POLLUTANTS IN AN AQUARIUM IN RELATION TO A SET REGIME OF PARTIAL WATER CHANGE

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In the sea, in rivers, and in lakes, the wastes generated by fish and other aquatic plants and animals do not accumulate to any significant extent, being diluted by the sheer volume of water of the habitat. This may be aided in cases by the fact that the water, such as river water, is being constantly renewed. In the closed environment of a home aquarium devoid of plants, however, the removal of pollutants generated by its inhabitants is dependent upon the water being changed from time to time. There is little dispute that at least periodic partial water change is necessary in order to maintain a healthy aquarium that fish can live in without undue stress. There is little disagreement either that an aquarium would benefit from more frequent water change, generally "the more frequent, the better." Nevertheless, how much water should be renewed at each water change and how often such changes should take place are often matters of faith for the aquarium keeper. The consequences of increasing or decreasing the frequency of water change or the volume of water replaced on each occasion may only be guessed at. Common questions that many fish enthusiasts frequently ask, but have difficulty finding unambiguous answers to in hobbyist books and periodicals, may therefore include the following:

- Since not all the pollutants are removed during partial water change, would pollutants in the aquarium rise unabated with time if a set regime of partial water change were maintained? Is a complete water change from time to time indispensable to prevent the pollutants from reaching a harmful level otherwise?
- Would doubling the amount of water renewed at regular intervals (e.g., from 5% to 10%, or from 20% to 40%) actually double the benefit to the aquarium?
- If a constant proportion of water in an aquarium were changed routinely, would a small increase in the volume of water changed (e.g., by a further 10%) make much difference to the pollutant load? Would the additional effort be worth the trouble?
- Can the period between water change be extended without detriment to water quality by increasing the proportion of water changed? By how much would the proportion of renewed water need to be increased to compensate?

TABLE 1: BUILD-UP OF POLLUTANTS IN AN AQUARIUM WHERE 50% OF THE WATER IS CHANGED DAILY

Day	Pollutants before water change (grams)	Pollutants after 50% water change (grams)
1	2	1
2	2 + 1 = 3	1.5
3	2 + 1.5 = 3.5	1.75
4	2 + 1.75 = 3.75	1.875
5	2 + 1.875 = 3.875	1.9375
6	2 + 1.9375 = 3.9375	1.96875
7	2 + 1.96875 = 3.96875	1.984375
8	2 + 1.984375 = 3.984375	1.9921875
9	2 + 1.9921875 = 3.9921875	1.9960937
10	2 + 1.9960937 = 3.9960937	1.9980468

2 grams of pollutants are generated in the aquarium daily.

TABLE 2a: BUILD-UP OF POLLUTANTS IN AN AQUARIUM WHERE 40% OF THE WATER IS CHANGED WEEKLY

End of Week	Pollutants carried over from last water change (a)	Pollutants generated in the current week (b)	Total pollutants before water change (a+b)	Pollutants remaining after 40% water change 0.6 x (a+b)
1	0	1	1	0.6
2	0.6	1	1.6	0.96
3	0.96	1	1.96	1.176
4	1.176	1	2.176	1.306
5	1.306	1	2.306	1.383
6	1.383	1	2.383	1.430
7	1.430	1	2.430	1.458
8	1.458	1	2.458	1.475
9	1.475	1	2.475	1.485
10	1.485	1	2.485	1.491
11	1.491	1	2.491	1.495
12	1.495	1	2.495	1.497
13	1.497	1	2.497	1.498
14	1.498	1	2.498	1.499
15	1.499	1	2.499	1.499
16	1.499	1	2.499	1.499

The amount of pollutants generated by the aquarium's inhabitants within one week is taken as 1 unit. A 40% water change is made at the end of the week.

