# Aquaponic System Design Parameters:

## Media Beds and Sizing

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Hobby-scale aquaponic systems extensively use the media bed approach; the media bed being an area to grow the plants, perform biofiltration (nitrification – the conversion of toxic ammonia to non-toxic nitrate) and perform solids filtration and mineralisation (the break down of solid fish wastes to dissolved nutrients). In addition, the use of media beds in some proportion of the total grow bed area is being adopted in small-scale commercial aquaponics (often called "Hybrid" aquaponic systems).

Using media beds to perform all these processes has been done for over 100 years in the waste water treatment industry. Therefore, there is much scientific and engineering information and data available in terms of their performance and design sizing.

This fact sheet discusses the biological processes that occur in media beds with respect to aquaponic systems and introduces the use of available and proven approaches to sizing these media beds in an aquaponic context.

### The Functions of Aquaponic Media Beds

As stated above, aquaponic media beds perform 4 key functions in the aquaponic system:

1. Plant growth – media beds act as the primary site for plant growth in 100% media bed systems and act as a site for a proportion of the plant growth in hybrid style systems.

2. Biofiltration – the media in media beds acts as a site of high surface area for the colonisation of the bacteria that perform the nitrification process (the conversion of ammonia to nitrate).

3. Solids filtration – the media bed acts as a site to mechanically filter out solid fish waste particles and other solid particles.

4. Solids mineralisation – the media bed acts as a site for solids mineralisation; the process of breaking down solids and dissolving the constituent elements back into the water column.

Because media beds perform all of these functions, they are very appropriate for use in some aquaponic systems as they have the potential to lower the requirement for other, often more complex, filtration and treatment components. However, an understanding of the treatment and processing potential of media beds as related to all of the above functions is crucial for long-term aquaponic system operation and optimisation.

### The Site for Plant Growth

Media beds in hobby-scale aquaponic systems often account for 100% of the plant growing area of the system. In small-scale, hybrid (mixed media bed and deep flow growing zones) aquaponic systems, they generally account for the minority of the plant growing area. In either configuration, media beds act very well as a site for plant growth and the media in the bed may be seen as a soil-type analogue where the particle size is far greater than for normal soil.

The media bed acts as a zone where the plant roots may grow and plants seem to like the fact that their roots are held within a solid, but particulate, media and as long as all nutrient requirements are present, thrive in media beds. The media bed therefore, acts as the zone of nutrient uptake by the plant, as the roots are exposed to the nutrient-rich water produced by the fish.

## The Site of Biofiltration

In aerated (or aerobic) aquatic systems, biofiltration is the overall name given to the biologically assisted conversion of organic wastes (ie: fish wastes) to an oxidised (oxygen-rich) state. In aquaponic systems it is most often associated with the nitrification process, where ammonia ($NH_3$) is converted to nitrate ($NO_3$).

The conversion of ammonia to nitrate is a critical process in systems that contain fish. This is because ammonia (which is directly excreted across the fishes gill as a gas that immediately dissolves into the water) has the potential to be toxic to fish. If ammonia concentrations become too high, they can quickly and easily kill fish. On the other hand, fish have the ability to accept and live in relatively high concentrations of nitrate without any toxic effects.

Therefore, it is an essential element of aquaponic systems to convert potentially toxic ammonia to non-toxic nitrate as quickly as possible.

The conversion of ammonia to nitrate is mediated (performed) by several bacterial species. These bacteria may use a surface to grow upon and the media in the aquaponic media bed provides this surface area for bacterial colonisation. Therefore, the media in the bed is critical to providing enough surface area so adequate bacterial numbers can be present to effectively and quickly convert all the ammonia released by the fish.

Rarely, if ever, is there an inadequate amount of surface area to treat the ammonia waste produced by the fish in 100% media bed aquaponic systems. Even in hybrid style systems, where the media bed represents a minority of the total grow bed area, there is usually more than enough surface area to grow the numbers of bacteria required to treat and convert all the ammonia in a timely manner.

