Aquaponic Media Bed Sizing Calculator - Metric

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Welcome to Version 2.0 of the Hobby Scale Aquaponic Media Bed Sizing Calculator. The calculator has been updated in a number of ways. The first change you will notice is that two of the outputs have been removed; the biofilter volume output and the bed surface area for fruiting plants output. The biofilter volume output has been removed because in all cases, when the media bed is sized for the fish feed to bed area ratio (based on the UVI ratio's), the output gives a surface area that when using a 300mm deep media bed will always meet the biofiltration volume requirement. The fruiting plant bed surface area output has been removed because the original leafy green plant bed surface area is most often used, and if fruiting plants are to be grown, then the far lower planting density of fruiting plants (when compared to leafy greens) means that in the vast majority of cases, all things even out.

The major upgrade to the calculator has been an improvement to the mathematics used to calculate the surface area of the bed required to mineralise the fish solid wastes. In the original version, due to the complex "log" based mathematics used, there was a "black hole" that appeared at lower fish densities which manifested as an inconsistency in the output whereby the surface area output could in some cases actually drop when the fish density rose. This has now been rectified and so no "black hole" should now be present in Version 2.0 and the bed surface area will rise as the fish density does. The other change is that there has been a slight "tweaking" of the UVI feed rate ratios. This is because I have gained more knowledge and insight into how much nutrient can be contributed by leaving solids in the system to mineralise and breakdown in the media bed.

This current explanation document has also had several small changes done to it to reflect the changes in the calculator as outlined above. The major addition is a short discussion on how the addition of worms to the media bed MAY, or MAY NOT affect the media beds ability to breakdown and mineralise fish waste solids.

I hope this calculator assists with your hobby scale aquaponic designing.

Introduction:

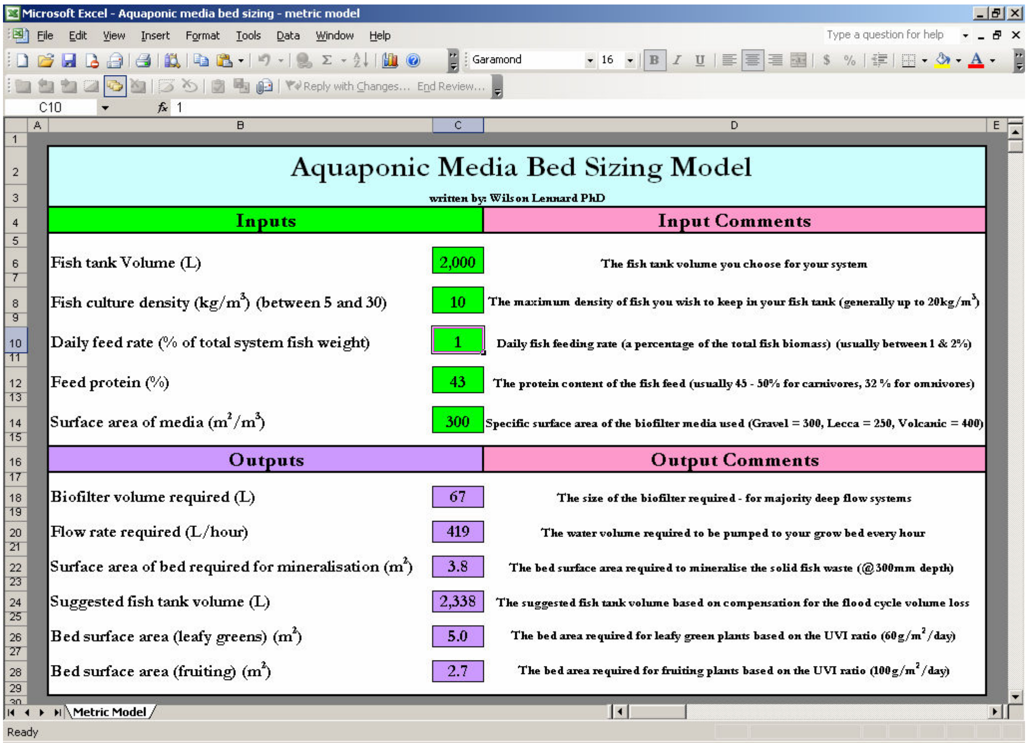
Many backyard, hobby and domestic aquaponic system users, designers and builders are confused about the ratio between the fish tank size and the media bed size (gravel, Lecca etc…) in their systems. There are many "rule of thumb" approaches to this fish tank to media bed ratio, but these are not based on established scientific, technical or engineering principles. This document and the attached Spreadsheet calculator is an attempt to provide a useable method and model so that any hobby or domestic scale aquaponic system user or designer may have a guide to design and size their systems. This model and the outputs it produces are based on accepted and established scientific and engineering principles that are directly applicable to the design of aquaponic systems.