TABLE 2b: BUILD-UP OF POLLUTANTS IN AN AQUARIUM WHERE 60% OF THE WATER IS CHANGED WEEKLY

End of Week	Pollutants carried over from last water change (a)	Pollutants generated in the current week (b)	Total pollutants before water change (a+b)	Pollutants remaining after 60% water change 0.4 x (a+b)
1	0	1	1	0.4
2	0.4	1	1.4	0.56
3	0.56	1	1.56	0.624
4	0.624	1	1.624	0.650
5	0.650	1	1.650	0.660
6	0.660	1	1.660	0.664
7	0.664	1	1.664	0.666
8	0.666	1	1.666	0.666
9	0.666	1	1.666	0.667
10	0.667	1	1.667	0.667
11	0.667	1	1.667	0.667

The amount of pollutants generated by the aquarium's inhabitants within one week is taken as 1 unit. A 60% water change is made at the end of the week.

TABLE 3: BUILD-UP OF POLLUTANTS IN AN AQUARIUM WHEN THE POLLUTANT EQUILIBRIUM IS REACHED

Percent water changed	Time interval between water change							
	1 week*		2 weeks		3 weeks		4 weeks	
	Before water change	*After water change*	*Before water change*	*After water change*	*Before water change*	*After water change*	*Before water change*	*After water change*
5	20	19	40	38	60	57	80	76
10	10	9	20	18	30	27	40	36
15	7	6	13	11	20	17	27	23
20	5	4.0	10	8	15	12	20	16
25	4	3.0	8	6	12	9	16	12
30	3.3	2.3	7	4.7	.10	7	13	9
35	2.9	1.9	6	3.7	9	6	11	7
40	2.5	1.5	5	3.0	8	4.5	10	6
45	2.2	1.2	4.4	2.4	7	3.7	9	4.9
50	2.0	1.0	4.0	2.0	6	3.0	8	4.0
55	1.8	0.8	3.6	1.6	5	2.5	7	3.3
60	1.7	0.7	3.3	1.3	5	2.0	7	2.7
65	1.5	0.5	3.1	1.1	4.6	2.6	6	2.2
70	1.4	0.4	2.9	0.9	4.3	1.3	6	1.7
75	1.3	0.3	2.6	0.6	4.0	1.6	5	1.3
80	1.3	0.3	2.5	0.5	3.8	0.8	5	1.0
85	1.2	0.2	2.4	0.4	3.5	0.5	4.7	0.7
90	1.1	0.1	2.2	0.2	3.3	0.3	4.4	0.4
95	1.1	0.1	2.1	0.1	3.2	0.2	4.2	0.2
100	1.0	0	2.0	0	3.0	0	4.0	0

DERIVATION OF FORMULA FOR THE POLLUTANT EQUILIBRIUM

The main text can be read without referring to this section

The manner in which pollutants accumulate in the aquarium over a period during which partial water changes are made can be described by an equation.

Let x = proportion of water changed
y_r = residual pollutants carried over from the *previous* partial water change
y_a = pollutants in the water immediately after partial water change
y_b = pollutants in the water immediately before partial water change
p = pollutants generated by inhabitants of the aquarium in the time interval (e.g. 1 week) between water changes.

Just before a partial water change, the pollutants in the aquarium comprise the residual pollutants carried over from the previous partial water change (y_r) and pollutants deposited in the water since the last water change (p).

The pollutants in the aquarium just before water change is therefore

$$y_b = (p + y_r).$$

When a partial water change (any proportion between 0 and 1) is made, that fraction of water (x) is removed, carrying with it a proportionate amount of pollutants in the water. The proportion of pollutants that is left in the aquarium is then (1 - x).

Therefore, the amount of pollutants in the aquarium immediately after water change

$$y_a = (p + y_r)(1 - x).$$

As shown in Tables 2a and 2b, $y_a = y_r$ when the pollutant equilibrium (PE) is reached. Therefore at PE,

$$y_a = (p + y_a)(1 - x).$$
$$y_a = p - xy_a + y_a - px$$
$$xy_a = p(1 - x)$$

Hence, $y_a = \frac{p(1 - x)}{x} = y_r$

This is the amount of pollutant in the aquarium immediately after a partial water change when PE is reached. From this point in time until the next partial water change, newly generated pollutants (p) would have been deposited in the water. The total amount of pollutants just before a partial water change is due would then be

$$y_b = p + \frac{p(1 - x)}{x}.$$

If p is defined as 1 unit of pollutant, then at PE

$$y_b = 1 + \frac{(1 - x)}{x} = PE. \approx \frac{1}{x}$$

And finally, perhaps the most frequently asked question:

- What proportion of the aquarium water should be changed at each partial water change?

