douce de la pisciculture Taste of BC, en Colombie-Britannique, a été mesurée en 2016. Quinze périodes d’échantillonnage, d’une durée de 24 heures chacune, ont été effectuées afin de mesurer tous les intrants et les extrants au système d’élevage, et cela pour le phosphore total, les matières en suspension et les matières totales.

Les charges de rejets larguées par les poissons additionnées à celles introduites par les eaux neuves ont été comparées à celles mesurées dans les 2 effluents du système d’élevage. L’efficacité de récupération moyenne était 83 % pour le phosphore total. Pour le phosphore total, l’efficacité globale de récupération de l’entreprise pourrait varier de 63 % à 79 % si elle utilisait les techniques en opération au Québec. Dans cette situation, l’efficacité de récupération globale serait supérieure de 40 % qui est reconnue par les intervenants gouvernementaux de différents ministères du Québec.

La pisciculture Taste of BC représente le modèle de système en recirculation intensive de l’eau douce que l’industrie piscicole québécoise désire développer. Les mesures d’efficacité environnementale permettront de définir l’impact de ces systèmes et de faciliter leur implantation.

INTRODUCTION

Water recirculation in fish farms is an emerging technology that has attracted global attention. Intensive water recirculation allows the production of fish with very little new water while optimizing production parameters and maintaining biosecurity. Recirculation systems are classified into different intensity levels regarding the use of new (make-up) water (Heldbo et al. 2014).

1) Moderate recirculation: The volume of new water used allows the rearing water to be renewed several times a day without the use of biofiltration.
2) Partial recirculation: This level is characterized by the use of a biofilter to treat rearing water. This reduces the amount of new water required to maintain a healthy growth environment. Complete turnover of rearing water takes approximately one or two days.
3) Intensive recirculation: This system uses the lowest amount of new water, with a complete turnover of rearing water in three or more days. This requires more advanced rearing water treatment systems, such as the use of ozone to maintain the highest possible rearing water quality. Reducing the volume of new water requires more intense rearing water recirculation, and thus more investment in water treatment infrastructure.

The development of the freshwater aquaculture industry in Quebec is currently hampered by both the use of large volumes of high-quality fresh water and the return of high-phosphorous waste water to the environment via effluent. This limits the development of many production sites and regions. Recirculation technology is seldom used in Quebec. Less than a dozen salmon farms use recirculating systems (internal MAPAQ data). Three of them are considered to use partial recirculation, due to the biofilter placement in their fry production units. Other fish farms use moderate recirculation, reusing their rearing water more than once without biofiltration.

There are no fish farms in Quebec that use intensive recirculation throughout their production cycle, so it is difficult to determine the environmental effectiveness of such systems—which, in turn, makes it difficult to convince provincial authorities that they are more environmentally friendly. There is not enough real data on how effectively these systems reduce the phosphorous content in their effluent, and this hinders their implementation in Quebec. This is clear in comparison with other studies measuring the quality of rearing water in rearing systems (e.g., Davison et al., 2011 and 2016). There has been no comprehensive review of the total phosphorous in the effluent of a recirculating production system for rainbow trout (or other salmonids) reared in freshwater. Martins et al. (2010) explain that, in general, intensive recirculating water systems can reach phosphorous recovery efficiencies of 65 to 96%. In other words, the system can recover 67 to 96% of the total phosphorous produced by the fish, in the growing water, in the treatment system or in the accumulation of fish waste.

The waste treatment system can vary from site to site depending on environmental constraints. This treatment can be achieved through sedimentation or filtration with or without the aid of coagulants (Timmons and Ebeling, 2010). In Quebec, most recirculating systems use a three stage waste treatment system: waste concentrator, catch basin for waste concentration and, treatment with hydrated lime. Regardless of whether the waste concentrator or catch basin is used to reduce the waste volume, there remains the presence of a supernatant (overflow) in these catch basins. Therefore, hydrated lime is used to reduce the phosphorous in the overflow (Gagnon, 2014). The recovery efficiency of total phosphorous in this system is 76% (MAPAQ 2009). By combining the recovery efficiency values for phosphorous reported by Martins et al. (2010) with the 76% waste treatment efficiency, total efficiency for an intensive recirculating aquaculture facility can range from 49 to 74%.

These values are substantially higher than the minimum 40% currently required by Quebec authorities for the treatment of effluent from non-intensive recirculating aquaculture facilities currently in operation in the province (MDDELCC 2017). Based on this information, we proposed to measure the environmental effectiveness during actual fish production at Taste of BC Aquafarms in Nanaimo, British Columbia. With an annual rainbow trout production of 100 tonnes, this fish farm accurately represents the model that the Quebec aquaculture industry wishes to develop.

PROJECT OBJECTIVE

To document the environmental effectiveness of the intensive recirculating water rearing system used by the Taste of BC fish farm, so that similar businesses in Quebec can use the results when requesting environmental authorization.

ACKNOWLEDGEMENTS

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METHODOLOGY

Characteristics of the fish farm

The facilities at Taste of BC Aquafarms were designed for an annual production of 100 tonnes of rainbow trout, with a weekly harvest of about 1900 kg of commercial-sized trout (about 1 kg) for the table market. The farm began operations in 2012 and is approaching its full production potential. The total quantity of feed distributed in 2016 (between January 1 and October 20) was 92,144 kg, which is very close to the maximum system design of 110,000 kg/year. Fish are grown in 16 circular tanks with Cornell dual-drain technology: one 8 m^3 tank, four 25 m^3 tanks, four 40 m^3 tanks and four 96 m^3 tanks, for a total rearing volume of 652 m^3. There are also two 25 m^3 tanks for purifying fish before sale. Three pumps (Fairbanks Morse Mixed Flow Propeller, 8211 – 10’’ model, 20 hp per unit) recirculate the water and one pump brings in new water (3 hp Pentair Aquatic Eco-Systems, Sparus™). Rearing water is treated with a biofilter (media composed of 34 m^3 of sifted silica sand) with a fluidized bed, a carbon dioxide degassing system (perforated tray fitted above a forced-air ventilation system), a low-pressure pure oxygenation system (low head oxygenator = LHO) and a drum filter equipped with an 80-micron membrane (PR Aqua model RFF60096). Pure oxygen is generated on-site and cylinders of liquid and gaseous oxygen are available in case of emergency. Oxygen is distributed to each of the tanks through a network of diffusers and the injection of ozone via the LHO. Approximately 100 grams of ozone per hour are injected in order to maintain an oxidation-reduction potential of approximately 150 mV, measured in the LHO by two independent sensors. The rearing tanks are gravity-fed from the LHO. A plate heat exchanger system is available to control (raise) the temperature of the rearing water. However, it is rarely used because the temperature is constantly maintained above the design value of 15°C. Fry are not produced on site but are introduced three to four times per year, at an average unit size of 10 grams. Appendix 1 illustrates the design principle of this rearing system.

The fish farm is supplied with new water at a rate of approximately 135 litres/minute. This flow is initially directed into the two fish depuration tanks. Each of these tanks is equipped with its own CO_2 degassing and water oxygenation column. Through this flow, the entire volume of rearing water is renewed every three to four days. Given the distributed feed, this produces an average recirculation intensity of 540 litres of new water per kilogram of feed used. As defined in the introduction, the ratios for moderate, partial and intensive recirculation are approximately 15,000, 5000 and 500 litres of new water/kg of feed, respectively. This fish farm therefore uses an intensive recirculating water system for fish rearing. The new water comes from a pond fed by groundwater sources, and the effluent (overflow) is directed to an artificial marsh established on site. The rearing system was designed by PR Aqua, a firm in Nanaimo that specializes in such designs. The rearing system was constructed under a dome covering a 62 metre by 22 metre area. As the system has self-cleaning rearing units and is designed to prevent the accumulation of fish waste in the treatment units, the drum filter is the only equipment used to collect fish waste. Minor accumulations of fish waste may appear in the LHO, but they are pumped into the drum filter on a daily basis. This waste is then sent outside of the dome, via the filter backwash, to a separator/accumulation system. The system consists of a vertical reservoir in which solid wastes accumulate at the bottom; waste is accumulated over several weeks before being removed and disposed of. This project did not measure the recovery efficiency of this separator as the design did not permit sufficient solubilisation of solids within the reservoir. Given our objectives, the daily amount of waste was only recorded for the fish farm's rearing system, as illustrated in Appendix 1.