Therefore, in a design context, the media bed used will almost always meet the surface area requirements of the system to enable the colonisation of an adequate number of bacteria to treat the systems ammonia waste concentrations.

## The Site of Solids Filtration

The media in the media bed of an aquaponic system forms a complex matrix with the majority of the bed being taken up by solid media particles. The rest of the space in the bed is the free spaces (interstitial spaces) that exist between the solid media particles. It is through these free spaces that the water flows. These free spaces are of varying sizes when gravel is used as the media because gravel particles are of varying sizes and shapes. When media such as expanded clay balls are used, the free spaces are far more uniform in size and shape.

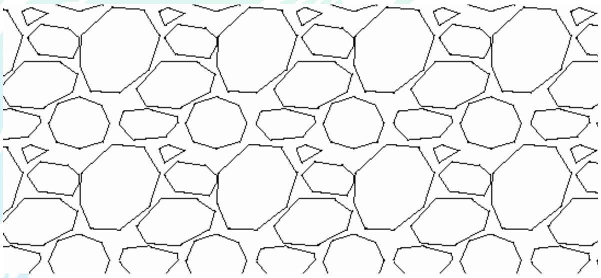

Figure 1: Gravel particles and the associated interstitial spaces in a media bed.

As we have seen, bacteria grow on the surfaces of the media. The individual bacteria form colonies and these colonies form what is known as biofilm. This biofilm is just like a thin film in nature and covers most of the surface of the media. This biofilm causes two outcomes which make the media in the bed act as a mechanical filtration device:

1. The biofilm occupies some of the free spaces between the media particles and therefore, makes the spaces smaller and this acts to trap solid fish waste particles.

2. The biofilm acts as an attractant for solid fish waste particles and sort of acts like a glue that traps and holds solid fish waste particles.

The overall effect is that the biofilm occupied, and non-biofilm occupied, spaces between the media particles help the media to act as a filtration zone that traps solid fish waste particles. This means that the media bed effectively acts as a type of solids screen filter, removing solid fish waste particles from the overall water column.

As the aquaponic system matures over time, the interstitial spaces become smaller and smaller due to the build-up of biofilm and solid fish waste particles and so as time advances, the media bed acts as a more efficient mechanical solids trap and traps smaller and smaller solid fish waste particles. However, this also means that as time advances, the interstitial spaces have the potential to become so small that they can restrict water flow to the point where the flow rate of water through the bed is less than the influent water flow rate, and the bed can eventually become clogged and water flows may become restricted.

In addition, this may also lead to what is called "channelling"; a process where some interstitial spaces are so clogged that water will flow around them and seek interstitial spaces with clearer flow paths. This means the clogged spaces do not pass water and the remaining spaces that do flow must take more of the treatment burden.

Luckily, the media bed also contains colonies of bacteria that like to break down (or mineralise) the solid fish waste particles and dissolve the constituent elements (nutrients) back into the water column. Therefore, if we can balance the build-up of the solid fish waste particles with the break down of them via mineralisation, then the media bed has the potential to continue to mechanically filter the water without clogging for extended periods of time.

## The Site for Solids Mineralisation

Plants do not have the ability to internalise large, organic molecules across their root surfaces. This means that plants can only take up nutrients in basal, inorganic and ultra-small forms. As an example, nitrogen often exists as nitrate, and nitrate is a small molecule that consists of one nitrogen atom attached to three oxygen atoms ($NO_3^-$), phosphorous often exists in an oxygenated form as phosphate ($PO_4^{3-}$), and calcium exists as a simple, single atom ($Ca^{2+}$). All of these substances can cross the plant root surface and be internalised by the plant.

Solid fish wastes, when released from the fish, are complex, large organic structures and therefore, cannot directly cross the plant root surface and must be converted to the smaller constituents if they are to cross into the plant. It is certain species of bacteria in the media grow bed that break down and convert the solid fish wastes, via the process of mineralisation, that make them available to the plant.

