Estimating waste production resulting from aquaculture operations and options for reduction and treatment

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Summary

In the first part of this paper, a method is described to estimate the amount of waste compounds created as result from fish or shrimp farming. This method is based on data of the amount and composition of the feed given to the aquatic organisms and the production that was realised in a certain period. In the second part, various options to reduce the amount of waste expelled from an aquaculture facility to the environment are presented. These options are aimed at reduction of waste by applying better feed management, and addition of facilities such as settlement basin, constructed wetland and duckweed ponds. The facilities described are selected because they are relatively easy to construct and operate. For the various facilities, the basic design will be shown and the effectivity of the facility in relation to size and Hydraulic Retention Time (HRT) will be discussed.

1. Estimating solid and soluble waste

Fish or shrimp that are fed in an aquaculture facility to produce fish for consumption or fingerlings use part of the feed to build additional body mass (muscles, bones, organs, etc). But a percentage of the feed may not be consumed at all. Think of sinking pellets that are fed to fish in cages. Because of various reasons (sub-optimal water quality, health issues, low temperature, saturation) the fish in ponds or basins may not eat all the pellets; what is not consumed sinks to the bottom, is decomposed and adds to the amount of suspended solids and dissolved compounds.

Only a part of the feed that passes through the digestive system of fish or shrimp is digested. The undigested part leaves the body as manure (faecal loss). In aquaculture we normally prefer feed with high digestibility because this usually results in more growth (kg fish or shrimp) per kg of feed (= lower Feed Conversion Rate FCR). Digestibility is strongly linked to feed composition. The percentage of the feed that is excreted as faecal loss depends on the digestibility of the feed ingredients and on how the feed is prepared. High quality feed with high digestibility has a lower percentage of faecal loss than low quality feed. For the determination of feed dry matter digestibility the following information is required:

(1) the dry matter composition of the diet;

(2) the amount of diet dry matter fed and the concentration of an inert marker in the diet dry matter;

(3) the amount of faecal dry matter collected in a faecal waste collector (see photo 1). It is important that make sure that only faeces and no spilled feed are collected. Digestion of faeces before, during or after collection should be avoided by cooling and freezing the samples.

(4) analysis of the concentration of the inert marker in the collected faeces

(5) Calculation of the dry matter digestibility using the inert marker in feed and faces dry matter.

Figure 1. Research facility to determine faecal loss of fish (Photo: Aquaculture Research Facility, CARUS, Wageningen University)

The faecal loss of a high quality feed is generally approx. 20 – 30 % of the feed, but for a low quality feed this percentage will be higher. Table 1 shows data of African catfish growing from 15 to 900 gr at a temperature of 25 – 26 ^{o}C .

Table 1. Waste produced by African catfish (*Claris gariepinus)*; digested and undigested feed; dry matter; solid and soluble waste

	Dry matter (gr/kg feed)		%	%
Feed	920			
Faecal loss:	290		31.5	
settable		122		42
non-settable		168		58
Non-faecal loss	295		32	
Weight gain (growth)	335		36.5	
Oxygen consumption	283			
Carbon dioxide production	360			

Ref: Eding et al (1999)

For the situation of fish in Table 1 (several cohorts of African catfish of different sizes growing from 15 to 900 gr in recirculation systems at constant temperature of 25-26^{o} C) this means that for each kg of feed consumed 290 g of faecal dry matter (undigested part) is released to the environment. 122 g of this 290 g can be recovered as settled particles (assuming that 42% is settable), and the remaining part (168 g) is non settable (often particles < 75 µm = 0,075 mm). The settable part depends on diet composition and other factors. It should be noted that the amount of feed that is retained as fish biomass in this African catfish farm is higher (and the percentage of the feed that leaves the farm as waste is consequently lower) than is the case with most other fish or shrimp farms, due to the fast growth, high quality feed and efficient feed conversion of African catfish in this type of farms.

