Water changes – overflow vs drain and refill

By Spike Cover
With math by Norm Meck

Summary:
If your pond has good mixing of new water with old water and you use the overflow method to change water (add new water to a full pond and let the excess overflow to drain), there is not a great deal of difference in that method and the drain and refill method unless you change more than about 25% of the original volume.

The details.
When it comes to changing water in a pond, there is a misconception that drain-and-add produces a much higher dilution of the old water than merely adding water and allowing the excess to over-flow. What follows will hopefully dispel that myth.

First let's define some of the terms and conditions: Drain and refill, is fairly straight forward. If you drain water from your pond and then refill it with the same amount of new water, you have indeed made a dilution exactly equivalent to whatever amount was originally drained.

However, adding water to a full pond and allowing the excess to overflow (e.g., via a standpipe), is not quite so straight forward. If you put the water in right next to the overflow and your mixing is poor, much of the new water will exit the overflow without being diluted with the existing pond water. If however, you add the water opposite the standpipe and/or there is good mixing in the pond, the situation is much different.

For those of you that are mathematically inclined, we have the Norm Meck derivation (Unfounded assertions are one thing but, as Clara Peller of Wendy's commercial fame might say, "Here's the beef!"):

Assume a container holds **Y** amount of water and **Z** amount of other stuff ("OS"). An amount of water, **ΔX,** is added, completely mixed and an amount equal to **ΔX** containing some **Y** and **Z** overflows.

Then:

$$\mathbf{Y + Z = K}$$, where **K** is the total volume of the container

For each step in the addition:
Amount of OS remaining = Original amount of OS – Amount of OS removed by adding **ΔX** water to the container, completely mixing and allowing the excess to overflow, or in equation form, it may be written as:

$$\mathbf{Z_{n+1} = Z_n - \Delta X * Z_n / K}$$

Or (rearranged):

$$Z_{n+1} - Z_n = - \Delta X * Z_n / K$$
$$\Delta Z = - \Delta X * Z_n / K$$

In the limit as ΔX and $\Delta Z \rightarrow 0$

$$dZ = - Z * dX / K$$

Or:

$$dX / K = - dZ / Z$$

with X_f the total amount of water added,
and with Z_0 the initial and Z_f the final amount of Z in the container.

$$\int_{0}^{X_f} dX / K = - \int_{Z_0}^{Z_f} dZ / Z$$

or:

$$X_f / K = \ln Z_0 - \ln Z_f$$

Then expressing X_f as a multiple of K, C is the percentage change divided by 100.

$$C = \ln Z_0 - \ln Z_f$$

Which leads to:

$$Z_f = Z_0 \, e^{-C}$$

There now, wasn't that simple? No?

What part of

$$\int_{0}^{X_f} dX / K = - \int_{Z_0}^{Z_f} dZ / Z$$

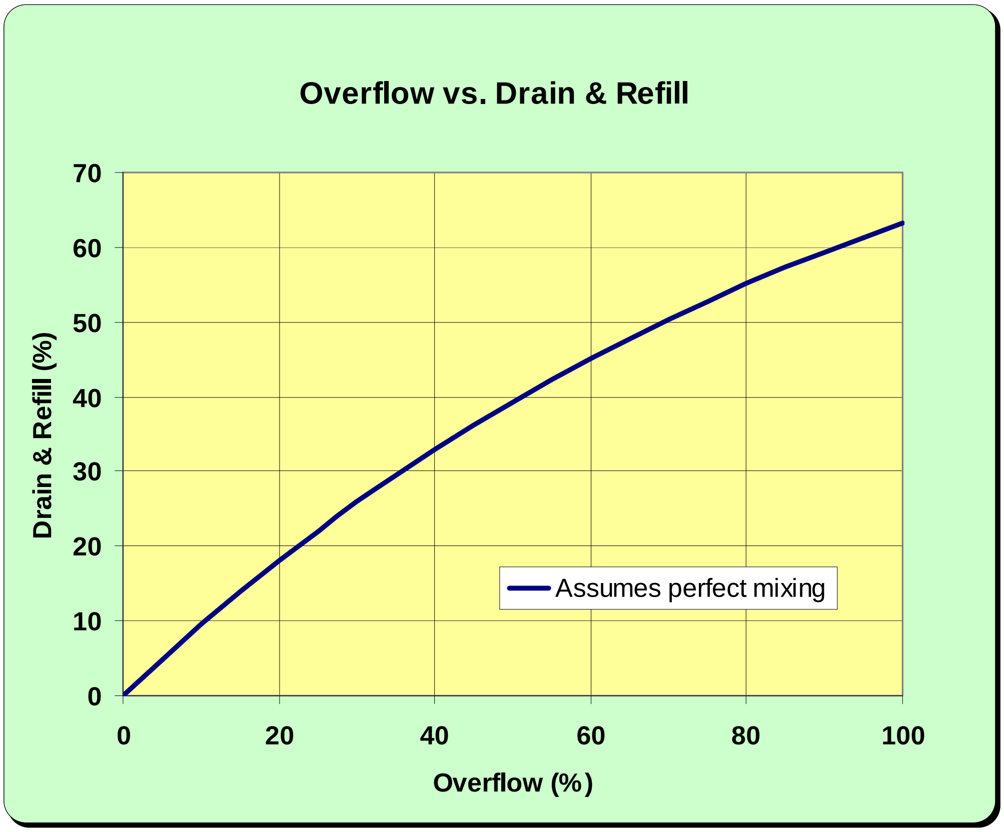
didn't you understand? <LOL> (nerd joke).