Therefore, solids mineralisation is the process where certain bacteria which inhabit the media bed break down the solid fish waste particles to the constituent elements which dissolve back into the water column. These elements are the nutrients that feed the plants.

The solids mineralisation process can only occur at a certain rate; the bacteria take time to initially break down the solids into smaller particles and more time to convert them from large, organic macromolecules into the constituent elements.

## Solids Mineralisation Rate and Bed Sizing

Because it takes time for the bacteria to fully mineralise the solid fish wastes, we must account for this when we size the media bed so that the rate at which the solids enter the bed is equal to the rate at which the bacteria can mineralise the solids. It is therefore evident that sizing a media bed for solids treatment so that it doesn't clog is a function of the input rate of the fish waste solids and the mineralisation rate of the bacteria present in the bed. If these two factors are balanced, then the bed is far less likely to clog and should operate efficiently for an extended period of time.

Fish produce solid fish waste at a predictable rate based on the amount of fish feed that they are fed on a daily basis. In addition, the fish waste solids mineralisation rate of the bacteria also occurs at a predictable rate based on the amount and concentration of fish waste solids present and the area available for the mineralisation bacteria to colonise.

Therefore, with an understanding of these two processes, we can size the media bed so it treats and removes the solid fish waste at a rate that is equal to, or faster than, the rate at which the fish produce the solid waste so that the bed has a low chance of ever clogging.

The bacteria we want to inhabit the aquaponic media bed that mineralise the solid fish waste are aerobic in nature (ie: they like an oxygen-rich environment). We want aerobic bacteria because we have an oxygenated system due to the fact that fish, plant roots and nitrification bacteria all like water with good concentrations of oxygen in it. There are also bacteria that operate in oxygen poor or zero oxygen environments; these are called anaerobic bacteria. We want to avoid anaerobic bacteria in aquaponic systems because they have the potential to release toxic compounds that are detrimental to the fish, plants and nitrification bacteria and can kill them. They also have the ability to affect the system water chemistry in ways that are not desirable and consume alkalinity in the system, making pH less stable.

If we encourage aerobic bacterial growth in our media beds, we must understand that these bacteria also use oxygen and so have the ability to compete with the fish and plant roots for oxygen in the water. Therefore, the oxygen usage rate of the bacteria is also a factor in sizing the media bed.

Luckily, a precedent has been set with respect to sizing media beds for solids mineralisation capacity. This has been done by scientists and engineers who have worked for many years in the field of constructed, media-based wetlands for the treatment of an array of organic solids. These scientists have produced models that allow them (I have worked in this field also) to size media beds so they treat and mineralise solids at a predictable rate. These media bed sizing models have been tested against actual treatment wetlands in a real situation and have been proven to have a high rate of accuracy in terms of solids mineralisation.

Therefore, with the ability to predict the amount of solid wastes the fish produce and the solids mineralisation capacity of the media grow bed, we can produce design models for the appropriate sizing of media beds in an aquaponic context with a high amount of predictability.

## Aquaponic Media Bed Sizing Calculators

There are currently a number of ways to size a media bed for a 100% media bed aquaponic system (usually small, hobby-scale systems). Most of these are not based on the amount of dissolved nutrients the fish will produce related to the amount of nutrients the plants will use, but rather, unpredictable ratios based on water volume and media bed volume. Any approach to size aquaponic media bed systems based on anything other than nutrient dynamics will only ever be an approximate approach and will only lead to an aquaponic system design that is based on chance.

Like solid wastes, fish produce a very predictable amount of dissolved waste nutrients based on the amount of feed they are fed. In addition, the plants use a predictable amount of nutrient each day. Therefore, it is clearly self-evident that the sizing of any aquaponic media bed should be based on a ratio between the amount of fish waste the fish produce (which is based on the amount of feed the fish are fed) and the amount of nutrient the plants can take up.

