EFFECTIVE FILTER BACKWASHING WITH MULTIPLE WASHES OF AIR AND WATER

Samantha van Staden and Johannes Haarhoff

Department of Civil Engineering Science, University of Johannesburg
Corresponding author: S.J. van Staden, PO Box 524, Auckland Park, 2006, South Africa
Tel: +27 11 489 2395, Fax: +27 11 489 2148, E-mail: sjvs@ing.rau.ac.za

ABSTRACT

In general, filters develop problems over time due to the routine running of the filter, including backwashing. The difficulties in maintaining filters in good condition, given the eutrophic state of many of our raw waters, the high water temperature and resulting development of difficult-to-remove biofilm, are well known to South African water treatment plant operators. These difficulties are usually related to the deposits accumulated by the filter. The backwashing system, therefore, has to be really good to ensure filter cleanliness in the long run. This paper deals with a fairly simple operational option to significantly improve backwash efficiency at treatment plants where air and water are used consecutively.

If air scour continues for more than about a minute, the media compacts, air channels form and the abrasion amongst media grains largely ceases. By interspersing shorter cycles of air and water, rather than using one single cycle, the media is repeatedly fluidised, giving each new burst of air renewed opportunity to effectively abrade the media grains. This concept is not new – at some South African treatment plants the "double" or even "triple" wash had been used for 15 years with reputed success. However, from 2003 to 2005, the Water Research Group at the University of Johannesburg (UJWRG) has systematically investigated this concept at five water treatment plants and in the laboratory, through the testing of both media and backwash water samples, to determine the quantitative benefits of multiple wash cycles.

The paper describes the methods used and the typical results obtained. Multiple washing does indeed show great promise for improving backwash efficiency. On the average, a second wash removes about an additional 40% to 50% of the solids that would have been washed out with a single wash. Furthermore, a third and even fourth wash still continues to remove additional dirt from the filter. Multiple washing, therefore, may be used as a useful tool for effective ***rehabilitation*** *as well as for routine* ***operation****.*

INTRODUCTION

The life cycle of a filter works on the theory that it starts out with new, perfectly clean media, with pores that gradually clog up with particles as they are trapped during the filtration process. A backwash cycle is initiated when the amount of "clogging" gets to a point where either the head loss or the filtrate quality reaches predetermined "unacceptable" limits and, as a result, the combined action of air and water quickly returns the media to its original perfectly clean state and so the process continues. However, reality teaches us otherwise. It is common to find a filter that has been in commission for a decade or more with unacceptably dirty media and backwash systems that are incapable of returning the media to its initial state of cleanliness. Many times these problems, however, cannot be attributed to operational or design faults, but rather to some other yet elusive reason.

It was for this reason that the Water Research Group at the University of Johannesburg (UJWRG) began investigating this phenomenon approximately five years ago beginning with the development of methods to measure filter media cleanliness and backwash efficiency. The group then progressed to regular visits and sampling of full-scale treatment plants in order to establish benchmarks for the parameters measured. With this data insight could be provided into the causes and nature of filter media deposits.

The methods of determining backwash efficiency can be divided into two categories, namely backwash water testing and filter media testing. In theory, these two methods should yield the same results, but in reality both face practical obstacles. In the case of the media method, if the media is dirty and the backwash is inefficient, there is the danger of placing too much faith in a small difference derived from two much larger numbers. In the case of the washwater method, the time lag between media contact and sampling and the difficulty of taking representative samples from a large flow of backwash water which is not necessarily homogenous in terms of its SS concentration pose some concerns.

Taking an average of 55 backwash cycles, the media method yielded very erratic data, with negative numbers obtained in 10 of the 55 cases – an obvious impossibility. The washout method, which did not suffer from such instability, is, therefore, the method of choice for determining the reduction in solids during backwash and will be used to discuss the results obtained from tests performed at full-scale treatment level.

ANALYTICAL PROCEDURES

In order to facilitate direct comparison between the amount of solids washed out from various plants, a common unit of measure needs to be used. It is suggested that (mass of specific deposit) per (unit volume of filter media) would best facilitate such a comparison. This would require additional information to allow for the conversion of suspended solids (commonly measured in mg/l) to this common unit, namely choosing an appropriate time step, measuring the backwash rate and the media bed depth.

For each backwash test, a representative sample was obtained by taking a number of samples at specific time intervals, e.g. every 30s, from the backwash channel. This backwash water can be tested using two methods:

- The nephelometric method (measurement of turbidity)
- The gravimetric method (measurement of suspended solids)

<u>Nephelometric method</u>

The measurement of turbidity provides a rapid method of measuring the dirtiness of backwash water, without having to filter the sample and waiting for filter papers to be dried. There are two main problems when measuring turbidity, namely dilution errors and fluctuations in readings. Dilution errors come into play because backwash water samples are too dirty to be measured directly and needs to be diluted quite a bit before measurement is possible and then corrected afterwards for the dilution factor used.