The amount of waste present in the effluent of a shrimp or fish farm is directly related to the quantity and strongly correlated to the quality (composition) of the feed given to the cultured animals. The exact percentage is different for each situation and depends besides feed quantity and quality (digestibility) also upon the characteristics of the animal species, age and health status of the animal and the temperature. In addition, feeding level and feeding frequency have an influence on the percentage of the feed that is consumed, digested and excreted. For example, fish or shrimp that are fed at maintenance level (= enough to support normal activity without weight loss but not enough to enable any weight gain) excrete a higher part (100%) of the consumed feed than animals that are fast growing.

The fish species and the composition of the feed determine what part of the faeces can be recovered as settable matter. Some fish species produce a firmer type of manure (faeces) than other species. By adding so-called 'binders' to the feed the settable part of the faeces can be increased. This is important for especially water treatment systems that require removal of organic compounds that may interfere with the efficiency of the water treatment systems (i.e. biological filters in recirculating aquaculture systems – RAS).

Fish and shrimp also excrete dissolved compounds such as ammonium and carbon dioxide (via the gills). These chemicals are the result of metabolic processes that convert the digested part of the feed. These chemicals are invisible (because they are dissolved) but also affect the composition of the effluent

2. Options for reduction of waste

The following options exist to reduce waste:

- Reduce the part of unconsumed (wasted) feed by checking carefully if all feeds are eaten. Make sure that only as much feed is given as the fish or shrimp will consume. In ponds this can be achieved by feeding floating (extruded) feeds or by placing part of the feed on platforms that are raised approx. 15 minutes after feeding to near the water surface to check if all the feed has been eaten. If some feeds are remaining less feed should be given in the next feeding.
- Maintain optimum health of the fish or shrimp by ensuring good water quality, good quality feed, regular checks on the health of the fish and by prevention of diseases. Fish that are not healthy or not living in optimal conditions will reduce their feed up-take, or the consumed feed may not digest properly. The result is a higher proportion of the feed that enters the environment as waste.
- Use feed that is highly digestible and well suited for the fish species and life stage. Each fish size has a corresponding optimal feed pellet size.
- Feed young fish frequently (8 to 5 times/day) but only as much as they can consume. Older fish can be fed less often (2 -3 times/day).

3. Treatment of waste from an aquaculture facility

For agricultural crops, the wastewater (effluent) from freshwater aquaculture facilities is often very fertile. When no harmful chemicals such as medicines (anti-bacterial or anti-fungal compounds) have been applied during the culture period, it is recommended to use the wastewater for irrigation of crops or grass lands.

Discharge of <u>untreated</u> wastewater from aquaculture facilities (hatcheries or production farms) to the surface water (canal, river, lake, reservoir, coastal area, etc.) can have the following impacts:

- The fine sediments from the pond bottom and organic solids present in discharges water of ponds or basins can cause increased turbidity. After settling on the bottom the organic material will decompose and can create an anoxic zone near the bottom. The species composition and quantity of flora and fauna that live on the bottom will be affected. When settling of fine particles takes place on submerged aquatic plants and coral reefs the photosynthesis is hampered, which may cause a decrease or disappearance of the plants or corals.
- The dissolved nutrients (nitrate, phosphate, etc) can lead to eutrophication and increased densities of algae and phytoplankton. This will increase the turbidity of the water which affects light penetration and species composition of flora or coral on or near the bottom. If changing environmental conditions (changing weather conditions, change) cause death and decay of large

quantities of algae, the lower oxygen levels resulting from algae decomposition will affect many other species of flora and fauna in the water column and on the bottom.
- Medicines and chemicals used to treat fish or regulate water quality parameters can also affect flora and fauna in the environment. The effect and the extent will depend on the specific chemical and the quantity that is discharged.

For the treatment of the wastewater that leaves the aquaculture facility it recommended to remove first the particles (primary treatment) before the remaining water is treated further (secondary treatment) and discharged. The removal or solid matter (particles) is called primary treatment. With the particles, the major part of the organic matter (BOD/COD) is removed as well as a 60-80% of the phosphor/phosphate. Particles can be separated by means of settlement, with a screen filter, a swirl filter or a granular filter. Of these possibilities for particle removal, settlement is often the cheapest, simplest and most robust way, but the facilities (settling basins) may require a larger space (more m^2) than a screen-, swirl- or granular filter.