Measurement points and sampling method

The fish farm's environmental effectiveness was established by measuring the amounts of waste for consecutive 24-hour periods (See Appendix II). Water samples were taken, in triplicate, at four locations (sampling points A, D, E/G and F). Calculations were performed using the averages for each triplicate for each day. Automatic water samplers were used (Sigma model SD900 portable sampler) to carry out sampling. Sampling points A, D and E/G correspond to the new water entering the system, the drum filter backwash and the rearing system water overflow, respectively. These points therefore represent all water entering and exiting the rearing system. Point F is where water exiting the rearing units was sampled. At points A, E/G and F, samplers collected water in a small container (spillover) at the outlet of the new water pipe, at the head of the LHO and at the entrance of the drum filter, respectively. At point D, the sampler's suction point was installed at the centre of the sump pit. However, to prevent fish waste particles from sedimenting at the bottom, a mixing pump (Gould submersible pump with a capacity of 80 US gal/min) was used to homogenize the water in the sump pit. It took water from the bottom of the pit and returned it to the surface on the opposite side from the suction point. Since decantation tests showed that the largest waste particles had a sedimentation time of more than 15 minutes, the pump was capable of mixing the full volume of the sump pit water in about 10 minutes.

The samplers took approximately 125 mL of water every 20 minutes during each 24-hour period. The water was collected in a 10-litre container (approximately 9 litres taken per day). At the end of each 24-hour period, the 10-litre containers were gently stirred to suspend the sediment particles. Once homogenized, samples of approximately 250 mL were collected in bottles as instructed by the Maxxam Analytics analytical laboratory in Burnaby, British Columbia. The Maxxam Analytics laboratory (ISO 17025 certification) then analyzed the following parameters for each sample: total phosphorous (TP), total dissolved phosphorus (TDP), total solids (TS), suspended solids (SS) and orthophosphates (ortho).

All samples were kept in a refrigerator (4°C) between collection and transportation to the laboratory. During transport, they were kept on ice in coolers, as instructed by the laboratory. The samples were delivered by sea plane to Vancouver and received at the laboratory within 24 hours after collection. All of the samples were received in good condition. Laboratory analyses were performed in accordance with the standard procedures used by Maxxam Analytics (Maxxam, 2016a, 2016b and 2016c). All results were expressed as concentrations in milligrams per litre.

In 2016, sampling was performed over five periods, consisting of three samples taken on three consecutive measurement days (sampling 24 hours/day). Samples were not taken during the summer as the ozonation system malfunctioned; requiring a reduction in feed to reduce fish stress. The times at which samples were taken included different points in the production system and therefore variations in fish biomass. For example, fish biomass may vary in accordance with water temperatures experienced at different months; by sampling throughout the year this variation can be captured.

These sampling days were:

- February 21, 22 and 23;
- March 21, 22 and 23;
- May 25, 26 and 27;
- August 31 and September 1 and 2; and
- October 12, 13 and 14.

Water flow

Water flow was measured using flowmeters, at the locations shown in Appendix 1. The daily volume of new water was measured by flowmeter #1 (Midwest Instruments and Controls model ET15 electronic propeller flowmeter, accurate to 1.5%), installed on the pipe that conducts new water to the rearing system. Flowmeter #2 (Greyline model PDFM 5.1 Doppler effect portable flow meter, accurate to 2.0%) was used to measure the flow pumped from the sump pit toward the solid waste separator. This flow represents the daily volume of backwash generated by the drum filter.

Unfortunately, it was not possible to measure the water overflow from the rearing system (point E). The overflow pipe outlet was below the water level in the marsh, and the intermittent flow in the pipe prevented any adequate flow measurements. This flow was determined by subtracting the flow at Point D from the flow at Point A.

Production data

Each sampling day, the fish culturist provided their production records to establish the amounts of feed distributed for all types of feed used. During this project, they used Skretting feed (2, 3, 4, 6 and 9 mm) and some 7 mm Ewos feed. The Skretting feed was a variation of their BioTrout high-energy feed, adapted for use in recirculating systems. This feed is now sold under the name Nutra RC through their Bio-Oregon Division. EWOS's Pacific feed was used. The fish were fed seven days a week, with feed distributed over the 24-hour period by automatic feeder. Feeders were adjusted to each rearing tank to meet the fish's food requirements, according to a feeding chart (based on fish size).

On sampling days, temperature was measured and water quality (pH, alkalinity and total ammonia) was measured using a Hach test kit. The feed conversion rate identified by the company was also provided. Rearing water quality measurements are not required to carry out the system treatment efficiency calculations, but they represent the system's rearing conditions.

Feed analysis

On each sampling day, two samples of each feed (±100 grams each) were taken from two different bags of the same feed. These samples were identified according to their size and manufacturer before being sent to the Analysis Department at the Centre d’expertise en analyse environnementale du Québec (CEAEQ) in Laval. Each sample was analyzed to determine its moisture content and total phosphorus concentration using a laboratory procedure developed specifically for fish feed (MDDELCC, 2016).

Efficiency calculations

At measurement points A, D and E, the daily amounts (kg/day) were calculated for TP, TS and SS. These amounts were obtained by multiplying the concentration values identified in the laboratory by the daily water volume for each of these points. Based on the daily amounts used in the calculations, the station's recovery efficiency was determined using the following three equations.

It can be difficult to accurately measure dissolved particles in fish culture water using automatic samplers. After verifying the effect of sampling method on efficiency calculations using the literature, three equations were used (see below). It was found that particles could rapidly sediment and therefore not be collected by the autosampler. There is a risk of underestimating the concentrations of SS, TS and TP as a small fraction of the phosphorous expelled by the fish is in particulate form. The results from the samples taken at the measuring points with the lowest particle loading are considered the most representative. For example, a water sample with a large dissolved phosphorous loading and a low particulate phosphorous loading produces a more uniform sample composition. This is the case at sample points A and E; a greater variability was observed at sample point D.

Using the measurements taken at Point D:

Calculation of the recovery efficiency from the drum filter in comparison to those from the make-up water and the waste excreted by the fish.

(1) $$Recov.Eff.\#1 = \frac{\mathrm{C}_{\text{point D}}}{(\mathrm{C}_{\text{point A}} + \mathrm{C}_{\text{fish waste}})}$$

Where:

Recov. Eff. #1 = Recovery efficiency in the rearing system using the amounts collected by the drum filter, %

$C_{\text{Point D}}$ = Amounts measured at point D, kg/day;

$C_{\text{Point A}}$ = Amounts measured at point A, kg/day;

$C_{\text{fish waste}}$ = Amounts of fish waste (gross waste), kg/day.

For these three parameters, the amounts of waste excreted by fish were measured based on the following:

- $C_{\text{fish waste}}$ for TP = $TP_{\text{feed}} - TP_{\text{fish}} = (Kg_{\text{feed}} \times TP\%_{\text{feed}}) - (Mass_{\text{fish}} \times TP\%_{\text{fish}})$

Where:

TP_{feed} = daily total phosphorus load contributed by the feed, kg/day;

TP_{fish} = daily total phosphorus amount retained by fish, kg/day;

Kg_{feed} = daily quantities of feed distributed, kg/day;

$TP\%_{\text{feed}}$ = level of TP in feed determined by the laboratory, %;

$Mass_{\text{fish}}$ = Kg_{feed} x FCR = gain in biomass (fish), kg/day;

$TP\%_{\text{fish}}$ = total phosphorus levels for all fish cohorts = 0.40% = normal level used to calculate phosphorus amounts (Ouellet, 1999). In comparison, Boucher et al. (2013) measured an average level of 0.35% for rainbow trout.

- $C_{\text{fish waste}}$ for TS = $[Kg_{\text{feed}} \times (1 - moisture\%_{\text{feed}})] - (Mass_{\text{fish}} \times TS\%_{\text{fish}})$

Where:

$humidity\%_{\text{feed}}$ = proportion of water in the total feed mass, determined by the laboratory, %;

$TS\%_{\text{fish}}$ = proportion of dry matter in the biomass = 30% (Gokoglu, 2004).

- $C_{\text{fish waste}}$ for SS = 25% x Kg_{feed}

Where:

25% = proportion of the mass of feed in the form of SS excreted by the fish (Timmons and Ebeling, 2010).