The fluctuations errors that occur are as a result of the non-colloidal nature of backwash water and were overcome by vigorously stirring the suspension, rapidly transferring it to the sample cell and taking consecutive readings at 5s intervals, starting at 5s and ending at 30s. The average of the six readings was taken as the representative turbidity of the sample.

Gravimetric method

Mass determinations were made by vigorously stirring the suspension with magnetic stirring apparatus and drawing off between 20ml and 100ml of the sample and filtering it using filtration apparatus through a weighed glass pre-fibre filter. The total suspended solids could then be determined using standard method 209C (1).

Converting turbidity to suspended solids

In order to have all the results in a uniform unit of measure, turbidity (NTU) was converted to suspended solids (SS) using experimentally determined NTU/SS ratios when SS was not measured directly (see Table 1). The data used for the determination of the NTU/SS ratios was screened using the following rejection criteria, resulting in a database of 247 pairs where both turbidity (in NTU) and suspended solids (SS) were measured:

- Mass of retained solids on filter paper < 5mg.
- NTU/SS ratio < 0.15 and > 2.0.
- Less than 3 data pairs available for a correlation.

Table 1: Summary of washwater NTU/SS ratios determined at full-scale treatment plants.

Plant	Date	N	Ave. ratio
A	09/2003	25	0.724
	07/2004	3	0.989
	01/2005	11	0.862
B	09/2002	3	0.736
D	08/2003	16	0.773
	08/2004	6	1.034
	01/2005	11	0.605
E	09/2002	4	0.527
F	08/2003	18	0.397
	07/2004	12	0.524
	01/2005	11	0.794
G	09/2003	43	0.530
	01/2005	9	0.584
H	10/2002	6	0.464
	09/2003	52	0.536
	07/2004	6	0.745
	01/2005	11	0.636

Measuring specific deposit washed out from backwash water

A total of 55 washout tests were conducted (made up of 45 full-scale tests and 10 column tests conducted in the laboratory) representing 720 individual samples. Some 198 SS values were measured directly, while the remaining 522 samples only had the turbidity measured – these values had to be converted to SS values. This data set of 720 values formed the basis for the washout analysis.

Time step readings

In order to get a representative picture of how a filter is washed, approximately 5 to 10 samples would need to be taken over the duration of the backwash procedure. For this investigation, samples were therefore taken every 30 seconds.

Figure 1 shows a typical washout curve, based on a series of samples taken every 30 s. For calculation purposes, this curve is discretized into the intervals as shown, with the length of the intervals as follows:

- The 0 second sample represents time 0-15 s, i.e. a 15 s time step length.
- The 30 s sample = 15-45 s, i.e. a full time step length of 30 s.
- The 60 s sample = 45-75 s, i.e. a full time step length of 30 s, and so on.
- The last sample also represents a full time step length of 30 s.