OK, fortunately I do understand all of "no" so let's try this: From the above final equation, we can produce the following table of dilutions for adding water and allowing the excess to overflow (assuming complete mixing in the pond and where "OS" represents stuff other than water (i.e., "other stuff") – same as in the derivation above). Note: the water added in the first column is equivalent to the dilution obtained in a drain-and-fill situation.

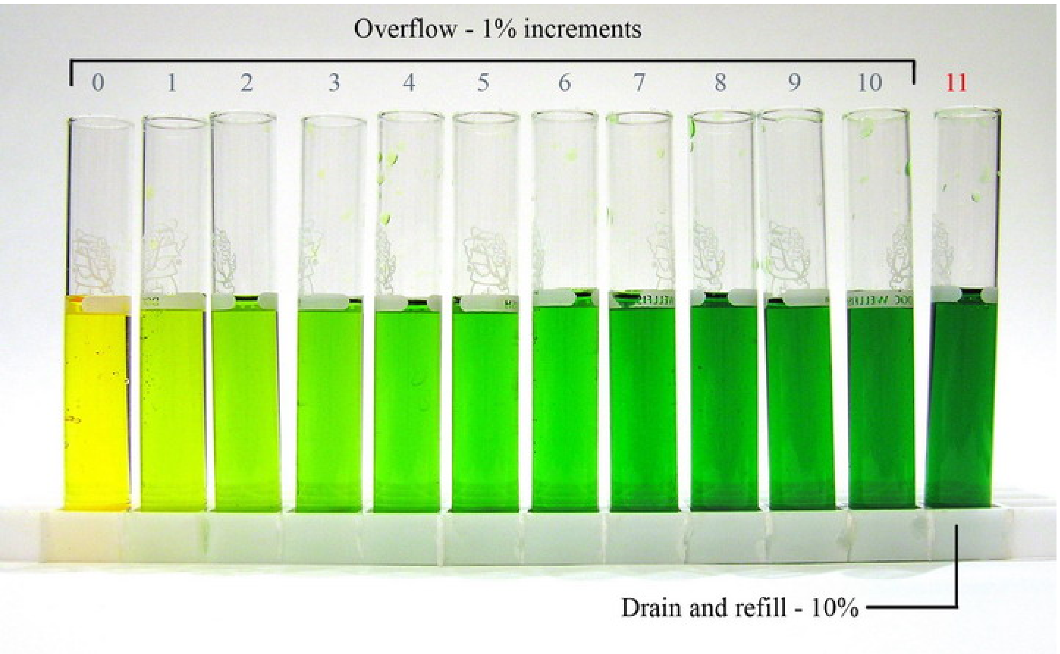
Water added	Amount of remaining OS as a fraction of the original OS $(Z_f / Zo) \times 100\%$	Actual % dilution $100\% - (Z_f / Zo)$
1%	99.005	0.995%
5%	95.12	4.88%
10%	90.48	9.52%
25%	77.88	22.12%
50%	60.65	39.35%
100%	36.79	63.21%

I also managed a much less elegant solution by creating a spread sheet that allowed the amount of change to be divided into smaller increments and then calculated the final dilution for a total of the serial fractional dilutions, e.g., I broke a 10% water change into a series of 1% water changes. I took the results of each dilution and diluted it again by 1% for a total of 10 times. The smaller the increments I broke the dilution into, the closer my results jibed with Norm's theoretical results. This is not surprising as Norm has derived an equation that represents the situation as the increments approach zero (i.e., get really small). If any of you want to see the spread sheet, please email me at scover@pacbell.net.

Here is a graph from Norm's equation:

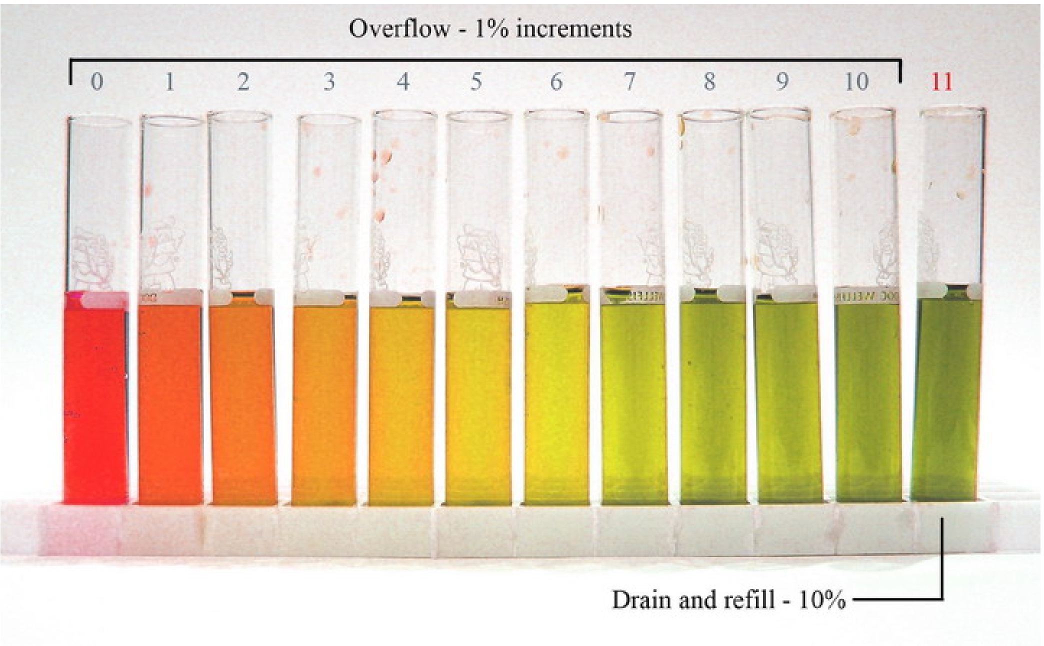


Here is the same concept in pictures of an actual test for you visual types. Below is a series of tubes into which was place the same amount of yellow water (food coloring). Into some of those tubes, blue water (more food coloring) was added as described next. (Hopefully you are all aware that blue and yellow make green.) The sequence goes from left to right and starts with an undiluted tube of yellow water (tube "0"). As you move right, tubes 1 thru 10 had 1% by volume of the blue water added, was mixed and a volume equivalent to the volume of the addition was removed. Then tubes 2 thru 10 had an additional 1% of the blue solution added, were then mixed and a volume equivalent to the addition was removed. This progressive sequence was repeated until the result closely resembled that of continual blue water additions with good mixing with the same amount being drained to overflow - see picture of below of the 12 tubes.



Tube 11 had 10% of its original volume removed and replaced with the blue solution, i.e., a drain and fill situation. You will notice that the colors in tube 10 and 11 are very nearly indistinguishable. The slightly darker color in tube 11 may be due in part to the somewhat left to right gradient of the lighting, from light to darker, as seen in the background. However, this corresponds well with the theoretical prediction of 9.5% vs 10% dilutions by the two different methods – see table.

With the "magic" of Photo Shop, the hue and saturation of the picture above was modified (the entire picture was modified as a unit not the individual tubes) to get better differentiation – see modified picture below.



Some discussion:
Let's explore what might cause the theoretical analysis NOT to be true and when will it likely reflect reality. If the new water is added near the standpipe (overflow to drain), there is more of a chance that new water, only partially mixed, will drain out the standpipe and the percentage of actual dilution will be less than the theoretical prediction. If there is poor mixing and the currents in the pond tend to move the new water directly toward the overflow, this can also result in less dilution.

On the other hand, if the water is put into the system at a point hydraulically distant (typically across the pond or into the pre-filter), it may well bias the conditions such that totally or nearly totally undiluted water will exit the overflow (standpipe). In the extreme case we have a raceway system where the all the new water comes in one end and, with very little mixing, and old water exits the other end. That said, I know of no koi pond that resembles a raceway system either physically or hydraulically. This is trout farming stuff.

If the water is added a goodly distance from the overflow and there is good mixing in the pond, Norm's equation and the numbers that result from it (See table), will probably be very close to the real situation.

From the table we can see that up to about 25%, we don't loose much efficiency by just adding water and allowing the excess to overflow (again, assuming good mixing). This will be of particular interest to those of us who constantly add water to our ponds and allow the excess to overflow. And, it should be of interest to those who do water changes w/o draining a given amount first, e.g., by just tossing in the hose and letting it run for a fixed time.

Caution: be very careful with either technique. They can and have killed fish in areas where the tap water is chlorinated or chloraminated and the hobbyist forgot the hose was running! Some solutions to this problem are: buy a water timer and use it; the Norm Meck solution of picking something up and not putting it down until the hose is turned off and/or setting an audible timer somewhere you can hear it when it goes off. And, even doubling up on the safeguards is not a bad idea just in case one fails. The take-home message is that unless you have something that reminds you to shut off the water or does it for you, you will forget and fish will die! This is one of those many corollaries to Murphy's Law.

Here is an example of a relatively inexpensive hose timer that can save your collection (~$20 at Home Depot). I'm sure there are others.

By the way, I believe Norm advocates adding dechlor for any water change up to 10% and adding an ammonia binder for changes over 10%. You certainly couldn't go wrong with this advice.

As a final note and a purely personal observation (but also shared by many other koi keepers): there seems to a correlation between the total volume of water changed on a regular basis and the health of the koi. More water changed seems to correlate with better fish health. Example: I do 10% per day in my pond on a continual basis and more in my quarantine tank (add and overflow in both). My fish are usually pretty healthy.

Any questions? Ask Norm at normeck@pacbell.net <grin>.