Using measurements taken at point E:

Calculation of the recovery efficiency of the loading produced by the water outflow in comparison to those from the make-up water and the waste excreted by the fish. This calculation represents the proportion of waste not captured by the drum filter.

$$Recov.Eff.\#2 = 1 - \frac{C_{\text{point E}}}{(C_{\text{point A}} + C_{\text{fish waste}})} \tag{2}$$

Where:

Recov. Eff. #2 = Recovery efficiency in the rearing system using the loads evacuated by the station's water overflow, %

$C_{\text{Point E}}$ = Amounts measured at Point E, kg/day;

Comparing only the measurements taken at points D and E:

Calculation using only two measuring points in the rearing system.

$$Recov.Eff.\#3 = \frac{C_{\text{point D}}}{(C_{\text{point D}} + C_{\text{point E}})} \tag{3}$$

Where:

Recov. eff. #3 = Recovery efficiency in the rearing system using only the amounts measured at both of the station's output points, %

RESULTS AND ANALYSES

Flows

Table 1 presents the measurements obtained for water flows. The new water flow was close to the design flow of 135 L/min, despite a decrease toward the end of the project. However, this decrease is related to droughts in the region in 2016, which lowered water levels in the supply pond. Despite this, the flow measured at point D remained relatively constant throughout the project. Since the design flow for the drum filter (filtered water) is 766 m³/h, the backwash represented an average 0.34% of this amount. For comparison, Timmons and Ebeling (2010) provide values of 0.2 to 2.0%. Also, based on actual on-site measurements, MAPAQ (internal data) suggests values ranging from 0.3 to 0.5%. Considering the accuracy of flowmeter #1, whose values are correlated with the flow indicator of the new water supply pump, all the information indicates that the water flow values obtained are realistic. Consequently, and considering the diagram in Appendix 1, the flow at point E was determined by subtracting the flow at point D from the flow at point A.

Table 1. Water flows measured at points A and D.

Measurement sessions	A – New water	D – Drum filter backwash	
	Flowmeter #1	Flowmeter #2	
	litre/minute	litre/minute	This flow's proportion of the total filtered flow, %
21-Feb-16	141	31	0.25%
22-Feb-16	135	30	0.23%
23-Feb-16	102	33	0.26%
21-Mar-16	135	44	0.34%
22-Mar-16	129	38	0.30%
23-Mar-16	127	38	0.30%
25-May-16	135	44	0.34%
26-May-16	129	38	0.30%
27-May-16	127	38	0.30%
31-Aug-16	113	58	0.45%
01-Sep-16	117	59	0.46%
02-Sep-16	115	58	0.45%
12-Oct-16	83	44	0.34%
13-Oct-16	82	46	0.36%
14-Oct-16	85	43	0.34%
Average =	117	43	0.34%

Concentrations measured

Appendix 3 presents a table of the concentration values determined by the laboratory for all measurement points and for each sample day. For the new water (measurement point A), all concentration values were seen to increase during the fourth sampling session. While this increase cannot be explained, it does not seem to have affected the recovery efficiencies.

Phosphorous:

In all of the analyses of new water, almost all of the TP was in dissolved form (TDP), which consisted of approximately 96% orthophosphate (ortho).

For all measurements at Point D (filter backwash), an average ratio of 2.6% was obtained by calculating the proportion of TP contained in the SS. According to Gagnon (2014), this ratio normally varies between 1.3 and 2.8% based on the recovery efficiency of the drum filters. The only exception was the measurement from October 12, which had a lower ratio and TP concentration. Only an error during sampling could explain these lower values. For this backwash, an average of 47% of the TP was in dissolved form (TDP), which consisted of approximately 58% orthophosphate (ortho). It was calculated that about 45% of this TDP comes from phosphorous (which is almost entirely in the form of orthophosphates) already present in the filter backwash (water from Point F). It therefore appears that about half of the TP recovered in the backwash was in particulate form, a quarter was in the form of orthophosphates from the use of rearing water as membrane backwash, and the remaining quarter was rapidly dissolved (non-orthophosphate) recovered particulate phosphorus.

For Points E/G and F, almost all of the TP (99%) was in dissolved form (TDP), which consisted of approximately 98% orthophosphates.

SS and TS:

All the values obtained when sampling upstream (Point E/G) and downstream (Point F) of the rearing units are very similar, except for the SS concentrations. These are logically higher (average of 150% for all measurement sessions) upstream of the drum filter (Point F). For TS, similar concentrations were measured upstream and downstream of the drum filter. This shows the inefficiency in recovering these solids, which must be appearing in dissolved form or at sizes too small for the membrane. No particle size analysis was planned for the project. As a result, these TS accumulate in the rearing water before being removed by the overflow.

A comparison of the three consecutive measurement days for a given session reveals much greater variation in the concentrations measured at point D. This is due to the great difficulty of collecting a representative sample of this backwash using an automatic sampler. This water contains large particles (some over 60 to 80 µm) that can easily escape sampling due to rapid sedimentation in the recovery ditch, despite the mixing pump. In comparison, the samples from points A and E are considered more reliable, as the parameters of the water collected are more homogeneous. There are very few suspended particles (measured and observed) and phosphorus is almost entirely present in dissolved form. This phenomenon supports the use of the second formula and the conclusions thereof.

Though the effects of the ozone could not be evaluated (because the system could not be monitored when not using ozone), its dosage in the rearing water helped to keep concentrations of SS below 10 mg/L in the rearing water (point F). Davidson et al. (2011) showed that ozone reduces the SS load in the rearing water of recirculating systems. It causes a microflocculation of fine particles, increasing their rate of recovery by filtration equipment. Using ozone, they measured reductions of SS in the rearing units up to 50%. However, they did not demonstrate that it improves phosphorus recovery. A monitoring report prepared by Taste of BC (2015) with and without the use of the ozone dosage system also shows that it slightly reduced SS loading in rearing water, though it remained between 5 and 15 mg/L with or without ozone. However, this report indicates that without the use of ozone, the rearing water was a brown colour that made it difficult to see the fish. It is possible that the fine particles that are not recovered are broken down into colloids or dissolved. The use of ozone provides some advantages for SS recovery efficiency, but also seems to explain the high concentrations of TS in the system.

Feed and production

Table 2 shows the results of the laboratory analyses of the feeds used during the project. Based on these data, Table 3 presents an evaluation of gross fish waste according to the feed distributed on each sampling day and the gain in biomass.

For measurements of rearing water quality, temperatures varied between 12 and 19°C during the tests. They remained between 17 and 19°C during the first four measurement sessions. The minimum was reached in October. Throughout the project, measurements of pH, alkalinity and the concentrations of total ammonia, nitrites and nitrates ranged from 6.6 to 7.4, from 35 to 50 mg/L, from 1.8 to 2.9 mg/L, from 0.04 to 0.12 mg/L and from 48 to 142 mg/L, respectively. At all times during the tests, the quality of the rearing water remained adequate. The fish culturist evaluated the conversion rate by measuring the average weight every week, obtaining a value of 1.10.

Table 2. Feed analysis results.

Feed		TP% (average of all analyses)	moisture% (average of all analyses)	Number of analyses per parameter
Brand	**Size**	**mg/kg**	**%**	
Skretting	9 mm	9,255	4.79	12
	6 mm	9,520	6.24	10
	4 mm	11,550	5.91	12
	3 mm	12,250	5.00	6
	2 mm	11,217	7.89	8
Ewos	7 mm	13,500	4.74	6

Table 3. Production data.

Measurement sessions	Feed distributed		Biomass of fish	Gross fish waste (prior to any processing)		
	kg/day	**Input of TP from feed (kg TP/day)**	**Production, kg/day**	**kg TP/day**	**kg TS/day**	**kg SS/day**
21-Feb-16	252	2.73	229	1.81	--	63
22-Feb-16	243	2.63	221	1.75	--	61
23-Feb-16	261	2.96	237	2.01	--	65
21-Mar-16	300	3.19	273	2.10	202	75
22-Mar-16	280	3.02	255	2.00	188	70
23-Mar-16	291	3.10	265	2.04	196	73
25-May-16	317	3.31	288	2.15	215	79
26-May-16	317	3.31	288	2.15	215	79
27-May-16	317	3.31	288	2.15	215	79
31-Aug-16	382	3.46	347	2.07	254	96
01-Sep-16	404	3.64	367	2.17	269	101
02-Sep-16	404	3.65	367	2.18	269	101
12-Oct-16	410	4.05	373	2.56	272	103
13-Oct-16	380	3.77	345	2.39	251	95
14-Oct-16	410	4.05	373	2.56	272	103

Loads calculated

Figures 1 to 3 present the results of the load calculations at the measurement points used for the recovery efficiency calculations. The data are the average values obtained over the three consecutive days in the sample period. The growing conditions are considered to be constant over these three days. Figures 1 and 3 illustrate the loads of TP and SS (respectively) collected by the drum filter as well as the variability in results obtained for suspended solids, respectively. In Figure 2, as previously discussed in connection with the difficulty in recovering TS, the loads of these TS are distributed relatively equally between points D and E.