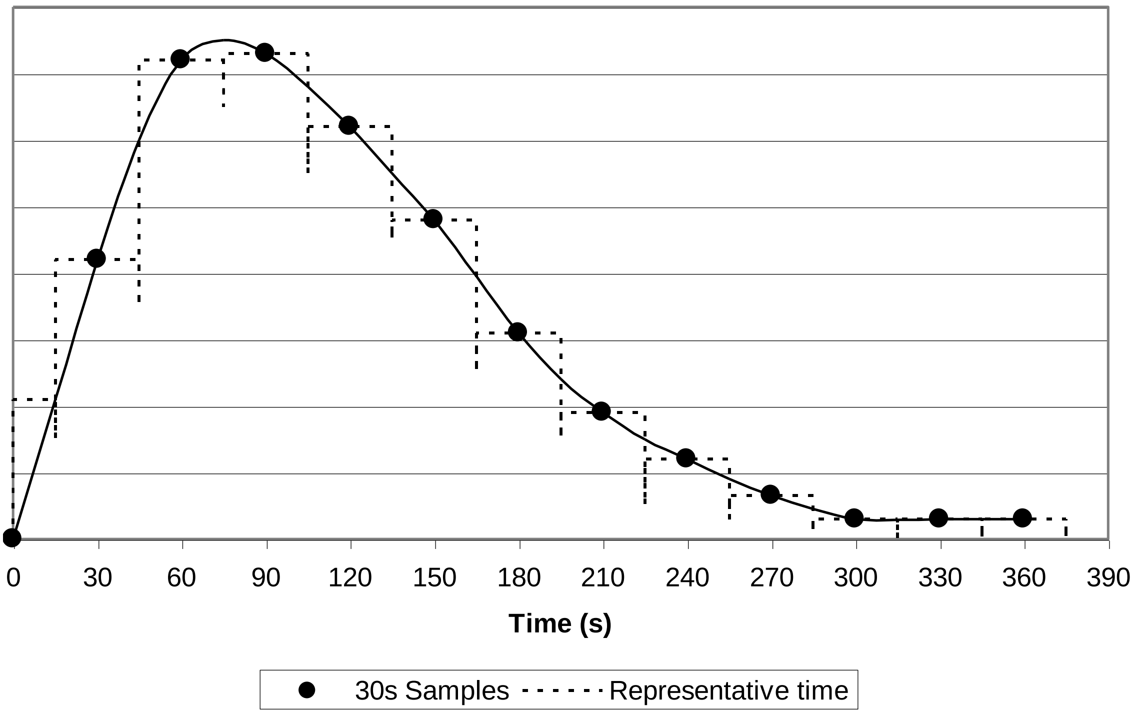

Figure 1. Time step illustration.

Backwash rate readings
In the case of plant backwashing, the backwash rate was measured by noting the time taken (in s) for the water to rise a certain height (in mm) within the filter, thereby giving the backwash rate directly in mm/s (after correcting for the area occupied by the backwash trough).

Conversion equation
For each sample, Equation 4 was used to convert mg/l solids washed out in the backwash water (SD) to kg/m^3:

$$\text{SD } \left(kg/m^3\right) = \frac{\text{SD}\left(kg/m^2\right)}{\text{bed depth}\left(mm\right)} \times 1000$$

$$\textbf{where } \text{SD } \left(kg/m^2\right) = \frac{TS\left(mg/\ell\right) \times \text{volume}\left(\frac{m^3}{m^2}\right)}{1000} \qquad [4]$$

$$\textbf{and } \text{washwater volume}\left(\frac{m^3}{m^2}\right) = \text{time step length}\left(s\right) \times \frac{\text{backwash rate}\left(mm/s\right)}{1000}$$

The total amount of specific deposit washed out during a wash is obtained by adding the values for all the time intervals.

APPLYING THE PROCEDURE TO SOUTH AFRICAN FILTRATION PLANTS

Eight treatment plants at seven different locations were sampled intermittently between May 2002 and January 2005, with a total of 31 sampling visits being made.

Measuring solids washout in a uniform manner

Since the filters sampled are washed at different rates and have different bed depths, the concept of "empty bed volumes" is used in this paper as a unifying measure of the volume of backwash water passed through the bed. In other words, one bed volume of washwater is equal to the total volume occupied by the media bed.

Two different sets of backwash data are presented here:

- The first set comprises those "first" backwashes that were conducted after the filters had been taken out of service at the time of the visit (see Figure 2).
- The second set comprises "second" backwashes immediately following the first described above (see Figure 3).