3.1 Settling tank or settling basin

In a settling tank a relatively quiet situation (with minimal water flow, movement and turbulence) is created that allows particles in the waste water that are $\geq$ 100 µm to settle on the bottom. The efficiency of the basin or tank is determined by the dimension and shape of the tank and by its size in relation to the amount of water passing through. The latter is expressed as hydraulic retention time HRT, which is defined as

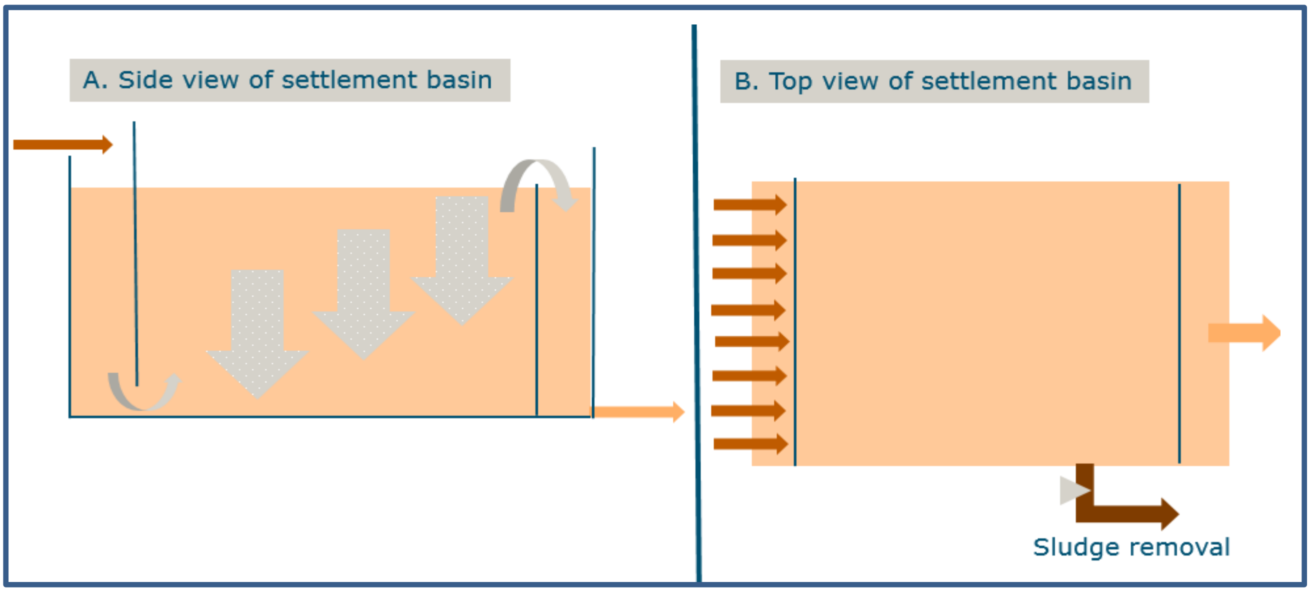
$$\text{HRT (hrs or days)} = \frac{\text{Volume of the basin}}{\text{Volume of water passing per hour (or day)}}$$

Example: if 1000 m^3 of water passes in 24 hours (1 day) through a settling basin of 250 m^3, the HRT = 250 / 1000 = 0.25 days (= 6 hours).

The longer the HRT, the bigger the part of the particles that will settle on the bottom and the higher the efficiency of the basin or tank. With a HRT of 8 hours 75% of the solids and Phosphor and 40% of the BOD (organic matter) will settle on the bottom. The solids (sludge) on the bottom should be removed regularly; if left in the basin the anaerobic bacteria will decompose the sludge, a process that will lead to dissolving of part if the settled material and possibly development of harmful gasses such as hydrogen sulphide (H_2S).

A length/width ratio of the 1.4 to 1.6 for the part where settlement takes place is optimal. Structures at the inlet of the basin that force the water to enter over the whole width of the basin and at the bottom contribute to a more quiet and even flow and better settlement. The water should leave the section of the basin where settlement takes place near the surface (Figure 2).

Figure 2. Possible design of settling basin (side and top view).