Distribution of the Model:

This model has been produced for FREE use by anyone who wishes to use it. It can be downloaded for FREE at www.aquaponic.com.au and other web sites. This means that the model can be effectively shared between users and you are welcome to distribute it, unaltered, at your discretion. The model and associated information (ie: how to use…) document is **not to be sold** by or to any person, organisation or party. The model has been produced and is available in both Metric and USA versions. All I ask is that if you use this model in a multi-user (ie: teaching classes or you are a system sales company) capacity, that you properly credit me as the writer and distributor of the documents.

The Model:

The Spreadsheet model that accompanies this document is a tool that allows you to size the area of the media bed in your system based on a number of important inputs. In addition, the model provides outputs for a number of parameters. Basically, the model will size the surface area of the media bed for you based on whether you wish for the bed to operate as a biofilter or as a solids mineralisation filter or as a plant growing component or a combination of all three. It is up to you, the user, to decide which bed size is best for your situation. However, it is recommended that the **largest** bed size given by the model will be the best for your system.



Microsoft Excel - Aquaponic media bed sizing - metric model

Aquaponic Media Bed Sizing Model

written by: Wilson Lennard PhD

Inputs		Input Comments
Fish tank Volume (L)	2,000	The fish tank volume you choose for your system
Fish culture density (kg/m^3) (between 5 and 30)	10	The maximum density of fish you wish to keep in your fish tank (generally up to 20kg/m^3)
Daily feed rate (% of total system fish weight)	1	Daily fish feeding rate (a percentage of the total fish biomass) (usually between 1 & 2%)
Feed protein (%)	43	The protein content of the fish feed (usually 45 - 50% for carnivores, 32 % for omnivores)
Surface area of media (m^2/m^3)	300	Specific surface area of the biofilter media used (Gravel = 300, Lecca = 250, Volcanic = 400)
Outputs		**Output Comments**
Biofilter volume required (L)	67	The size of the biofilter required - for majority deep flow systems
Flow rate required (L/hour)	419	The water volume required to be pumped to your grow bed every hour
Surface area of bed required for mineralisation (m^2)	3.8	The bed surface area required to mineralise the solid fish waste (@300mm depth)
Suggested fish tank volume (L)	2,338	The suggested fish tank volume based on compensation for the flood cycle volume loss
Bed surface area (leafy greens) (m^2)	5.0	The bed area required for leafy green plants based on the UVI ratio (60g/m^2/day)
Bed surface area (fruiting) (m^2)	2.7	The bed area required for fruiting plants based on the UVI ratio (100g/m^2/day)

Component Ratio – plant growing area requirement:

It is often thought that the ratio in aquaponic systems is between the fish tank volume and the plant grow-bed surface area or volume. However, this is not correct. The ratio is actually between the daily amount of fish feed that enters the system and the grow bed surface area. This is confirmed by the years of research conducted at the University of the Virgin Islands by Dr James Rakocy and his team which has ascertained a range of ratios for daily feed input to plant growing area for deep flow based aquaponic systems.

The UVI ratio used in this calculator is:

1. 60g/m^2/day

As can be clearly seen, plant growing area is directly linked with the daily fish feed input to the system. These ratios are also appropriate for media based backyard and hobby scale aquaponic systems, so the attached model allows you to size the grow bed area based on the plant growing area requirement as set by this UVI ratio.

The UVI model is based on fish that eat 32% protein feed (*Tilapia spp.*). However, many fish also used in aquaponic systems eat higher protein content feeds (45%). Therefore, the UVI ratio in the attached calculator has been re-calibrated for situations were high protein content fish feeds are chosen. In addition, most backyard and hobby aquaponic systems use the media bed as a place for mechanical filtration and mineralisation of solid fish wastes and this approach will supply extra nutrients to the system (the UVI system design removes the majority of the solids from the system very quickly). Because of this, the fish feed to plant growing area ratios have also been re-calibrated to take solids inclusion to the system into consideration when calculating plant growing area.