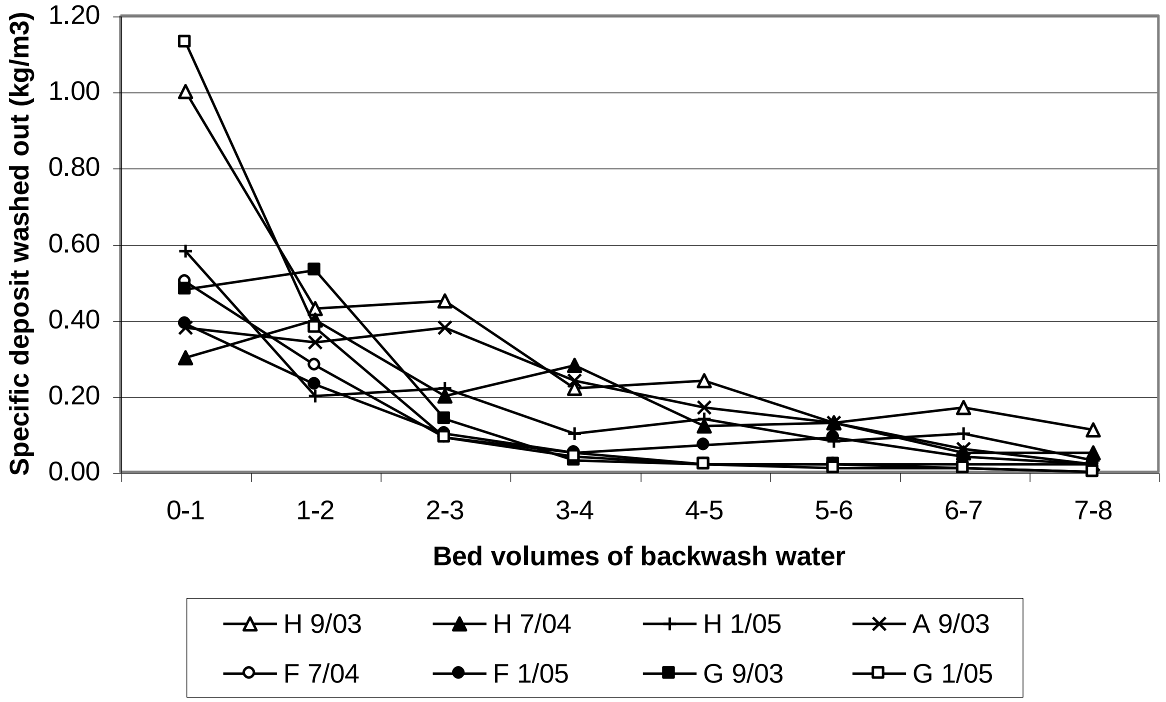

Figure 2. Rate of solids washout for "first" backwash data set, with month and year indicated after treatment plant label.

From Figure 2, it is clear that the majority of the solids are washed out after three bed volumes and that very little is washed out after five bed volumes of washwater. It should be borne in mind that the starting points of these filters range between 2.40 and 13.49kg/m^3 (average 5.59kg/m^3) of specific deposit. The amount of solids removed after five bed volumes ranged between 6% and 54%.

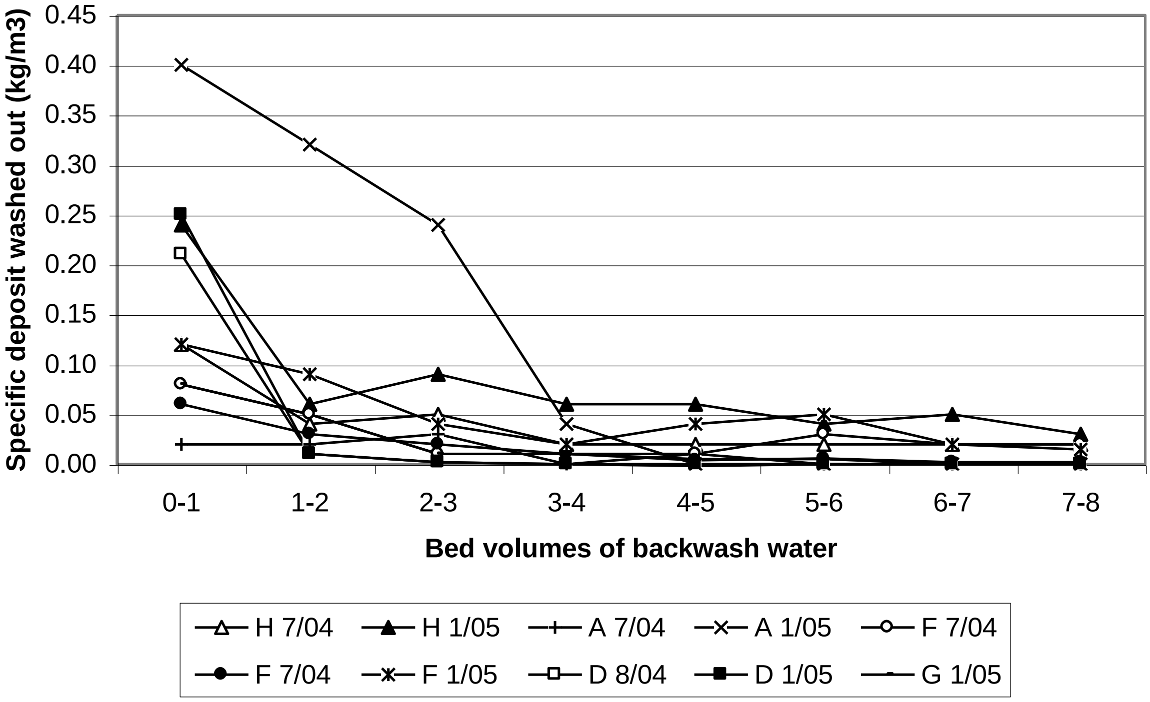

Figure 3. Rate of solids washout for "second" backwash data set.

Figure 3 indicates that the majority of the solids are washed out after two bed volumes of washwater (excluding the one outlier). These washes started with filters having between 1.39 and 12.45kg/m^3 of specific deposit with an average of 5.05kg/m^3. The amount of solids removed after five bed volumes ranges between 2% and 16%.

Hence, in comparing the two figures, a remarkably consistent pattern can be seen, namely that there was little benefit by using more than four or five bed volumes of washwater per wash. In the case of the "first" wash, less than 0.20 kg/m^3 of solids were removed per bed volume when the wash was extended beyond five bed volumes. In the case of the "second" wash, this value was less than 0.05 kg/m^3.