To answer these questions, this article will examine basic doctrines in aquarium maintenance and attempt to remove some of the ambiguities and guesswork surrounding water change for the home aquarium.

The breakdown of pollutants in an aquarium is a very complex affair, involving the action of microorganisms in the sand bed, on the surface of aquarium plants and decorations, and in the filtration system employed. Algae and water plants also play their part in detoxifying pollutants and recycling their byproducts. Since factoring in these variables would complicate arguments immensely, they are not considered here and it is assumed that removal of pollutants takes place entirely through water change. A few assumptions are necessary. First, it is assumed that the aquarium consists of a fish-only plain glass tank devoid of sand bed, plants, decorations, or filtration system. It is further assumed that the amount of pollutants deposited in the aquarium (fish wastes and uneaten fish food) between water changes (over one day, one week, one fortnight, etc., depending on the frequency of water change) is constant, and that such pollutants are evenly dispersed in the water where they remain until removed by water change.

Accumulation Of Pollutants With Partial Water Change

While a complete water change would remove all pollutants from an aquarium, this is not always practical or desirable. A hobby ceases to be one when it becomes a chore. Fishkeeping is a pastime to be enjoyed and routine aquarium management should not therefore entail more hard work and bother than absolutely necessary. The other argument against drastic water change is that fish may suffer physiological shock if the chemical parameters of the ambient water were changed suddenly and drastically. Partial water change is therefore the common practice in aquarium maintenance. Since not all the pollutants in the aquarium are removed in a partial water change, it is important to consider how the pollutant level changes in the long run and how this affects the aquarium and its inhabitants.

In the July 1999 issue of *FAMA*, contributor James Fuller alerted fishkeepers to what he saw as the perils of relying

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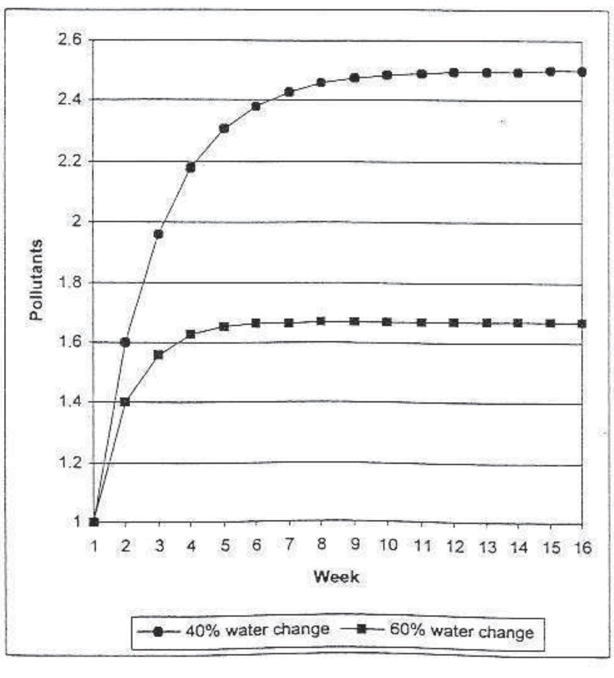

Figure 1. Accumulation of pollutants in aquaria where 40% 60% the water is changed weekly.