Component Ratio – biofiltration requirement:

The media bed in hobby and backyard scale aquaponic systems also acts as the primary location for biofiltration; the bacterial assisted conversion of potentially toxic fish waste ammonia to non-toxic nitrate. In actuality, the biofiltration requirement is not usually relevant to media based backyard and hobby scale aquaponic systems, because there is always an excess of media in the bed when the UVI ratios are followed and therefore, the biofiltration media volume requirement is always met.

Component Ratio – solids mineralisation requirement:

The UVI design (http://www.uvi.edu/sites/uvi/Pages/AES-Aquaculture-International_Aquaponics.aspx) or aquaponic system actually removes a high proportion of the solid waste generated by the fish. This is because solid fish waste can take time to break down and when it does break down, the process often consumes oxygen. This means that the bacteria doing the solids break down (known as mineralisation) actually compete with the fish in the system for oxygen. By removing solids, the UVI approach lowers the competition for oxygen in the system so that the fish always have enough.

Many backyard and hobby scale aquaponic systems do not filter out the solid fish waste and these generally end up in the media bed with the plants. As many people correctly suggest, the media bed will act as a solid fish waste mineralisation filter and the fish wastes will break down or mineralise over time. A flood & drain aquaponic media bed basically operates in the same way as a Reciprocating Vertical Flow Wetland (RVFW), which also uses a flood & drain approach and has very high treatment levels and can mineralise large amounts of solids. Therefore, aquaponic media beds can and should be able to do the same. However, many RVFW's are deeper than the standard

300mm depth used for media aquaponic systems. So, often the surface area required for such a shallow approach is larger than a standard RVFW. In addition, the top few cm's of the bed surface will always be the area of greatest oxygen content and therefore, will always perform the bulk of the mineralisation. If we wish to use the media bed as a solids mineralisation site, then it also needs to be sized so that there is enough surface area for the mineralisation bacteria to be able to efficiently do their work.

The solid mineralisation bacteria we want to establish in the media are oxygen loving (aerobic) in nature. Solids mineralisation will occur in deeper parts of media beds, however, often this is because as the bed gets filled with more solid fish waste, the deeper parts of the bed can actually turn anaerobic (ie: a lack of oxygen) and anaerobic mineralisation can occur. We must be very careful with anaerobic zones entering aquaponic systems because these zones can release gases and chemicals which may be toxic to the organisms living in the system, whether fish, plant or aerobic bacteria. Therefore, it is recommended that anaerobic zones are not encouraged and aerobic conditions are encouraged in aquaponic systems. This is why flood & drain water flow is recommended, because the drain cycle helps to suck atmospheric oxygen deeper into the gravel depth and allows more of the bed volume to act in an aerobic mineralisation mode.

The last important factor to understand in solids mineralisation capacity is that we always assume that the solid fish waste is uniformly spread across the bed surface area. This is an important factor in media bed sizing because the solids that enter many aquaponic media beds are not always uniformly spread across the entire surface. Solids are very difficult to spread across the entire surface when there is one, or only a few, sites for water addition. Reciprocating Vertical Flow Wetlands often use elaborate manifolds and feed flow mechanisms to try and uniformly spread solids across the entire bed surface area. Manifolds are often costly, unsightly and intrusive and are therefore, not often used anymore in media aquaponic systems. This means that the bed surface area becomes even more important. The model has also been calibrated to account for the fact that solids often enter the bed at one inlet point.

The model is calibrated to output the required bed surface area to aerobically mineralise the solid fish wastes using a 300mm deep media bed. This is not to suggest that shallower media beds don't work; they do. However, it appears that 300mm has become the industry standard and so that is what the model uses as it is the most often used bed depth. The model gives an output for media bed size based on the solids mineralisation requirement of the system and if no solids filtration is done prior to the media bed, then this size for the bed should take priority over the others if it produces a higher area output.

Using the Model– the input cells:

The model requires 5 different inputs that allow it to calculate the filtration potential and plant growing areas of the media bed. These input cells are coloured green so the user can identify them easily. In addition, these green cells are the only cells in the model that allow user entry.