<u>The benefit of multiple backwash cycles</u>

It is well known that a "second" and a "third" backwash will continue to remove solids from the bed, albeit in smaller consecutive amounts. This is ascribed to a further abrasion of the media grains by air scour, after the media had been refluidised by the previous water backwash. In light of this knowledge, the data of Figures 2 and 3 was used to plot in a different way (Figures 4 and 5), with five bed volumes taken as 100% of the solids that can be realistically removed during a normal backwash.

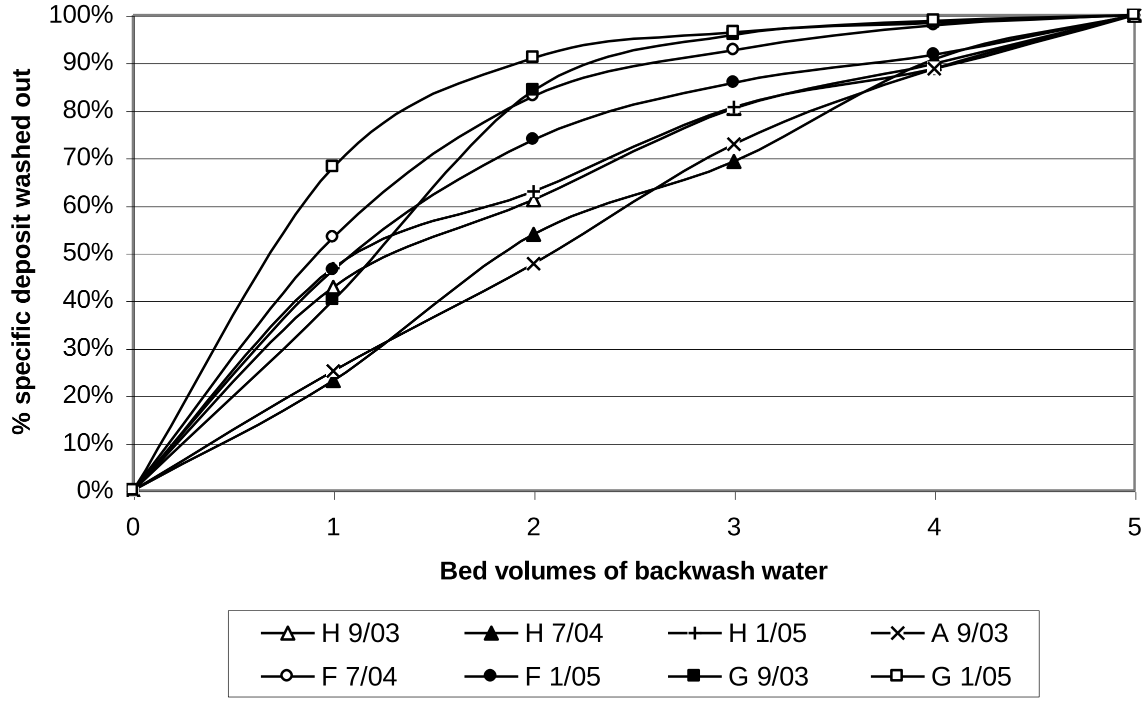

Figure 4. Percentage solids washout for "first" backwash data set.