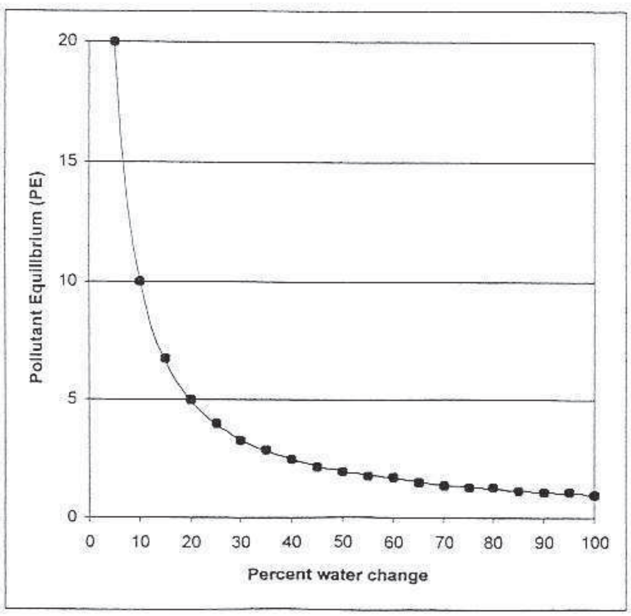

Figure 2. The Pollutant Equilibrium (PE) in relation to the proportion of water renewed at each water change.

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solely on partial water changes to keep aquarium water fresh. He presented the hypothetical example of John Doe's aquarium where 2 grams of pollutants were generated daily. He contended that even if John had made a 50% water change daily, only half the pollutants would have been removed and that "a full gram of pollutants (would) have been added each and every day." Mr Fuller advised that a complete water change should be carried out from time to time, as the pollutants would inevitably reach a harmful level otherwise. Let us examine this reasoning. A 50% water change removes one gram of pollutants and 1 gram is left in the water immediately after water change. No argument so far. At the end of the second day, 2 grams of new pollutants are deposited into the aquarium water and is added to the 1 gram carried over from the previous day. This adds up to a total of 3 grams of pollutants. The 50% water change at the end of the second day brings this down to 1.5 grams. Note, however, that the increase in pollutants after the second water change is only 0.5 gram, and not 1 gram as in the previous day. If this daily 50% water change carries on, the pollutants in the aquarium on subsequent days is shown in Table 1. Moving on to the third day, and then to the fourth day, etc., it can be seen that while the pollutants continue to increase, the quantum of increase at the end of each day gets smaller and smaller. Eventually, the pollutants just before water change approach the value of 4 grams, which happens to be two times the amount of pollutants generated in John Doe's aquarium in a day. No matter how often the 50% water change is repeated, the limit of 4 grams is not exceeded. In other words, pollutants in the aquarium would tend to stabilize at two times the amount of pollutants generated in a day, if 50% water changes were made daily. Mr. Fuller was hence wrong in assuming that pollutants would increase unabated with a regime of partial water change.

Concept Of The Pollutant Equilibrium, PE

Besides the specific case described above where pollutants generated in an aquarium are fixed at 2 grams a day, and where 50% partial water changes are made daily, let us look at what happens when other amounts of water are renewed during partial water change. In Table 2a, we see how pollutants build up in the aquarium when 40% of the water is changed weekly. Here, we shall say that the pollutants deposited into the aquarium water is 1 unit, which can be any specified amount such as 1 gram, 5 grams, or 10 milligrams, etc. Although weekly water change is stated in the example in Table 2a, the calculations are equally valid if water change interval were some other duration, such as daily, fortnightly, monthly, etc., so long as the interval is kept constant. The amounts of pollutants immediately before and immediately after water change are calculated as before. Starting from pollutant-free new water in the aquarium, it is apparent from Table 2a that pollutants gradually increase even as the water is partially changed periodically. After a period, pollutants in the water reach a steady state, as we have already seen in Table 1. In this article, we shall call this steady state the Pollutant Equilibrium (or PE for short). At that point, pollutants neither increase further nor do they decrease as long as a fixed proportion of water continues to be changed at a fixed time interval. PE is the amount of pollutant generated in the aquarium between one partial water change and the next. In a stable aquarium where partial water changes are made weekly, a PE of 2 means there is two times the amount of pollutant that is normally deposited in the aquarium in a week. Viewed another way, it is equivalent to the amount of pollutant generated in two weeks in the aquarium.