Fish tank volume

The first input is fish tank volume. This is the volume of the fish tank you wish to use in your system. You enter the fish tank size in litres (L). This is just a starting point because the model actually outputs a corrected size for the fish tank later on.

Fish culture density

The standard way to state fish keeping is by fish density, or kilograms of fish per cubic meter of water (1 cubic meter equals 1,000L). The maximum amount of fish you should keep in standard backyard or hobby aquaponic systems is approximately 25 kg/m^3 (fish culture densities above $10kg/m^3$ will require aeration). This is because if fish are kept above this density, high flow rates are required. Because most backyard and hobby aquaponicists are principally interested in the plants, limited fish numbers are not usually a problem. For backyard or hobby scale aquaponic systems I recommend a density of fish between 6 and 17 kg/m^3. The model will work at fish culture densities above 17 kg/m^3, but you will notice that at above the 17 kg/m^3 density the surface area required for solids mineralisation goes higher than the surface area for the plants. This is OK so long as you use the higher output for your grow bed sizing.

Daily feeding rate

The daily feed rate to the fish should be based on the amount or biomass of fish in the tank(s). Fish eat a percentage of their body weight depending on their age. For the model, the calculations are based on the MAXIMUM biomass the system will hold, and therefore, in terms of feed rate, the maximum daily feed addition will be for adult sized fish which will be eating at between 1 and 2% of their body weight per day. I usually recommend feeding adult fish approximately 1% of their body weight per day, although this does depend on the species of fish being grown.

Feed protein

Most fish kept in backyard and hobby scale aquaponic systems will be fed using commercially available pelletised feeds. Fish generally fall into two main categories:

1. Carnivores - fish that eat other fish and animals as their principle diet
2. Omnivores – fish that eat vegetable matter as their principle diet

Carnivores require high protein diets (45% protein content) because that is their principle dietary source whilst omnivores eat lower protein diets (32% protein content). The protein content of the fish feed is directly related to the amount of dissolved fish waste produced; high protein feeds produce higher waste profiles than lower protein feeds.

The model requires an input for protein content of the feed so it may perform the calculations.

Examples of high protein eating fish include:

- Trout
- Murray Cod
- Barramundi

Examples of lower protein eating fish include:

- Tilapia
- Jade Perch
- Carp species

Most high protein feeds are about 45%, and lower protein feeds are 32%. The model has been designed so that when you enter the feed protein content, the model calibrates itself based on that chosen protein content.

Surface area of media

The bacteria that convert dissolved and solid fish wastes need somewhere to grow and they do this on the surface of the media in the media bed (eg: gravel). The more fish we have, the more feed that enters the system and therefore, the more waste that is produced. The amount of daily waste the fish produce is predictable and we can use this to determine how much media we need to treat the waste streams. However, we need to know how much surface area is available for a given volume of media so we can determine the volume of media required to do the job.

The ratio of surface area of a media with respect to the medias volume is called the Specific Surface Area (SSA) of the media, and this is stated as m^2/m^3 (or surface area per volume). All commercial biofilter media come with a stated SSA. Gravels and other media have varying SSA's. If possible, the SSA of the media should be measured or determined, however, this is often very difficult for media such as gravel. The SSA of most gravel's is about 300 m^2/m^3, so this is often used as the "surface area of media" input. If a SSA is available for the media you wish to use, then this should be used as the input.

Once all of the above inputs are added to the model, it automatically calculates the outputs and these are located in the output cells in the model sheet.

Using the Model – the output cells:

The output cells give the answers that the model generates. There are several outputs and a choice needs to be made based on the requirements of your specific system.

Flow rate required

This output gives the flow rate required to the media bed in litres per hour. This flow rate will ensure that the ammonia waste that builds up in the system is treated in a timely manner so it cannot affect the fish. If a constant flow is used 24 hours per day, then this output will equal the required flow rate of your pump. However, if timer driven flood and drain is used (which is often the case in media bed systems), then this volume must be directed to the media bed within the flow time set on the timer. For example, if the model tells us we need to flow at 600 L/hr, and we use a 10 minute “on” time for our timer, and we only flood the media bed once per hour, then we need a pump that will direct 600 L of water from the fish tank to the media bed in the 10 minute “on” cycle, so a pump of 3,600 L/hr is required. This flow rate output is also applicable to flood and drain approaches which utilise a bell siphon. In this case, pumping to the grow bed at or above the output flow rate will meet all the required filtration requirements as in these style of systems, the pump is always on.