However, the ability of the media bed to break down and mineralise the solid fish wastes must also be taken into consideration when sizing the media bed.

Therefore, the sizing of the media bed should be based on two main functions:

1. The ratio of the fish feed input rate to the plant nutrient uptake rate.

2. The solid fish waste mineralisation rate of the media bed.

At Aquaponic Solutions, we have designed a spreadsheet model/calculator for hobby-scale aquaponic systems that does this and this calculator is freely available to anyone who wishes to use it (see www.aquaponic.com.au).

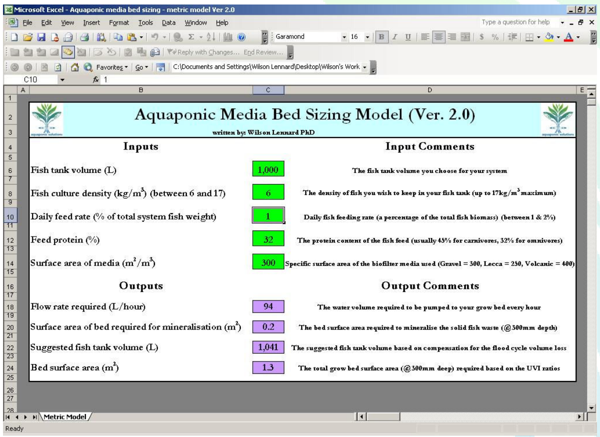


Figure 2: The Aquaponic Solutions Hobby/Backyard Media Bed Calculator.

Interestingly, the associations for nutrient balancing and mineralisation rate do not follow standard, basic mathematics and complex mathematics are involved. Also, the mathematical associations for the two functions are very different and operate at different rates.

The outcome is that an interesting phenomenon occurs.

As the fish stocking density (the weight of fish in a unit volume of water) increases, the requirement for media bed surface area based on the mineralisation rate increases faster than the media bed surface area required for nutrient balancing. Therefore, we quickly reach a point where the bed size based on the mineralisation requirement overtakes the bed size required for nutrient balancing.

So, if the fish stocking density goes too high (above approximately 17 kg/m$^3$ for fish fed a 32% protein diet – like *Tilapia spp.*), the bed size for the mineralisation requirement goes above that required for nutrient balancing. Therefore, for hobby-scale, 100% media bed systems, users should restrict fish stocking densities to below this 17 kg/m$^3$ density.

This occurs because the media bed mineralisation rate is directly proportional to the concentration of the fish waste solids in the water (concentration is the weight of material in a known volume of water). So whilst media bed solids mineralisation rate is related to the amount (or total weight) of fish waste solids produced, it is also dependent on the concentration of the solids in the water column.

This is because the concentration of these solids directly affects the ability of the bacteria to handle and process the amount of solids that are deposited in their general zone of living; if too many solids are present, it lowers the oxygen concentration available to the bacteria and the efficiency at which they mineralise the solids falls. In addition, this is also why the solids mineralisation rate is related to media bed surface area and not media bed volume; the surface of the media bed (even for the flood and drain approach) is the zone of the bed that contains the highest oxygen concentrations, so the bacteria prefer to migrate and live near the surface of the bed.

This also has an affect with respect to sizing the media bed component of commercial-scale hybrid aquaponic systems where a proportion of the grow bed area is media-based. As is seen with 100% media bed systems, designers must be careful to make sure that the fish stocking density of systems does not go too high so that the size of the media bed treatment area required is properly represented in the overall design.

## The Effect of Nutrient Balancing Ratios

As we have seen, there are two functions paramount to correct media bed sizing; nutrient balancing via fish feed input to plant grow bed area ratios and bed area requirement for complete and long lasting solids mineralisation. Mineralisation capacity is also directly related to the fish feed input to plant grow bed area ratio with relation to balanced nutrient flows between the fish and the plants.