As a further example, we can find tabulated in Table 2b the build-up of pollutants if 60% water change were made at weekly intervals. Again, a similar trend is observed, which is that the pollutants in the water first rise and then reach a steady state, the PE, after some time. This trend can be seen in Figure 1, which is a graphical representation of the data from Tables 2a and 2b. PE for 60% water change (which is 1.67) is significantly lower than PE for 40% water change (which is 2.5). In practical terms, this means that regular 60% water change would maintain the pollutant level in the aquarium at a level equivalent to 1.67 times the amount of pollutants generated in-between water change. This compares with 2.5 times the pollutant output in the period between water change if only 40% partial water changes were made regularly. If the water changed were only 10%, calculations similar to those used above would show the ensuing situation deteriorating further, with the pollutants stabilizing at 20 times the amount generated from one water change to the next. This observation is in agreement with that of contributor David Boruchowitz who advocated water changes of at least 50%, contending that a 10% water change was ineffective (*FAMA* December 2001). While, in his article, Mr Boruchowitz followed a line of reasoning different from that presented here, the conclusion arrived at is similar.

Besides the PE values differing with different extents of water change, the time it takes for PE to be reached also differs. With 40% water change, PE is 2.5 and 95% of the PE value (i.e., 2.375) is reached after 6 weeks. In comparison, 95% of the PE is reached after only 4 weeks when water change is 60%. In Mr. Fuller's example of 50% water change for John Doe's aquarium discussed earlier, 95% of the PE is reached after 5 weeks. From these observations, we know that PE is attained earlier as the proportion of water renewed at each water change increases. (The reason why we compare the time it takes for 95% of PE to be reached, rather than the time it takes PE itself to be reached, is that the pollutants gets closer and closer to PE with each partial water change but does not actually reach it, theoretically speaking. In mathematical terms, the exact PE is reached only after an "infinite" number of water changes.)

We can now make a general statement regarding the build-up of pollutants with routine partial water change. Starting from pristine unpolluted water, pollutants in the aquarium will gradually increase with time, even as partial water change continues at regular intervals. However, this increase does not proceed unabated, but stabilizes as it nears PE. The greater the proportion renewed at each water change, the lower would be the PE, and the shorter the time it takes for PE to be reached.

Applying The Pollutant Equilibrium In Aquarium Maintenance

The PE varies according to the proportion of water in the aquarium that is changed, and a PE value for any percentage of water change can be determined from step-by-step calculations similar to those appearing in Tables 1 and 2. However, there is a simpler way to arrive at the PE without tedious calculations. PE can be expressed as:

$$1 + \frac{(1 - x)}{x} = \frac{1}{x}$$

where x is the proportion of water renewed during partial water change. (Derivation of this simple formula is given in the box, but is not essential to reading this article.) While not all readers are interested in grappling with mathematical formulae, there is something to be said for having one at hand. The utility of the formula lies in the fact that the PE can be determined for any percentage of water change simply by substituting its value for x (e.g., 0.5 for 50%). For quick reference, a table of PE values for partial water changes between 5 to 100% is given in Table 3. As can be seen in the graphical representation in Figure 2, the change in PE is not linearly proportional to the percent water change. From 5% or lower, the PE drops rapidly as the percent of water change increases to about 20% when the rate of change tapers as the curve flattens out. From about 60% water change onwards, the decrease in PE with increasing percent water change is relatively slight.

Increasing the proportion of aquarium water changed from 10% to

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20% results in a PE change from 10 to 5, a change of 5 PE units (Table 3). However, further increasing water change to 30% drops the PE by only an additional 1.67. Therefore, greater benefit is obtained in increasing the percentage of water changed when the percentage is low in the existing practice. If water change were already extensive, there is little room left for improvement. In an actual situation, the owner of a 100-gallon aquarium who is already performing weekly partial water change might be considering whether the tedium of removing and replacing a further 10 gallons of water is really worth the trouble. If his current water change were 10% per week, increasing the water change to 20% would result in the PE being halved, from 10 to 5: in most instances a worthwhile investment in time and effort. On the other hand, if the fishkeeper were already changing 60% of the tank water at a time habitually, changing an additional 10 gallons would improve the PE only marginally, from 1.7 to 1.4. In this case, he might be justified in deciding the additional benefit as not being worth the additional trouble.