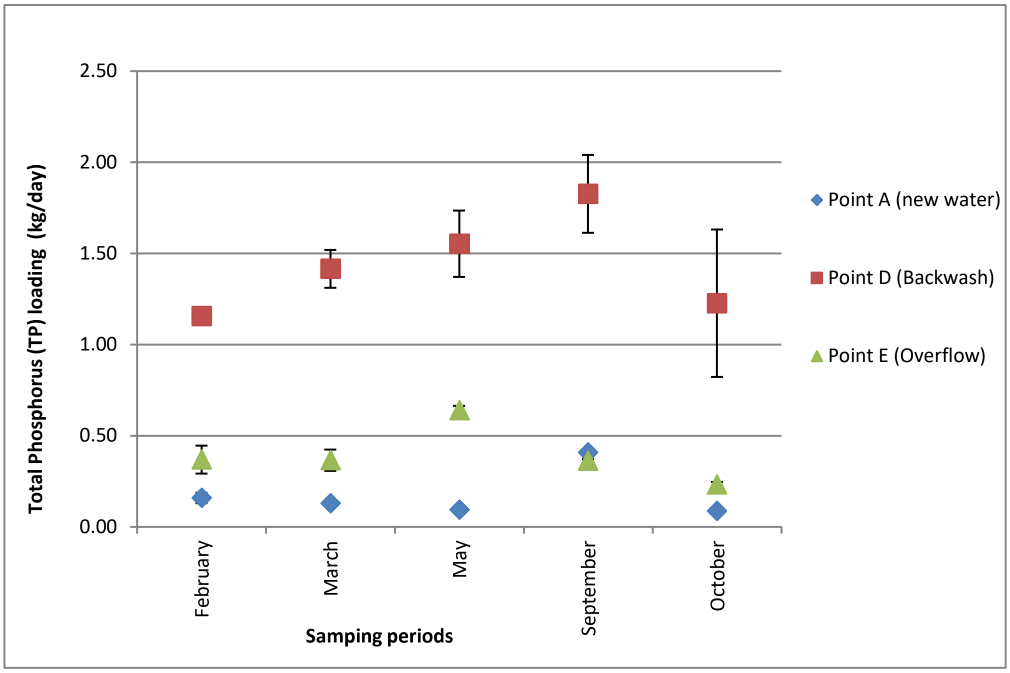

Figure 1. Average calculated Total Phosphorous (TP) loading with sandard deviation.

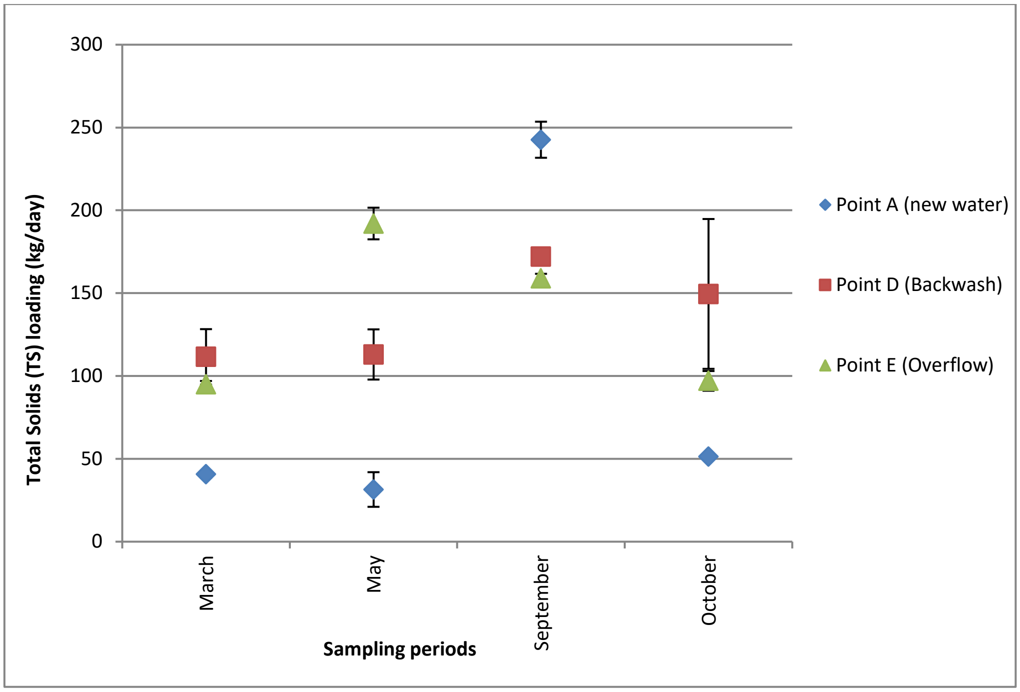

Figure 2. Average calculated Total Solids (TS) loading with standard deviation.

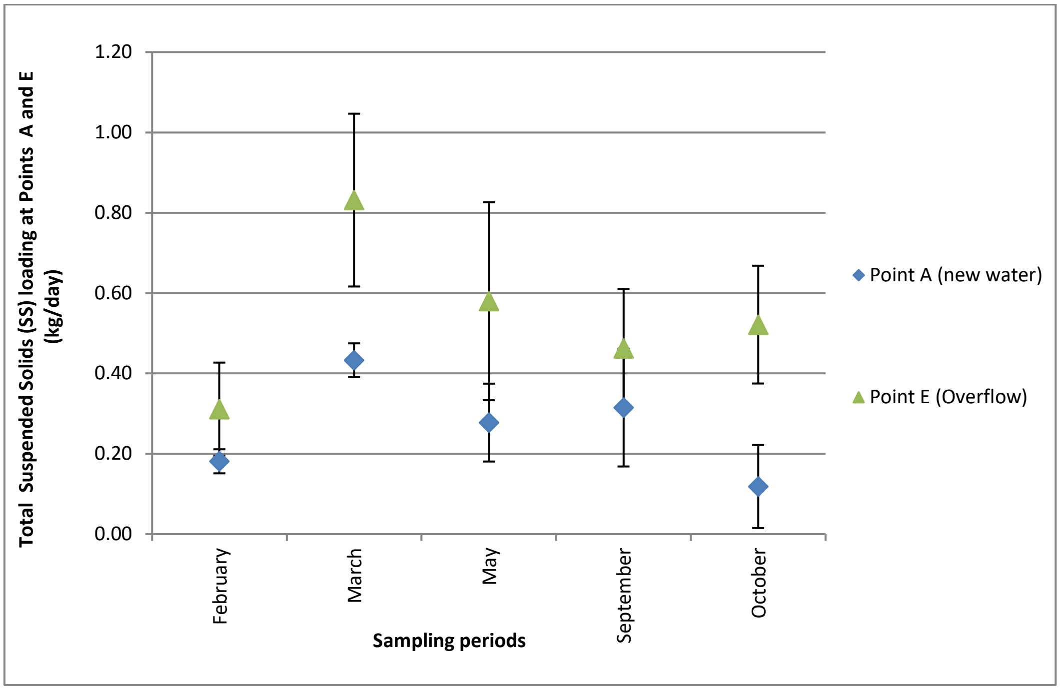

Figure 3.1. Average calculated Suspended Solids (SS) loading with standard deviation measured at sample points A and E.

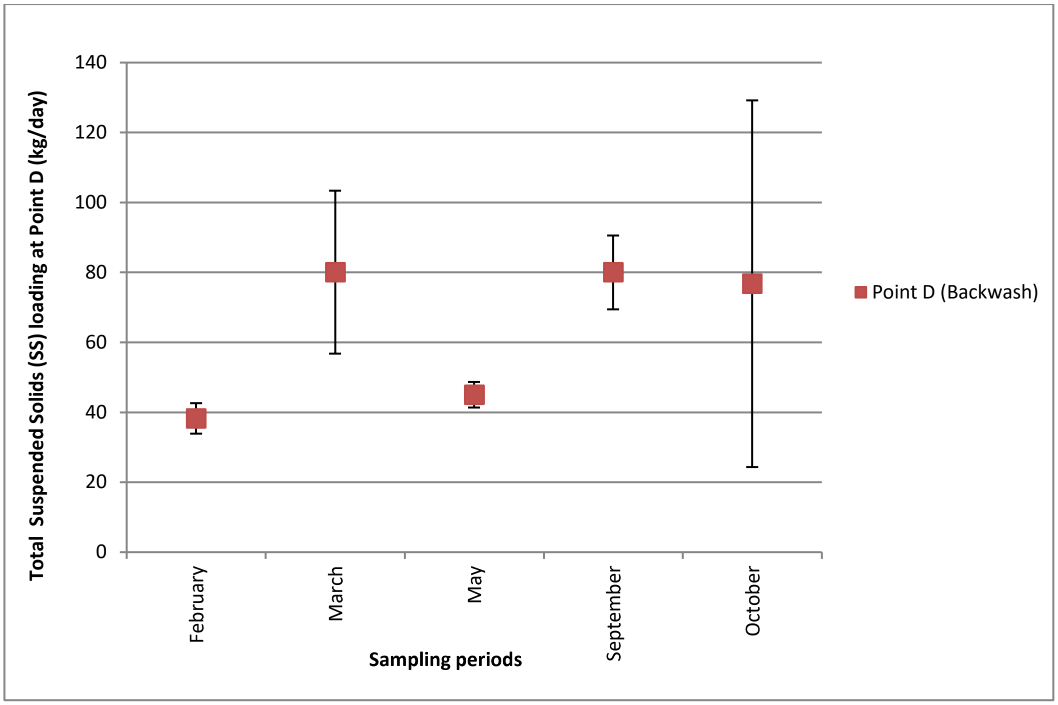

Figure 3.2. Average calculated Suspended Solids (SS) loading with standard deviation measured at sample point D.