Aquaponic design ratios are a hotly contested area of aquaponic system design. Currently, the only scientifically tested and confirmed fish feed to plant grow bed area ratios freely available are those produced by Dr James Rakocy and his team from the University of the Virgin Islands (UVI). However, these ratios are for aquaponic systems that employ almost complete fish waste solids removal.

Therefore, they do not represent completely the ratios that may be employed for systems where the solids are left in the system for complete mineralisation and eventual plant use. These UVI ratios may be modified however, to account for the fact that the fish waste solids remain in the system, and this is what the Aquaponic Solutions Hobby-scale media bed calculator does.

In addition, there are a number of operators who argue that these UVI ratios are too high and can be lowered further whilst still maintaining good plant growth and health (however, almost all of these views have never been scientifically verified). This means it is pertinent to test lowered fish feed input to plant grow bed area ratios with respect to solids mineralisation as well.

At Aquaponic Solutions we have modelled and tested lower fish feed rate ratios with respect to mineralisation rate and media bed surface area requirement. If we lower the original UVI leafy green feeding rate ratio by two thirds, the outcome is that the modelling demonstrates that when fish stocking density rises to as little as 20 kg/m$^3$, the media bed surface area requirement based on complete fish waste solids mineralisation still represents 40% of the total grow bed area. In more practical terms, this means that a hybrid system with a total grow bed area of 100 m$^2$ and a fish stocking density of 20 kg/m$^3$ requires a media bed area of at least 40 m$^2$, and therefore, only has a deep flow bed area of 60 m$^2$. This means that for a system as in this example, almost half of the grow bed area is media beds.

### Solids Distribution and Bed Surface Area

Another important factor in media bed solids treatment and mineralisation is distribution of solids to the surface of the media bed. Media-based constructed wetland designers go to great lengths to try and distribute the solids load across the bed as evenly as possible; utilising the entire bed surface area by using elaborate manifolded inlet distribution systems. However, in some media bed aquaponic systems (both 100% hobby-scale media bed systems and proportioned hybrid systems) the water from the fish tank is directed to the bed with single, or at most, duel or triple inlet point(s). This means that all the fish waste solids that the bed is required to mineralise are contained in only a small proportion of the overall media bed surface area.

Figure 3: Media grow beds with single inlet points; a good place for solids to accumulate quickly.

As we have seen, the media bed surface area is critical to the complete treatment and mineralisation of the fish waste solids as this is the zone of highest potential oxygen concentration and therefore, mineralisation bacteria work best in this oxygenated zone. So, if the solids are only directed to a limited proportion of the media bed surface area, then the entire bed surface area is not being utilised and so the treatment capacity in terms of solids of the bed is severely restricted.

The outcome is that if the solid waste load is distributed to the media bed at only one, or even two or three points of entry, then the fish waste solids are concentrated in these areas and so treatment is localised and takes far longer.

In addition, these areas of localised solids build-up become saturated with solids very quickly and treatment and mineralisation may not occur efficiently because the concentrated solids can cause localised anaerobic zones (with the associated risks to the system) and overload of the associated bacteria. As we have also seen, anaerobic conditions are not optimal for aquaponic systems and may lead to deleterious affects.

There is evidence from media-based constructed wetlands that solid wastes can migrate in a horizontal manner. However, the distance of migration horizontally is relatively short and if single inlet approaches are employed, then it is certain that solids are not being distributed across the entire media bed surface area.

Figure 4: A manifolded media bed inlet approach; far better for spreading fish waste solids across more of the grow bed surface area.

It may also be argued that the addition of worms to the media bed may assist a more even distribution of solids horizontally across the bed. However, a quick look at most media beds will confirm that even if worms are present, solids still accumulate at inlets to a far higher concentration than the rest of the bed (more so in hybrid systems that are required to use higher fish stocking densities than hobby-scale systems); proof that horizontal distribution is still limited.

The only real way to ensure that as much of the media bed surface area is utilised, is to employ multi-inlet, manifolded approaches.