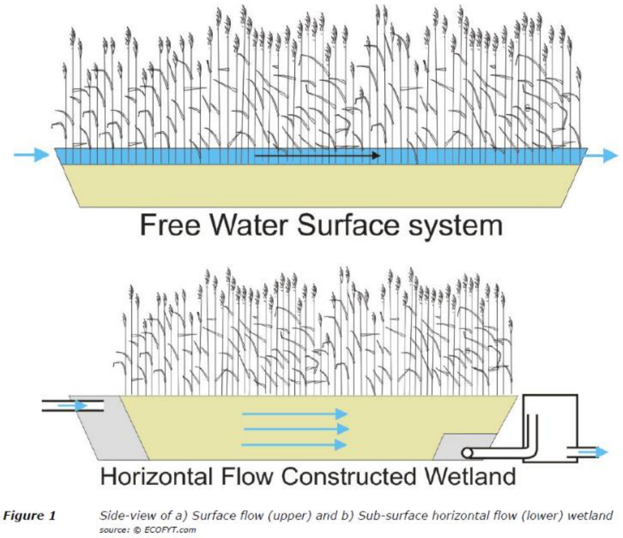


An existing or specially constructed pond can be dedicated to serve as settling basin to treat waste water from a shrimp or fish farm. The larger the pond, the longer the average retention time and the higher the fraction of the solid waste that is retained. When water enters the basin through multiple inlets instead of only one inlet, the water will flow more evenly through the basin and the rate of setttlement will increase. Regular removal of the sludge will improve the efficiency of the basin. The sludge from freshwater aquaculture facilities can be used as fertilizer on farm fields and grass lands. If there are longer periods (4 monhs or longer) that no wastewater is passing the settling pond, the pond can be drained, the bottom can be allowed to dry and crops can be planted on the very fertile and moist pond bottom. The aeration during the dry period will cause decomposition and disappearnace of a great part of the organic matter.

3.2 Constructed wetland

After removal of the solids by means of settlement or otherwise the water can be treated in a constructed wetland. Of this wastewater treatment system various types exist. Constructed wetlands are differentiated according to how the water flows through (free-flowing at the surface flow or through a substrate); the direction of the water flow (horizontal or vertical; whether the vegetation in the filter is emerged, submerged or floating). Also combinations of floating, submerged and emergent plants are used. The type of constructed wetland that is suitable for treating wastewater from aquaculture facilities (farms) should be able to deal with large volumes of water. In such conditions free-flowing (surface flow) filters tend to be more suitable then constructed wetlands in which the water passes through a substrate (sub-surface flow). The substrate in such filters often consists of fine gravel or course sand. Sub-surface flow filters are more suitable for smaller volumes of wastewater that may have higher levels of dissolved and undissolved compounds.

Figure 3. Surface flow (upper) and sub-surface flow (lower) constructed wetland



Source: © Ecofyt

Constructed wetlands are effective wastewater treatment systems that are tolerant to fluctuations in the water flow and composition. They are also applied to treat domestic and certain types of industrial waste water. They require very little energy for operation, look like natural elements in the landscape and only need occasional maintenance. A combination of various physical and biological processes taking place in the water and substrate lead to organic matter and nutrient removal:

- (suspended) solids are trapped as result of filtration and sedimentation;
- organic matter is reduced by heterotrophic bacteria;
- ammonium/ammonia and nitrite are used by nitrifying bacteria; nitrate is absorbed by plants and algae or reduced in the anaerobic parts of the filter by denitrifying bacteria.
- plants and algae absorb phosphate, carbon dioxide and many other compounds trough their leaves and root systems.
- metals and other chemical compounds are adsorbed to sand and clay particles.
- oxygen is transported from the air into the substrate by the root system of emergent plants. Oxygen is also added by diffusion from the air into the water.

Figure 4. Constructed wetland near Lake Manzala, Egypt

Figure 5. **Constructed wetland at private fish farm, *Egypt***

Also in constructed wetlands, a longer HRT means a more effective treatment (= a bigger part of the organic material and dissolved nutrients are removed). For the wastewater from a fish farm a HRT of 1 day is a minimum to obtain reasonable treatment efficiency, but a longer HRT (2 or more days) will result in higher removal rates. A higher HRT can be achieved by construction of a larger Constructed Wetland (larger surface area) or by reduction of the amount of wastewater by means of improved water management in the facility (if possible; Heijden et al, 2013). A larger constructed wetland means that a larger part of the total area available to the farm is used to treat wastewater, but with an effective treatment system it may be possible to re-use the waste water to fill and grow fish in other ponds or basins. This will reduce the dependency on external water as well as reduction of the chance of importing of diseases, parasites and polluted water from outside the farm.