Recovery efficiency calculation for the growing system

Figures 4 to 6 present the results of the recovery efficiency calculations for TP, TS and SS based on efficiency calculations #1 and #2 presented above. The results calculated using Recovery Efficiency #1 are both the lowest and the most variable. This confirms that it is difficult to continuously sample the drum filter backwash and that this leads to potential underestimation of the results. Despite this, the calculated average recovery efficiencies for all sampling days were 62%, 44% and 77% for TP, TS and SS, respectively.

Considering the greater reliability of the sampling results from point E, results calculated using Recovery Efficiency #2 are considered to be more accurate. The calculated average recovery efficiencies for all sampling days were 83%, 55% and 99% for TP, TS and SS, respectively. Like the calculation in equation #1, these efficiencies are based on the recovery of waste excreted by fish in addition to those introduced by the new water. Given the behaviour of the parameters in the water, for example the rapid solubility of phosphorous, it is impossible to distinguish the proportion that comes from new water or from fish waste for a given parameter. For phosphorus, considering loads from new water (point A) does not have a significant impact on recovery at the drum filter. This phosphorus is already dissolved and normally cannot be recovered by this filter. For reference purposes and comparing only the two rearing system effluents, Recovery Efficiency #3 (not illustrated in Figures 4 to 6) produced average recovery efficiencies for all sampling days of 79%, 51% and 99% for TP, TS and SS, respectively. These values are similar to those obtained using efficiency calculation #2.

When comparing the inputs and outputs of the amount of loading for all sampling days and the standard deviations there were, on average, decreases of 20%, 11% and 22% for the TP, TS and SS loads measured, respectively. This means that the amounts excreted by fish in addition to the amounts measured at point A (both inputs) did not match the lower amounts measured at points D or E (outputs). Regarding the inputs, the level of phosphorus contained in the fish would have to be raised or the rate of feed conversion would have to be reduced to balance the TP amount. However, this would require the use of unconventional and unmeasured values for this kind of fish farming production. In addition, the measurements at point A were considered to be accurate. Balancing these amounts using the outputs would mean considering two options: the accumulation of a fraction of the fish waste in the rearing system or an underestimation of the amounts measured at points D or E. Given that there is no accumulation of waste in the rearing system and that this system has been operating continuously for several months, this assumption was not retained. Given the difficulty of sampling adequately at point D, as mentioned above, underestimating the amounts recovered by the drum filter is the most plausible hypothesis. Figure 7 shows a correlation between these discrepancies and the results of Recovery Efficiency #1 for TP. Recovery Efficiency #1 increases when the value of these discrepancies decreases. Logically, if the values (%) of these decreases are added to the values (%) obtained from efficiency calculation #1, exactly the same values are found as those from efficiency calculation #2.

Considering the technical difficulties in measuring actual production conditions, their determination remains theoretical: the fraction of the distributed feed excreted as waste, the level of total solids (TS) and phosphorus (TP) contained in the total fish biomass. Other variables can also be difficult to evaluate on-site, such as the feed conversion ratio (FCR). The fraction of fish waste produced and the level of TS in the fish do not affect the TP recovery calculations. They are therefore not investigated further. However, Table 4 presents the impacts of potential variations in the values for fish phosphorus levels and FCR on the total phosphorous recovery efficiency calculations. It shows that these variations have little impact on the efficiency results or on the justification of decreases in total phosphorus to balance the amounts. Recovery Efficiency #2 can therefore be considered the most accurate.

Table 4. Theoretical impacts on the Total Phosphorous recovery efficiency amounts. Note: The values in bold represent the results obtained in the project, based on the original values of the variables.

Variations in the variable(s):	**Values used in the calculations**	**TP recovery efficiency for all sampling sessions**		**For all sessions, average of decreases to balance the TP amount**
		Efficiency calculation #1	**Efficiency calculation #2**	
TP_{fish}	0.45%	65.6%	81.8%	16.2%
	0.40%	**62.2%**	**82.6%**	**20.4%**
	0.35%	59.3%	83.3%	24.0%
FCR	1.20	60.2%	83.1%	22.8%
	1.10	**62.2%**	**82.6%**	**20.4%**
	1.00	64.9%	82.0%	17.1%
	0.90	68.5%	81.1%	12.6%
TP_{fish} and FCR	0.45% and 0.9	73.9%	79.8%	6.0%
	0.35% and 1.0	61.3%	82.8%	21.5%
	0.35% and 1.2	57.7%	83.7%	25.9%

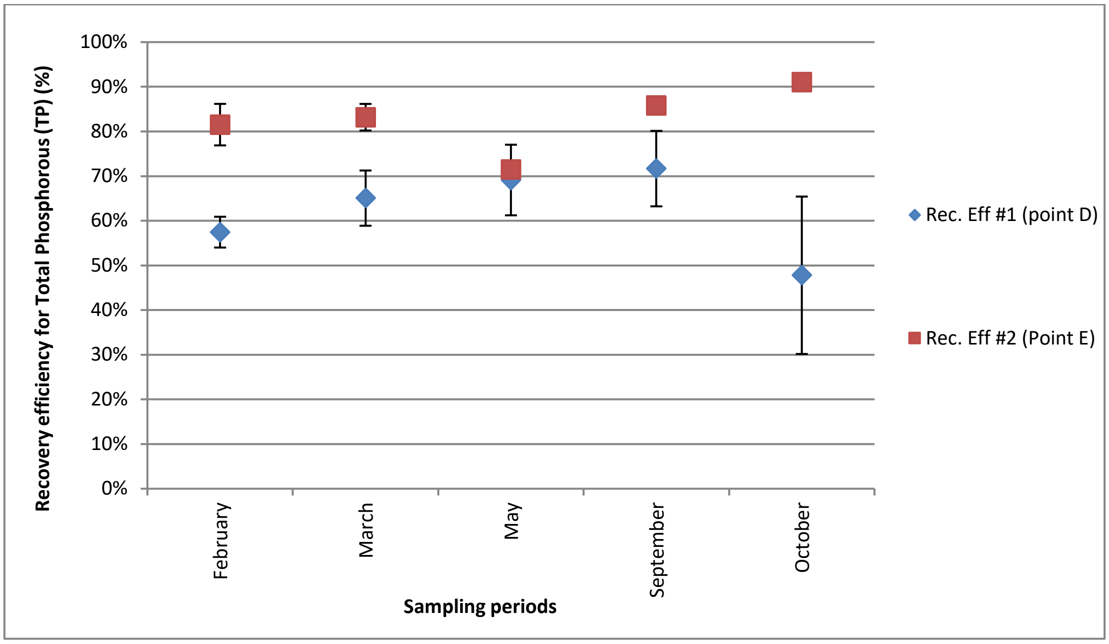

Figure 4. Recovery efficiencies determined for Total Phosphorous (TP) with standard deviation.

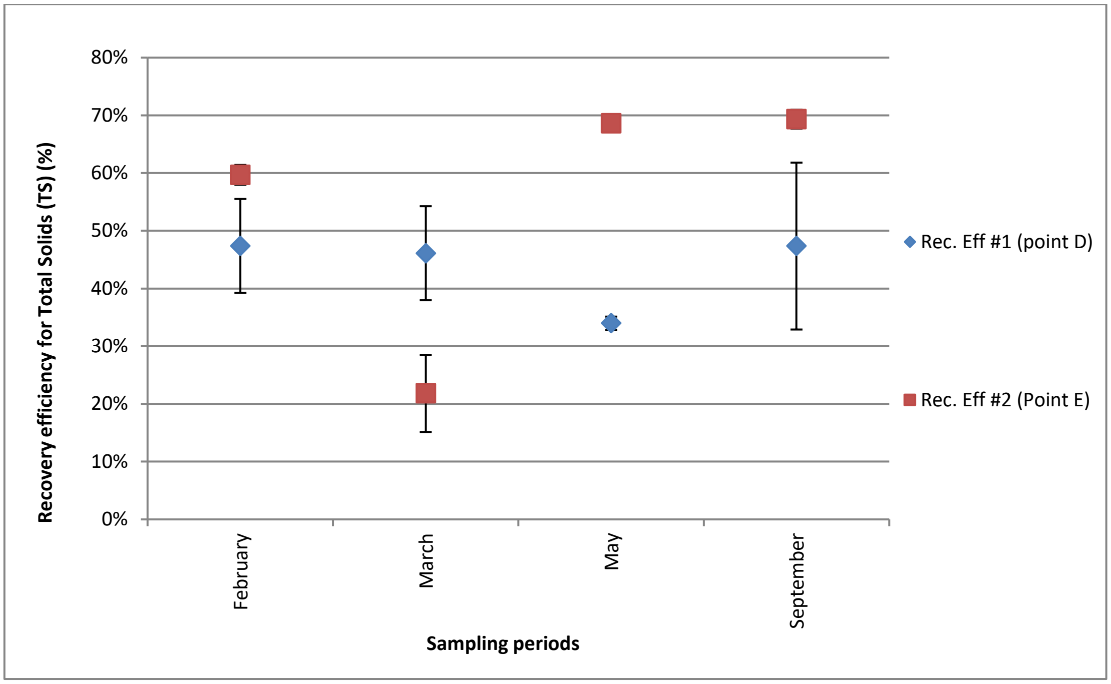

Figure 5. Recovery efficiencies determined for Total Solids (TS) with standard deviation.