Surface area of bed required for mineralisation

For backyard and hobby scale aquaponic systems that use a media bed as the principle place for plant culture in their systems, and where no solids are removed between the fish tank and the media bed (ie: simple, flood and drain media based systems) this is an important output in the model. This is because this output will give a desired surface area for the media bed to meet the fish solid waste mineralisation and break down requirement of the system. For situations below fish densities of 17 kg/m^3, the media bed size for solids mineralisation will often match, or be lower than, that size output given based on the fish feed to plant growth area of the UVI model (see below). However, once fish densities rise above 17 kg/m^3, the requirement for surface area to properly treat all the solid fish waste often rises substantially above the UVI feeding ratio size requirement. This can be tested by you by simply changing the fish densities used in the input cell for fish density in the model. Most home aquaponic systems operate at low fish densities (ie: less than 15 kg/m^3) so in general the solid mineralisation area required is met by using the UVI ratio’s for fish feed input to plant growing area.

Whilst the model does output a size for the media bed to meet all the mineralisation requirements of the solid fish waste produced, it is also highly recommended that a media bed maintenance approach be used for your home system, especially when fish densities above 10 kg/m^3 are employed. Media bed maintenance consists of cleaning the media by gently washing it in **system water** to remove any accumulated solids. This should be done once every 3 – 6 months, depending on the fish stocking density; higher densities should have more regular cleaning. Using system water allows you to maintain the bacteria on the surface of the media without affecting it. **Do not use any chemicals or detergents to clean your media.** This cleaning operation can often be performed by using a "gravel vacuum", which allows cleaning without removal of the media from the bed.

Solids mineralisation and the addition of earth worms:

Many people now add earth worms to their media beds to assist solids breakdown. One of the most often sited criticisms of Ver 1.0 of my Media Bed Calculator was that the surface area required for solids breakdown and mineralisation was grossly overstated because I did not take into account the addition of earth worms. True enough, I did not take earth worm addition into account when designing the first calculator. However, a consideration of what earth worms actually do needs to be taken into account here. When earth worms are added to a media bed they DO consume solid fish waste, just as they consume soil in the ground or scraps in a worm farm. BUT, what is the outcome of this soil or compost scrap consumption? One outcome is worm tea or liquor; the liquid component produced after the consumption. The other, more important component, is worm castings.

These worm castings are often thought of as soil analogues. When worms consume solid fish wastes, they also produce worm castings. Therefore, even though it is correct that worms consume solid fish wastes, they still produce a solid waste themselves and therefore, we must be careful to size the media bed correctly to also adequately breakdown and mineralise these worm castings. As for systems without worms, the breakdown and mineralisation of the fish waste solids or the worm castings or both is achieved via a bacteria and so we still require adequate surface area and volume to provide a site for these bacteria to do their important work. In all likelihood, bacteria will breakdown worm castings faster than they will breakdown fish waste solids. Some people use these worm castings (from a worm farm or compost heap) as a planting media for their seedlings (eg: as is done in the Growing Power approach) and these people will tell you that these castings are very similar to soil and will persist for very long periods of time.

There is little available scientific data on the volume reduction which occurs when fish waste solids are consumed by earth worms. By this I mean that if you add 1L of fish waste solids to a worm farm (or aquaponic media bed) how many litres of worm castings are produced? Because I cannot find comprehensive scientific data on this subject I have assumed a 1:1 ratio; meaning that 1L of fish waste will become 1L of worm castings (this approach has been followed as a "safe" approximation that covers all situations). Therefore, whilst it may be argued correctly that the addition of earth worms to a media bed will assist fish solid wastes breakdown, it cannot be assumed that:

1. The worms consume all the fish wastes.
2. The worms convert fish wastes solids and produce NO solid wastes of their own.
3. The solid wastes produced by the worms (worm castings) breakdown any faster via bacterially mediated mineralisation than fish waste solids do.

Therefore, Ver 2.0 of the calculator has NOT been changed in terms of the surface area of the media bed required to breakdown and mineralise the solid fish wastes and the calculation is still based on whether earth worms are added or not.