## The Worm Argument and Effect

Many people now add Earth Worms to their media grow beds. The argument is that these worms treat and process fish waste solids and so the beds ability to mineralise the fish waste solids is greatly enhanced. This means that the bed doesn't need to be as large if worms are employed.

We found this a very interesting argument at Aquaponic Solutions, so performed a literature search to try and find published, scientific information that supports the argument. Sadly, there is currently little scientifically verified information that supports this argument.

We then decided to do a search for any information related to the break down or mineralisation rate of worm castings. This is because there seems to be no accounting for the fact that worms produce their own solid waste particles; worm castings.

We searched for two main factors with relation to worm castings:

1. The amount of worm castings produced based on the intake mass of the worm (ie: the amount of worm casting produced based on the amount of solids the worm eats).

2. The persistence of the worm cast (ie: how long it takes for the worm cast to break down and mineralise).

We could find no mass balance information with respect to what weight of worm casts a worm produces based on the weight of solid the worm consumes. It is obvious that a worm eats and produces casts.

It is also fairly obvious that the weight of cast produced will be less than the weight of solid ingested (this is because the worm will utilise some of the nutrients in the solid to build itself and grow, and to reproduce and produce other worms – nothing comes for free and so the weight of cast produced must be less than the weight of solid eaten). However, as stated, we could find no information on the ratio of cast produced with respect to the weight of solid eaten.

It was also very difficult to find any scientifically verified information related to how persistent worm castings are (ie: how long they take to break down and completely mineralise). The only paper we could find related to the persistence of worm castings was in soil conditions in an open field and these are very different to the conditions in aquaponic media beds (for one, aquaponic media beds are constantly damp or wet, whereas soil may become completely dry depending on how often it rains!). The shocking outcome of this paper was that worm castings could persist for as long as 1 year in the upper layers of the soil! As stated however, this does not fully represent an aquaponic media bed situation and it can be confidently predicted that worm castings would not last for this amount of time in the wet environment of an aquaponic media bed.

The only other information we could find was a prevalence of "recipes" with relation to how to make worm teas from worm castings. This is an approach whereby worm castings are placed in a bag of some type and steeped for 24 hrs in a bucket of water that is highly aerated. The bag is then removed and the product is a worm tea of unknown concentration, but has obvious plant growth advantages. There is little to no mention of what happens to the castings and by how much they dissolve, but all say that the castings are returned to compost, so the assumption is that there are still plenty of castings left over after the 24 hrs of steeping. Again, it is fair to state that this also does not fully represent an aquaponic media bed in terms of the contact time between worm castings and water.

The outcome is that, based on the currently available information it is very difficult to determine:

1. What weight of castings exit the worm based on the weight of solids the worm consumes.

2. What the bacterially mediated break-down and mineralisation rate of worm castings is.

Therefore, we must take a cautious approach to these two factors and try and approximate what is happening in a "worst case scenario" approach to be able to make sure we account for all factors in a way that gives us the highest amount of predictability.

This all means that whilst it is evident that worms consume fish waste solids in media bed aquaponic systems, we have little if any ability to quantify the effect. The outcome is that we must accept at this stage (as stated, by adopting a worst case scenario approach) that worms may convert the fish waste solids to another form (ie: worm castings), but the amount by which they lower the overall weight or mass of the solids is unknown because we have no quantifiable information on this subject. We must also accept that at this stage (again, by adopting a worse case scenario approach) that we have no information on whether the mineralisation rate of worm castings by media bed bacteria is any faster than that of straight solid fish wastes.

Therefore, the overall outcome is that we must accept that we cannot currently put forward any quantifiable difference in terms of adding earth worms to media beds in terms of the overall mineralisation rate of fish waste solids.