A comprehensive review of constructed wetlands by the US Environmental Protection Agency concluded that significant reductions in many water quality parameters can be expected (see Table 2). It should be noted that the facilities did mostly treat other water than aquaculture wastewater (domestic and agricultural waste).

Table 2: Reductions of water quality parameters of constructed wetlands

	Range of recorded reduction
Ammonium / Nitrogen	86 - 98%
Total Inorganic Nitrogen	95 - 98%
Total Phosphate	32 - 71%
Suspended Solids	70 - 95%
BOD5	65 - 95%

Ref: Aqua-E-treat (n.d.)

By measuring or estimating the volume of waste water that is discharged over the year (average per week or month) as well as peak flows and by analysing the composition of the waste water at different moments it is possible to compute the minimum size of the constructed wetland needed for the aquaculture facility.

Constructed wetlands are most often used for treatment of freshwater but can be used also for treatment of brackish or marine water, provided endemic, emergent plants can be found that thrive in brackish or marine water. The reed species *Phragmites australis, cattail Typha orientalis, rushes Vetiveria zizanioides* and African arrowroot *Canna indica* have been used successfully to treat brackish water (up to 4.5ppt, Liang et al, 2017). Samphire *Salicornia bigelovii ,* Sea blite *Suaeda esteroa* and Salt bush *Atriplex barclayana* have also been tested in constructed wetlands. Samphire can be consumed by people; salt bush and sea blite can be used as animal fodder (Brown et al, 1999; Heijden et al, 2015). In addition, various mangrove trees have been used to treat saline waste water as well as basins with seaweed such as *Ulva sp*. Ulva can be used to feed sea urchins and abalone.

3.3 Duckweed and water hyacinth ponds

Wastewater from freshwater fish farms can be treated in shallow (0.25 – 0.4 m deep) ponds covered with duckweed (*Lemna sp*.) Duckweed are small floating plants that can multiply vegetatively and can have a fast growth and production of biomass, especially in warmer regions and when growing in water with sufficient nutrients. The can grow in freshwater water (upto 4 ppt salinity). The plants can absorb ammonium and nitrate which is converted to a high-quality protein. Duckweed plants can be more easily harvested than micro-algae, with fine-meshed sieves and nets. Under good growing conditions ¼ to 1/5 of the surface of the duckweed pond can be harvested/day, which may result in 15 to 25 tonnes of dry matter/year. The dry plant material can contain 25-35% crude protein. The protein content depends on the amount of ammonium and nitrate in the wate. Chickens, pigs, cows but also some fish species (grass carp, several tilapia species including *O. niloticus*) like to eat fresh duckweed. In fresh condition the plant contains approx. 92 to 94 % water, which makes fresh duckweed less suitable as sole (only) feed for fish or other animals. It can be fed as an additional feed. After drying, duckweed has a high nutritional value and can be mixed as a high protein ingredient in fish and animal feed.

Figure 6 and 7. Duckweed (Lemna minor) Photo: WholesaleWaterlillies.com

Instead of duckweed water hyacinth *Eichhornia crassipes* can also be used. Recommended depth of basins (0.5 to 1.0 m) is larger than for duckweed due to the longer roots. Other growth conditions are roughly the same as for duckweed. Water hyacinth has also a high growth rate and productivity and will also absorb many metal ions, minerals and nutrients from the waste water. It can be very efficient for treating aquaculture wastewater. However, unlike duckweed water, hyacinths cannot be easily applied as an animal feed or be given another useful function.

Use water hyacinths only in areas where the plant is already present and abundant. **Don't introduce water hyacinths to areas where the plant species is not yet!** Once it gets into open water this plant can easily become a nuisance and big problem!

Figure 8 and 9. Water hyacinths

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