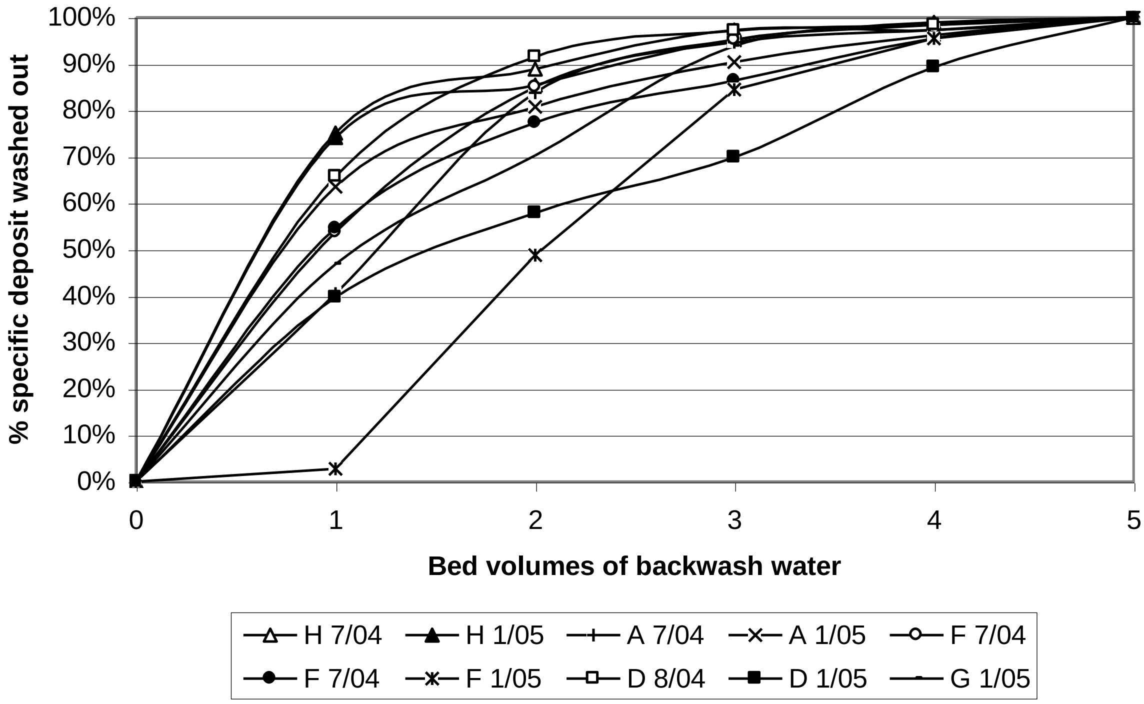

Figure 5. Percentage solids washout for "second" backwash data set.

Figure 4 shows that by using only two to three bed volumes of backwash water for a "first" wash (a saving of between 40% and 60% of backwash water) approximately 70% to 80% of solids can still be effectively removed. In this way, multiple washes become both economically and practically viable. Figure 5 shows that this water saving could be increased to between 60% and 80% of backwash water by using only one to two bed volumes of backwash water for a "second" wash, with an effective removal of between 60% and 70%.

While the above comments pertain to the general pattern observed at all the treatment plants, more specific insight can be obtained by analysis of individual treatment plants. The next figures (Figures 6, 7, 8 and 9) are examples of the removal efficiency of two plants (Plants D and F). Plant D was chosen because it was the plant which derived most benefit from a second wash, while Plant F was the one where the second wash had the least effect.

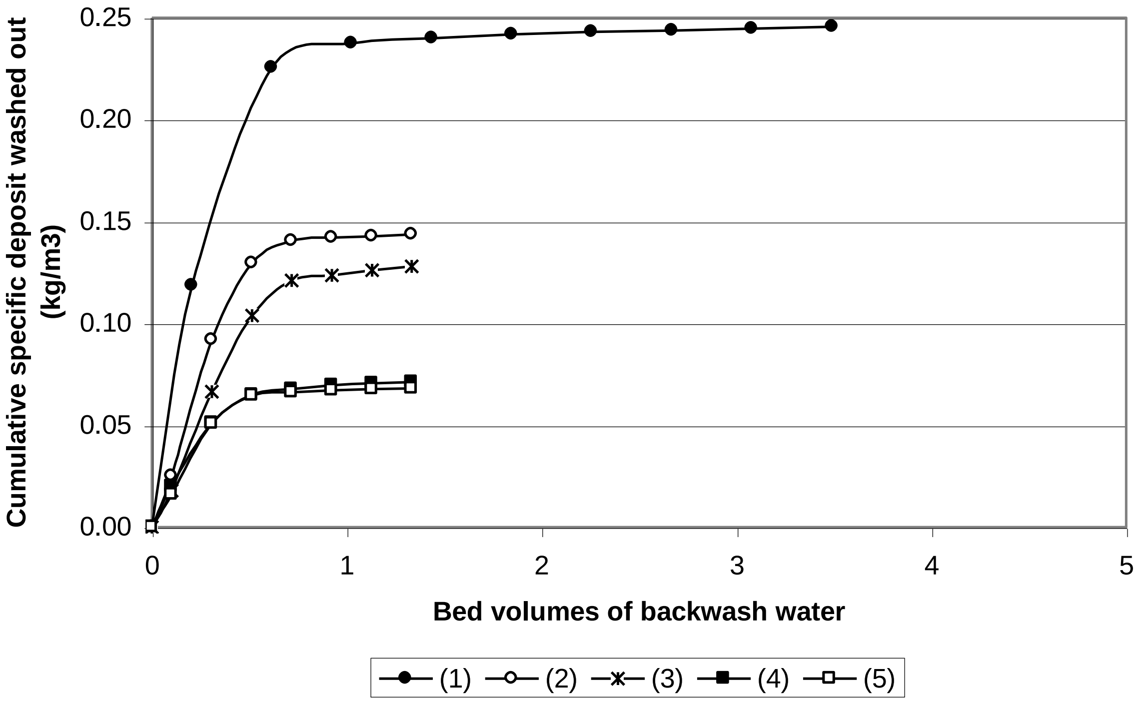

Figure 6. Cumulative washout of solids at Plant D for the 08/2003 visit.