The concept of the PE should be borne in mind in aquarium maintenance. It is especially important to consider how PE varies with the proportion of the water renewed at each water change. In the above example, the modest benefit of a 10% water change may not justify the effort, considering the trouble involved in sorting out pails, hoses, and other paraphernalia connected with changing aquarium water. A larger water change that reduces pollutants to a disproportionately greater extent may therefore be a more worthwhile practice. Up to a point, however, further increasing the amount of water changed begins to bring diminishing returns. Hence, the difference between a 60% water change (PE=1.7), a 70% water change (PE=1.4) or a 95% water change (PE=1.1) in the home aquarium would essentially be the unnecessary bother and perhaps a sore back and aching arms. In the large-scale operations of professional fish breeders, some of whom make almost complete water changes daily, cutting back on unnecessarily high rates of regular water change may enable savings in water and labor costs without sacrificing the quality of the water significantly.

Decisions On Water Change Frequency And Fish Stocking Rate

If an aquarium fish enthusiast performing 20% water change weekly (for a PE of 5) sees no need to decrease PE further, there could still be reason for him to increase the water renewed at each water change. Table 3 has columns for PE values for between-water change intervals of 1 to 4 weeks. Looking at the column for "2 weeks between water change" in Table 3, a PE value of 5 is given for 40% water change. This means that water change could be extended from one week to two weeks without increasing the pollutant level in the aquarium, provided that 40% of the water is renewed at the end of each fortnight. Thus, an appreciation of the PE enables greater flexibility in aquarium maintenance.

Another application of Table 3 is in determining how the fish population might be increased without further adding to the pollutant level of the aquarium. For example, a stable aquarium that receives weekly water change of 15% (for a PE of 7) might be supporting a school of a dozen fish without stress from the environment. If another two dozen similar fish were added to the aquarium, how might this be done if it is desired to maintain the same pollutant level? To answer this question, just change the heading of "1 week to 4 weeks between water change" in Table 3 to "1 dozen to 4 dozen fish." Under the column for "3 weeks" (now changed to "3 dozen fish"), a PE of 7 corresponds to a water change of 45%. Hence, the stabilized pollution load would be unchanged even with the fish population increased from one dozen to three dozen, provided that the weekly water is changed from 15% to 45%.

Safe And Harmful Pollutant Levels

A PE of 20 (arising from regular 5% water change) gives rise to a pollutant load 10 times that associated with a PE of 2 (arising from regular 50% water change). It is certainly true, therefore, that a PE of 20 is more likely to be harmful to the aquarium's inhabitants than a PE of 2. However, this does not necessarily mean that a PE of 20 is always harmful, whereas a PE of 2 is not.

Since PE is the amount of pollutants deposited in the aquarium in-between one water change and the next, a given PE value can represent a large amount of aquarium wastes or a small amount of wastes, depending on how much wastes are actually generated within that period. If a 100 gallon aquarium held only two guppies and 5% of the water were changed weekly, the fish are unlikely to be stressed despite the pollutants present being 20 times that generated by these two fish per week. Indeed, even if only 1% of the water were changed weekly with the ensuing PE of 99, the fish would still be unharmed because of the sheer volume of water in the aquarium relative to its biological load. It is therefore important to bear in mind that PE is a relative measure. Whether a particular PE value would be harmful would depend on whether the pollutant content of the aquarium exceeds the stress threshold for its inhabitants. If the biological load of the aquarium is nowhere near the stress threshold, then increasing the amount of water changed would bring little additional advantage, while decreasing the amount changed would add little harm.

Two factors determine if a given PE is tolerable for an aquarium environment. In the above illustration, there is the actual amount of wastes that is generated between one water change and the next (which is how PE is defined). The number and size of the fish determine this biological load. The type of fish may also have some influence because some fish are "messier" than others. The other factor to consider is how well the aquarium inhabitants tolerate a given biological load. Some fish (e.g., the discus) require an untainted environment whereas others (e.g., anabantids such as gouramis and fighting fish) will continue to thrive in water that is less than pristine. Therefore, whether a PE value is "acceptable" or "unacceptable" depends on how close it is to the tolerance threshold of the aquarium's inhabitants. A relatively low PE may still be unacceptable if the biological load of the aquarium is high (or the fish it contains are delicate), whereas a higher PE value may be tolerable if the biological load is low (or if the fish are hardy).