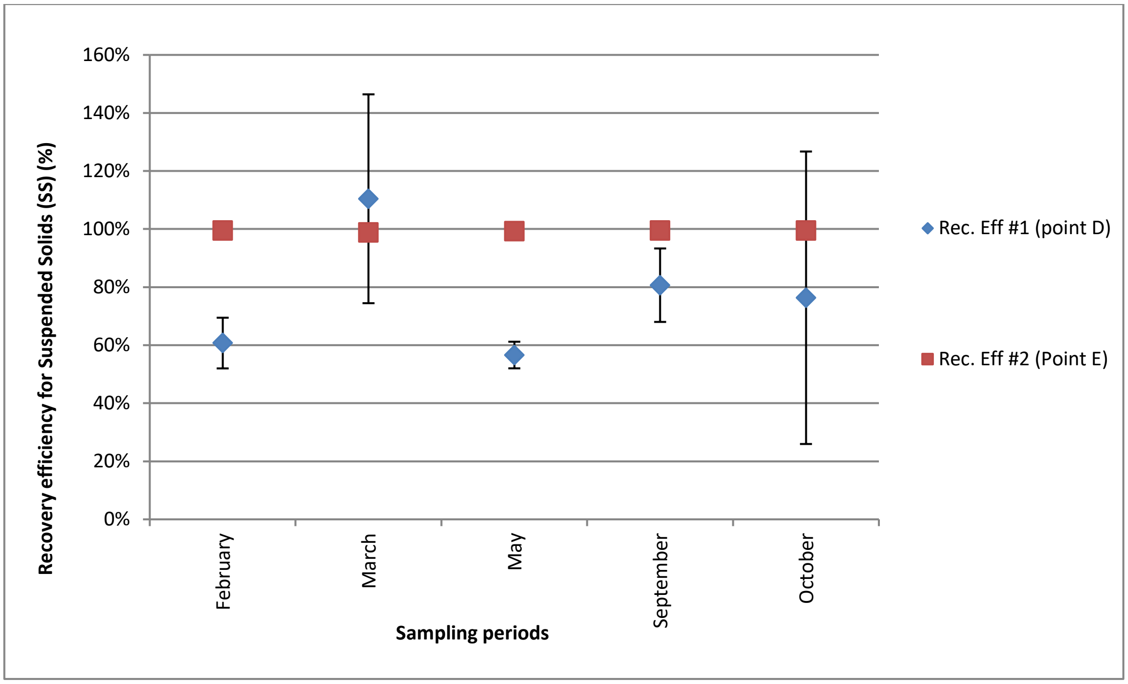

Figure 6. Recovery efficiencies determined for Suspended Solids (SS) with standard deviation.

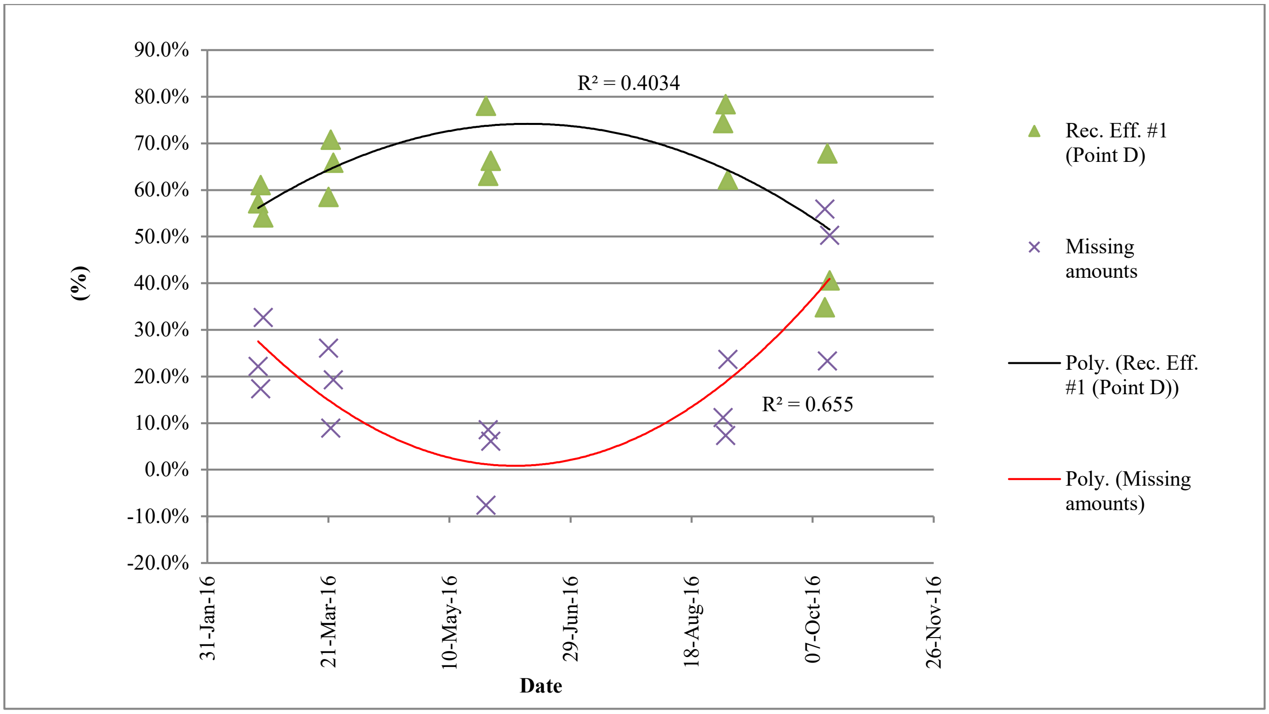

Figure 7. For Total Phosphorous, comparison between the results of Recovery Efficiency #1 and the missing amounts to balance the record.

Treating the entire output of both effluents

The objective of the project was to measure the recovery efficiency of this specific fish farm's rearing system, mainly for total phosphorus. But to bring this system to Quebec, they must also include effluent treatment. Quebec fish farmers already have techniques for treating fish waste which are adapted to their facilities (MAPAQ, 2009). In Quebec, most recirculating systems use a three stage waste treatment system: waste concentrator, catch basin for waste concentration, and treatment with hydrated lime (Gagnon, 2014). By applying the recovery efficiency values derived from calculation #2 for total phosphorous to the system described by Gagnon (2014), total recovery efficiency at Taste of BC fish farm could vary between 63-79%. Without the concentrator, the system has an ability to achieve more than 95% total phosphorous efficiency but requires a large volume of water. The addition of a concentrator reduces the amount of water required but reduces efficiency of TP retention by approximately 20%.

But due to the low volume of makeup water required to operate these intensive recirculating water systems, treating the entire output of the rearing system's two effluents is also a possibility (measured at points D and E). Table 5 illustrates the characteristics of the water to be treated by combining the measurements taken for both effluents of the Taste of BC fish farm on average for all sampling sessions, the water to be treated would contain 11 mg/L total phosphorus and 405 mg/L suspended solids. On average, according to the project measurements, about 58% of TP would be in dissolved form. According to data from ministère du Développement durable, de l'Environnement et de la Lutte contre les changements climatiques (MDDELCC) (2011), these concentrations are very similar to those for domestic wastewater (10 mg/L for TP and 300 mg/L for SS). For fish farms using intensive water recirculation, the use of domestic wastewater treatment systems to obtain the same recovery efficiencies is an option.

Table 5. Characteristics of the water to be treated, combining the two effluents (TP= Total Phosphorous, SS=Suspended Solids).