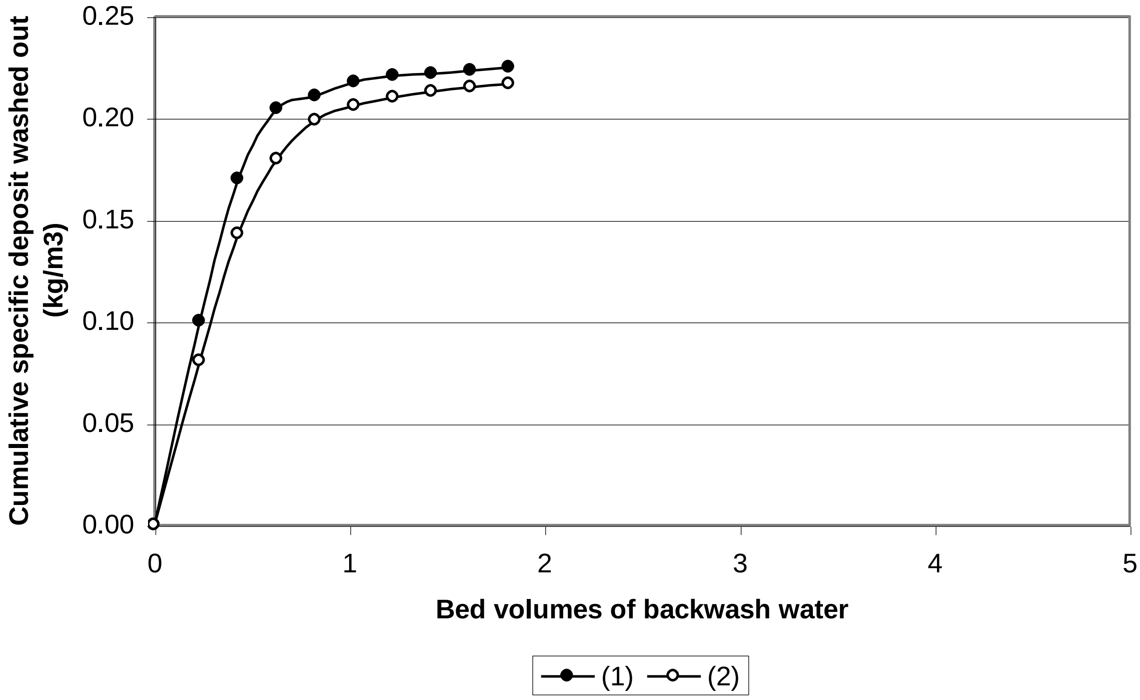

Figure 7. Cumulative washout of solids at Plant D for the 08/2004 visit.

Figures 6 and 7 illustrate a plant where multiple washes are of an obvious benefit. In Figure 6, the “second” and “third” washes remove up to 60% of the total specific deposit removed in the “first” wash, whilst the “fourth” and “fifth” washes remove up to 30% of this total. In Figure 7 the removal of the “second” wash is seen to be close to 100% of the specific deposit removed by the “first” wash. Another visit at a later date (data not shown) verified this result.