This would mean that, at this point where we have no scientific information or data to confirm any effects worm addition to aquaponic media beds may have, that we cannot lower the potential bed size based on worm addition in terms of fish solids mineralisation rates. So we must continue to use the standard solids mineralisation rates that are scientifically reported by the constructed, media-based wetland industry. This means that the media bed area requirement for fish waste solids mineralisation cannot currently change from those of current modelling outputs and therefore, the sizing examples listed above hold true for the time being.

**A Final Word**

I personally use a separated treatment approach to mineralise fish waste solids. The fish waste solids are quickly removed from the main aquaponic system using standard aquaculture solids separation filters (sedimentation, screening) and these solids are placed in a separate, isolated mineralisation tank. This mineralisation tank is highly aerated and the fish waste solids break down, mineralise and dissolve into the water column in this tank.

Figure 5: Separated, aquatic, media-less fish waste solids mineralisation tank. NZ, semi-commercial, NFT aquaponic system.

Everyday, more solids are added to the mineralisation tank and so every day, the aeration is turned off for a period of time and a proportion of the clarified liquid at the top of the mineralisation tank is added back into the main aquaponic system. This means that fish wastes solids are mineralised as completely as possible in a region separate to the main aquaponic system and the resultant nutrients are added back to the aquaponic system for plant utilisation.

This approach avoids any issues associated with directing solids through media or gravel beds contained in the normal water flows of the main aquaponic system.

This also means that media beds may be employed in the system design to whatever proportion is desired based on the plants that are wished to be grown, and market and sales requirements.

This separated approach also removes the need to worry about whether the media bed is sized correctly for complete and efficient solids mineralisation, removes the worry of inlet configuration and number to the media bed and lowers media bed cleaning frequency.

I have used this separated mineralisation approach for approximately 6 years now and I have noticed that there is always some solid material that cannot be mineralised completely by an aerated mineralisation approach. I have not analysed this material and it seems to represent a low percentage of the total solids load. All I can do is assume that it is a material that has a make-up and constitution that does not allow the aerobic mineralisation bacteria to completely break it down and dissolve it back into the water column. In appearance, it looks very similar to fibre or cellulose, but as I say, I have not analysed it so cannot confirm this. Dr James Rakocy tells me these are called "refractory" compounds and indeed, do not completely breakdown.

The outcome is that it seems apparent that there may always be a percentage of the fish waste solids that are unable to be completely mineralised in aerated or aerobic aquatic systems. This means that if fish waste solids are directed to media beds for mineralisation treatment, then at some stage, the bed will eventually start to clog because of the presence of these materials that do not appear to completely mineralise.

Hobby-scale aquaponic systems are small and so if any media bed cleaning is required, then it seems it would not be a huge or difficult task to perform.

Semi-commercial or commercial sized hybrid style aquaponic systems using media beds for solids filtration and mineralisation are only new to aquaponics and therefore, it is difficult to find any that have operated for appreciable periods of time (ie: several years). The media-based constructed wetland industry currently places a 7 – 10 year maximum life span on media-based treatment wetlands due to the fact that they eventually clog up with the materials that cannot be completely mineralised. In addition, this life span is applied even though these media-based constructed wetlands are sized correctly for solids mineralisation and are also almost always colonised by earth worms!

In conclusion it is argued that scientific and engineering principles (adopted from the associated media-based constructed wetland industry) may be applied to aquaponic media bed sizing so that the mineralisation rate of the fish waste solids can be balanced as closely as possible with the fish waste solids production rate so as to lower the cleaning frequency of the media bed as much as possible. However, it is also evident that some proportion of those fish waste solids may never be able to be broken down completely. This means that aquaponic media bed users (whether 100% media bed, hobby-scale systems or proportioned commercial hybrid systems) should accept that at some stage, their media beds may need some form of cleaning.

For small hobby style systems this seems of little consequence, but in the case of larger, commercial-scale hybrid systems, this may be a tedious and taxing task due to the size of the media bed area required.

I guess only time will tell!

Happy aquaponicing.

Wilson Lennard
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**Thanks to Dr James Rakocy for reviewing this fact sheet.