Measurement sessions	Combination of measurement points D (filter backwash) and E (rearing system overflow)				
	Total of flows	Total of amounts measured		Concentrations obtained	
	m^3/day	kg TP/day	kg SS/day	mg TP/L	mg SS/L
21-Feb-16	203	1.56	40.95	7.7	202.1
22-Feb-16	194	1.58	41.34	8.1	212.9
23-Feb-16	147	1.44	33.39	9.8	227.0
21-Mar-16	195	1.65	63.78	8.5	327.4
22-Mar-16	186	1.94	107.43	10.4	577.3
23-Mar-16	183	1.75	71.50	9.5	389.6
25-May-16	195	2.43	46.57	12.4	239.1
26-May-16	186	2.05	41.74	11.0	224.3
27-May-16	183	2.10	48.50	11.5	264.3
31-Aug-16	162	2.18	89.06	13.4	549.2
01-Sep-16	168	2.41	83.84	14.4	499.3
02-Sep-16	165	1.98	68.48	12.0	415.1
12-Oct-16	119	1.17	136.02	9.8	1145.0
13-Oct-16	118	1.90	61.21	16.1	517.9
14-Oct-16	122	1.31	34.63	10.7	283.2
Average	168	1.83	64.6	11.0	404.9

CONCLUSION

The environmental effectiveness of the intensive recirculating water rearing system at the Taste of BC freshwater fish farm in Nanaimo, British Columbia was measured 15 times between February and October 2016. However, the project did not monitor the efficiency of the treatment and accumulation system for fish waste recovered from the rearing system, the rearing system's inputs and outputs were measured over the course of 15 24-hour sampling periods. To determine these daily amounts, the volume of water used, and the feed distributed, biomass production and the concentrations of phosphorus, suspended solids and total solids in the water entering and exiting the fish farm were measured.

For this growing system, the results were average recovery efficiencies for all sampling days of 83%, 55% and 99% for total phosphorus (TP), total solids (TS) and suspended solids (SS), respectively. For TP, average recovery efficiencies could range between 63-79% if the drum filter effluent treatment system currently in use in Quebec was installed. In addition, the recovery efficiencies could increase to more than 95% by treating both sources of effluent using a domestic water treatment system. Regardless, the recovery efficiency of TP from the Taste of BC fish farm exceeds the minimum 40% required for fish farms by Quebec authorities.

TS accumulate in the rearing system before being removed via the system's water overflow. This is all due to the low recovery capacity of the drum filter, the only treatment system that can remove fish waste from the rearing system. SS are virtually absent from the system's water overflow and are mainly present in the drum filter backwash. SS concentrations in the rearing water were maintained below 10 mg/L, which provides very high water quality for fish (Timmons and Ebeling, 2010). Despite all this, and even with our best efforts, it was difficult to optimally, continuously sample these SS in the filter backwash due to their quick sedimentation. The final recovery efficiency values are therefore based on the measurements of amounts (TP, TS and SS) not recovered in the rearing system's water overflow. The use of an ozone injection system in the rearing water seems to have a favourable, but unquantified, effect on the recovery efficiencies obtained. Ozone clarifies the water by improving SS recovery and breaking unrecovered SS down into smaller particles not visible to the naked eye.

With an annual rainbow trout production of 100 tonnes, this fish farm accurately represents the model of intensive recirculating water system that the Quebec fish farming industry wishes to develop. These environmental efficiency measurements will help to better define the impact of these systems and facilitate their implementation. The project was conducted on a rainbow trout production, but all signs indicate that the results would be similar for other fish species, such as salmonids and percidae, already in commercial production. In fact, according to Dalsgaard et al. (2013), all recirculating systems are designed to ensure the best rearing conditions for fish. They allow for optimal fish growth and feed and oxygen consumption while ensuring the most efficient rearing water treatment, since they allow the quickest removal fish waste, among other things. The rearing system design parameters must be adjusted based on the requirements for the fish species, such as temperature, salinity, feed type or biomass densities. The intensive recirculating water system is then installed to ensure optimal productivity and rearing water quality. The project has confirmed that these intensive recirculating water systems are able to recover a very large proportion of fish waste while concentrating that waste into low-flow effluents. The overall environmental effectiveness of a production site will ultimately be determined based on the method used to treat and retain the phosphorous in the waste recovery line. This opens the door to the use of more advanced treatment systems to treat the entire output of the rearing system's two effluents: water overflow and the water line containing recovered fish waste.

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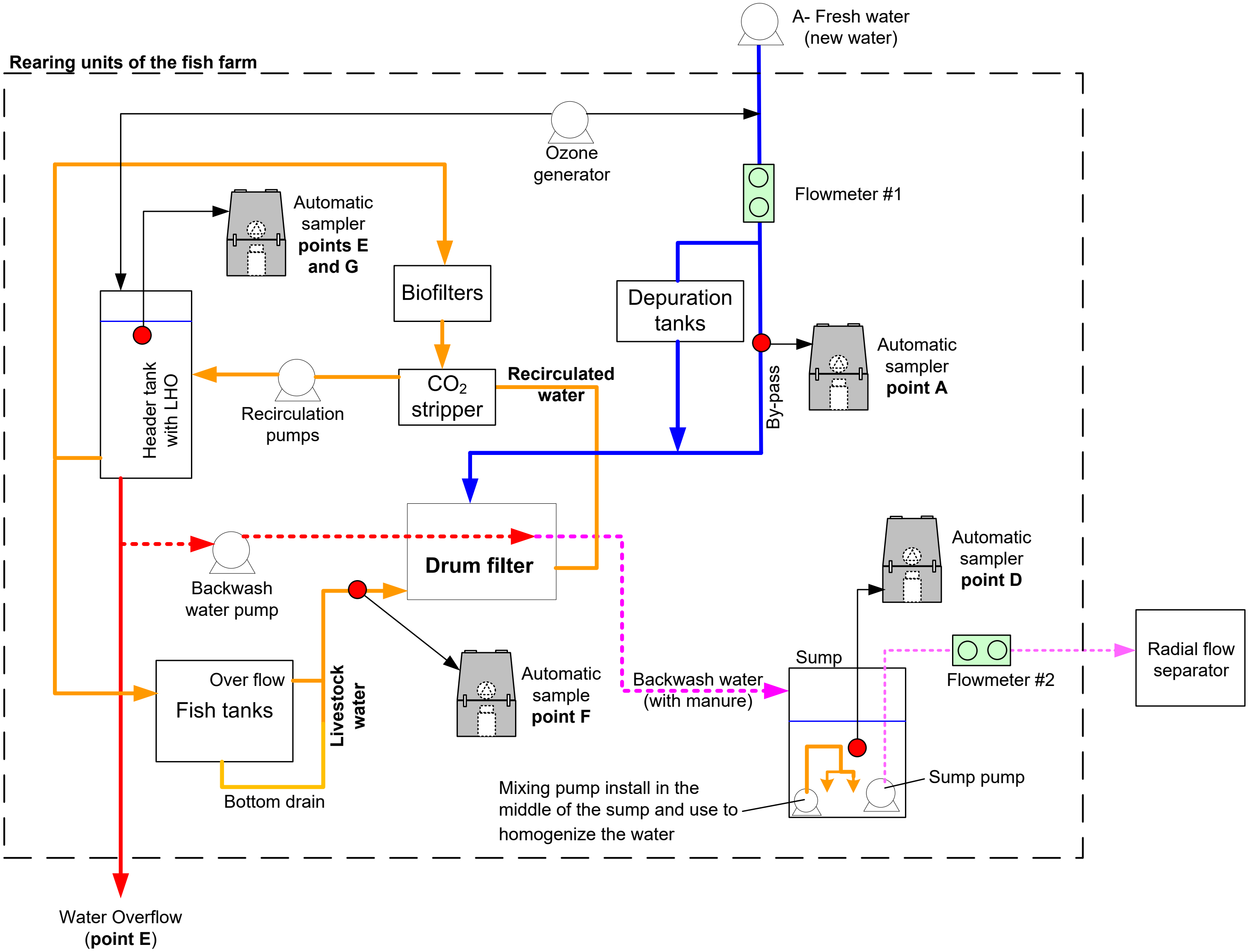
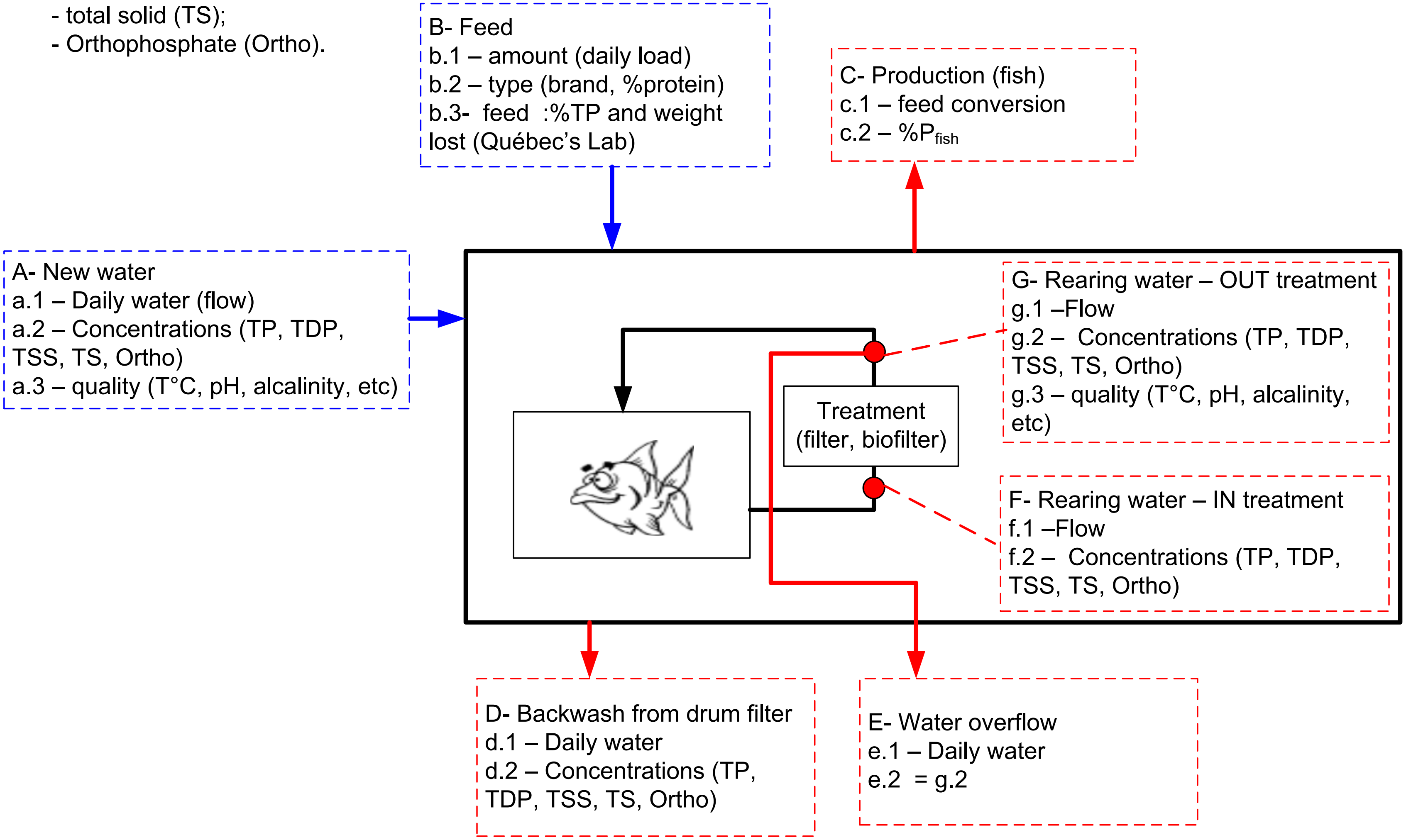
APPENDIX 1: Diagram of the Taste of BC rearing system and location of sampling points.