Suggested fish tank volume

The suggested fish tank volume is an output designed to give an updated fish tank volume required to compensate for the fact that, when the pump goes on during a flood cycle, water is removed from the fish tank and takes time to return. If this occurs and there is not enough water volume left in the fish tank, the fish may suffer. Many backyard and hobby aquaponic systems now have other devices (eg: bell syphons) and sumps employed in the design so that the volume of water in the fish tanks stays constant. If this is the case, then the original fish tank volume that you entered into the input area can be used for the fish tank volume.

The most important point to consider when using a direct flood from the fish tank (which removes water volume from the fish tank for the length of time of the flood and drain cycle) is that the volume of water directed to the grow bed at every flood cycle should not remove any more than 25% of the fish tank water volume. For example, if a 1,000L (250 Gallon) fish tank is used, then the water volume of this fish tank should not drop below 750L (185 Gallon) during the flood component of the cycle.

The suggested fish tank volume output from the model gives an updated fish tank volume that includes the flood volume so that an ideal fish tank volume is provided. In practice, most media bed aquaponic systems have adequate volume in the fish tank so that the flood volume doesn't remove too much water from the fish tank.

Bed surface area (UVI feeding rate ratio)

This output is the media bed surface area required to meet the design ratio requirements of the UVI model for plant production.

As stated above, this area is often lower than that which is required to meet the solids mineralisation requirement of the system for higher fish densities (above 17 kg/m^3). People using basic flood and drain aquaponic systems with media beds should use a media bed area based on solids mineralisation rather than this specific UVI based fish feed input to plant culture area ratio if the bed size based on the mineralisation area output is higher.

Because most backyard and hobby aquaponic systems do not remove solids prior to the media bed, the UVI ratio has been calibrated to account for the extra nutrient supplied by the solids break down over time. In addition, the UVI method is valid for fish that eat 32% protein feeds. When the user selects the feed protein content, the model automatically calibrates the UVI ratio to also reflect the fish feed protein content, so higher protein content feeds will require a higher media bed area.

Comments Columns:

The model includes a comments column which gives a short comment about what the input or output is in the same row as the comment.

Using the Model to Calculate Media Bed Size for Deep Flow Systems:

Many home aquaponic designers now want to use deep flow hydroponic plant culture as the principle plant culture technique, but still want to use a small media bed as a filtration device. In these cases, the media bed needs to act as the place of solids removal (mechanical filtration) and solids mineralisation. It is often more practical to use deeper beds in these situations, usually because more square or rectangular tanks are easier to source and purchase.

The surface area of the media bed required for solids mineralisation as output by the model is calibrated for a standard, 300mm deep media bed. However, this does not mean you cannot use deeper tanks to make media beds for solids mineralisation for your system, especially in a situation where the bed is used in conjunction with another hydroponic technique (ie: deep flow, NFT etc…). As has been explained above, aerobic solids mineralisation is directly related to bed surface area because it is at the oxygen-rich surface that the majority of the aerobic mineralisation operates. Therefore, you should always use the bed surface area as output by the model as your minimum media bed filter surface area. If you wish to use a tank deeper than 300mm for your solids and mineralisation filter that is fine, but always use a tank that meets the output media bed surface area as provided by the model as a minimum.

Conclusions:

This document and attached spreadsheet model is provided to assist people with the sizing of their backyard and hobby scale aquaponic systems. It is **not** a model for commercial scale aquaponic systems, which require more directed design and calculations.

The model can be used to size the media bed of your system, based on the fish tank volume, fish density, fish feeding rate and fish feed protein content. It is recommended that the **highest** area the model outputs is the best suggested area of the media bed for your system.

This model should be used as a guide only and is designed to be appropriate for the majority of situations where media beds need to be sized based on the parameters outlined. Hopefully, it will give backyard and hobby scale aquaponic system designers a useable tool to allow them to size their aquaponic systems using sound scientific and technical principles.

In addition, this model can also be used as a tool to inform you of the maximum fish culture density that your existing aquaponic system should attempt to hold so that you are always within the design limits of the solids mineralisation capacity and UVI plant growth ratio for your system. To use the model in this manner, simply enter different fish culture densities into the model, using your systems available fish tank volume, and match the highest fish culture density with the output media bed surface area that your system currently has.

Happy aquaponicing.

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