Quick Answers To Frequently Asked Questions

To round up, let's run through again the questions posed at the beginning of this article and see how they might be answered based on the above discussion.

1. Since not all the pollutants are removed during partial water change, would pollutants in the aquarium rise *unabated with time if a set regime of partial water change were maintained? Is a complete water change from time to time indispensable to prevent the pollutants from reaching a harmful level otherwise?*

Starting from completely clean water in an aquarium, pollutants do begin to build up gradually even as partial water changes are carried out periodically. However, this trend does not proceed interminably. Pollutant concentration reaches a steady state after a while when the pollution equilibrium (PE) is reached. While complete water change from time to time may be helpful from various viewpoints, it is not requisite insofar as pollutant accumulation is concerned.

2. Would doubling the amount of water renewed at regular intervals (e.g., from 5% to 10%, or from 20% to 40%) actually double the benefit to the aquarium?

It could, in a manner of speaking. At equilibrium, the amount of pollutants present in the aquarium would indeed be halved. However, whether the aquarium inhabitants benefit from this halving of pollutants would depend on how close the pollutant content of the aquarium is to the stress threshold for its inhabitants.

3. If a constant proportion of water in an aquarium were changed routinely, would a small increase in the volume of water changed (e.g., by a further 10%) make much difference to the pollutant load? Would the additional effort be worth the trouble?

It depends on what the existing routine is. If a regular 70% water change schedule is being maintained, for example, increasing the amount of water changed to 80% would have only a marginal effect. On the other hand, if partial water change were routinely 10%, increasing to 20% would result in a very significant advantage, and would certainly be worth the extra effort.

4. Can the period between water change be extended without detriment to water quality by increasing the proportion of water changed? By how much would the proportion of renewed water need to be increased to compensate?

To maintain the same pollutant level in the aquarium, the water changed should be proportional to the duration between water change. As shown in Table 3, PE for 20% weekly water change is 5, for example. To keep this PE unaltered while extending water change to once a fortnight, the amount of water renewed should be increased to 40%.

5. What proportion of the aquarium water should be changed at each partial water change?

There is no one answer here. Generally, the greater proportion of water that is changed, the lower would be the stabilized pollutant level in the aquarium. However, the law of diminishing returns kicks in as the amount of water renewed increases. I consider a 30% to 50% water change to be useful and practical in the general case. On the other hand, a 10% water change is hardly worth the time and effort.

References

Boruchowitz, D.E. Mythbusting. Freshwater and Marine Aquarium, 24, December 2001.

Fuller, J. The art of proper water change. Freshwater and Marine Aquarium, July 1999.

Addendum

Where the same partial water changes are made at constant intervals, the pollutant concentration in the aquarium will gradually reach equilibrium over a period of time. The numerical value of this pollutant equilibrium (PE) is directly proportional to the amount of new pollutants added to the aquarium between one water change and the next. For example, in an aquarium where one gram of new pollutants is generated between water changes, a PE of 2 means that there will be two grams of pollutants (new and previously existing) in the aquarium just before a scheduled water change.

PE can be predicted from the proportion of water replaced at each partial water change.

As stated in the article, PE is calculated as $1 + \frac{(1-x)}{x}$, where x is the proportion of water renewed at each partial water change. In fact, this simplifies to PE = 1/x. PE is therefore the *reciprocal* of the proportion of aquarium water replaced at each partial water change.

If, for example, one third (⅓) of the aquarium water is routinely changed at a constant interval, the expected PE is 3. Over an extended period, the pollutants (newly generated and previously existing) in an aquarium just before a scheduled water change will be three times the amount of pollutants newly generated between one partial water change and the next.

Another example: Constant partial water changes where one eighth (⅛) of the water is replaced each time gives a PE value of 8. If fish in the aquarium generate 1 gram of wastes between one partial water change and the next, the amount of pollutants present just before a scheduled water change will be 8 grams.

A further example: Where 60% (i.e. 60/100) of the water is replaced at each partial water change, PE is (100/60), or 1.67.

The lowest PE attainable is 1 where there is routinely complete, rather than partial, water change.

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