APPENDIX 2: Measurement parameters for calculating the mass amounts.

Daily mass balance, by measuring one or all of the concentrations of these variables :
- total phosphorus (TP);
- total dissolved phosphorus (TDP);
- total suspended solid (TSS);
- total solid (TS);
- Orthophosphate (Ortho).



APPENDIX 3: Water quality measurements determined in the laboratory.

Table 6. Concentrations of Total Phosphorous (TP), Total Solids (TS), Suspended Solids (SS), Total Dissolved Phosphorous (TDP), Orthophosphates (Ortho) from water samples (n.m= not measured).

Sample Date	Sample Point	TP	TS	SS	TDP	Ortho	% TDP / TP	% Ortho / TDP
		(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	%	%
21-Feb-16	A	0.92	n.m	1.0	0.92	0.92	100%	100%
	D	25.27	n.m	898.0	10.83	6.90	43%	64%
	E/G	2.63	n.m	2.3	2.66	2.62	101%	98%
	F	2.75	n.m	7.4	2.63	2.73	96%	104%
22-Feb-16	A	0.83	n.m	1.0	0.83	0.79	100%	95%
	D	27.07	n.m	950.0	6.96	7.25	26%	104%
	E/G	2.73	n.m	2.6	2.66	2.58	97%	97%
	F	2.75	n.m	4.8	2.71	2.72	98%	100%
23-Feb-16	A	0.88	n.m	1.0	0.89	0.84	102%	94%
	D	24.10	n.m	692.0	9.17	7.40	38%	81%
	E/G	2.83	n.m	1.8	2.89	2.72	102%	94%
	F	2.80	n.m	2.6	2.90	2.69	104%	93%
21-Mar-16	A	0.65	198.00	2.3	0.62	0.54	95%	87%
	D	20.67	1470.0	1000.0	13.37	4.71	65%	35%
	E/G	2.61	704.0	4.4	2.65	2.52	102%	95%
	F	2.59	692.0	8.2	2.63	2.54	102%	96%
22-Mar-16	A	0.71	218.0	2.5	0.68	0.60	96%	89%
	D	27.77	2300.0	1960.0	9.70	6.56	35%	68%
	E/G	3.28	730.0	5.4	2.60	2.56	79%	98%
	F	2.72	720.0	7.5	2.58	2.58	95%	100%
23-Mar-16	A	0.69	234.0	2.1	0.69	0.67	100%	98%
	D	26.00	2120.0	1280.0	14.90	7.63	57%	51%
	E/G	2.50	748.0	7.9	2.45	2.49	98%	102%
	F	2.53	748.0	7.9	2.53	2.49	100%	98%
25-May-16	A	0.52	100.0	2.0	0.53	0.50	102%	94%
	D	27.87	2050.0	726.0	11.64	5.15	42%	44%
	E/G	5.06	1510.0	5.6	5.03	5.02	99%	100%
	F	4.84	1460.0	5.1	4.83	4.99	100%	103%
26-May-16	A	0.49	196.0	1.2	0.51	0.48	104%	96%
	D	26.00	1830.0	754.0	5.23	4.85	20%	93%
	E/G	4.83	1490.0	5.4	4.99	4.90	103%	98%
	F	4.89	1520.0	9.2	4.75	4.32	97%	91%

27-May-16	A	0.49	210.0	1.2	0.47	0.48	97%	102%
	D	27.00	2000.0	876.0	6.17	4.99	23%	81%
	E/G	4.82	1410.0	2.3	4.76	4.79	99%	101%
	F	4.74	1370.0	6.3	4.79	4.74	101%	99%
31-Aug-16	A	2.37	1460.0	1.1	2.44	2.35	103%	96%
	D	21.90	2070.0	1060.0	19.20	0.73	88%	4%
	E/G	4.48	1990.0	7.7	4.37	4.33	97%	99%
	F	4.37	1910.0	6.4	4.40	4.35	101%	99%
1-Sep-16	A	2.54	1520.0	2.8	2.54	2.47	100%	97%
	D	23.93	2020.0	978.0	18.70	1.33	78%	7%
	E/G	4.47	1910.0	5.7	4.50	4.37	101%	97%
	F	4.35	1940.0	7.0	4.33	4.31	100%	100%
2-Sep-16	A	2.51	1430.0	1.8	2.53	2.43	101%	96%
	D	19.40	2060.0	820.0	18.20	3.89	94%	21%
	E/G	4.47	1980.0	3.8	4.45	4.53	100%	102%
	F	4.67	2040.0	6.0	4.67	4.34	100%	93%
12-Oct-16	A	0.72	416.0	1.6	0.71	0.69	99%	97%
	D	14.60	3040.0	2140.0	5.00	4.46	34%	89%
	E/G	4.36	1870.0	12.4	4.30	4.10	99%	95%
	F	4.41	1830.0	7.9	4.45	4.14	101%	93%
13-Oct-16	A	0.80	444.0	1.4	0.82	0.77	102%	94%
	D	25.47	2330.0	918.0	5.80	4.16	23%	72%
	E/G	4.18	1790.0	8.5	4.18	3.98	100%	95%
	F	4.21	1730.0	10.2	4.18	4.03	99%	96%
14-Oct-16	A	0.64	428.0	0.0	0.64	0.63	100%	99%
	D	17.20	1640.0	549.0	5.89	3.54	34%	60%
	E/G	3.99	1570.0	7.2	4.01	3.99	101%	100%
	F	4.07	1570.0	7.2	4.04	3.81	99%	94%