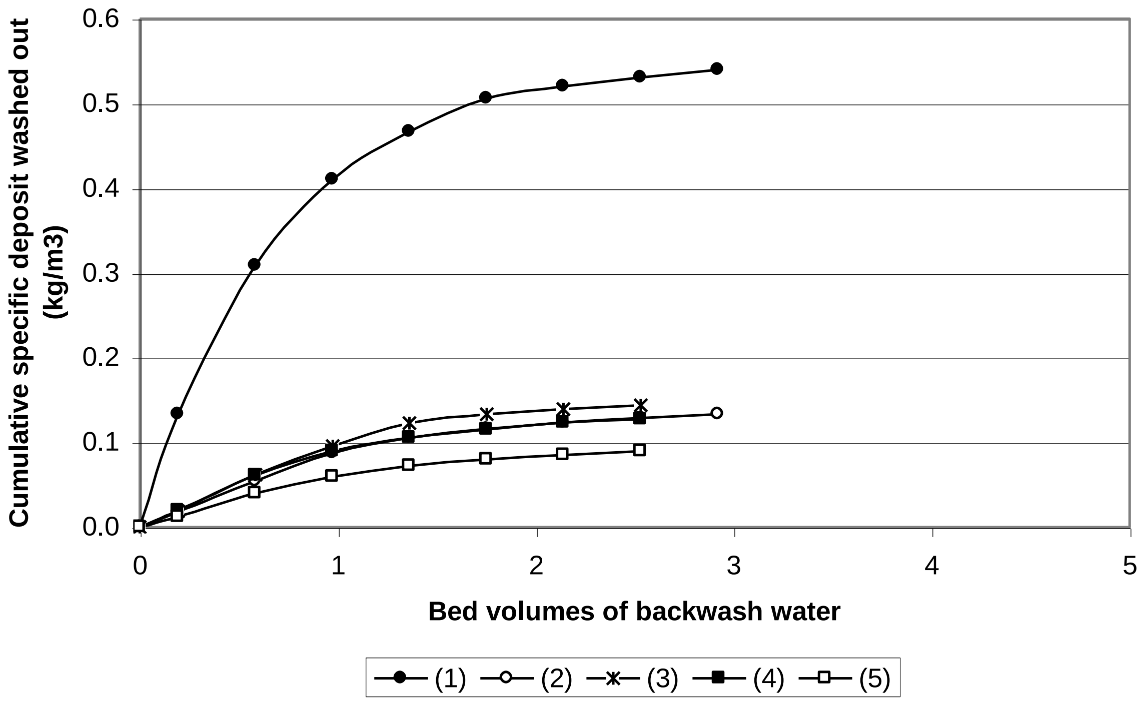

Figure 8. Cumulative washout of solids at Plant F for the 08/2003 visit.

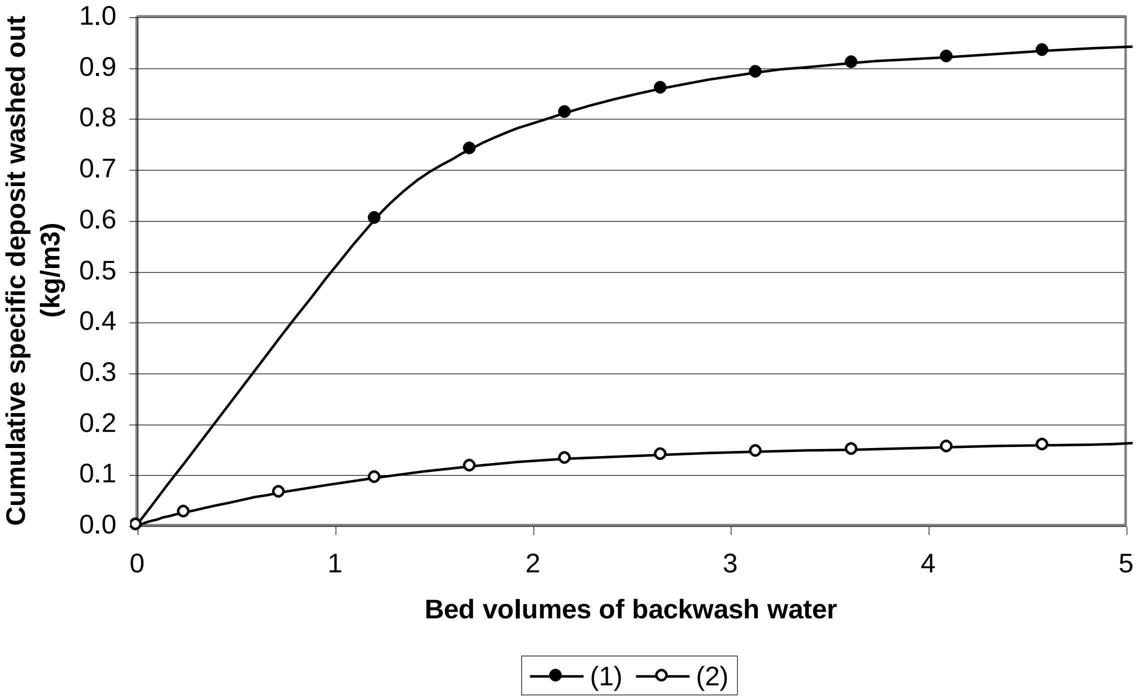

Figure 9. Cumulative washout of solids at Plant F for the 07/2004 visit.

Figures 8 and 9 illustrate a plant where multiple washes have very little benefit. Figure 8 shows that the “second”, ”third”, “fourth” and “fifth” washes removed only 20 to 25% of the total solids removed during the “first” wash. This same finding can be seen in Figure 9, which is supported by the findings from a further two visits, not reported here.

CONCLUSIONS

From the results summarised above, a number of observations can be made:

- The concept of bed volumes of washwater is useful for comparing backwash data when backwash rates and media bed depths are different.
- The vast amount of solids was washed out during the first two bed volumes of backwash water when using air and water consecutively. There is, therefore, little point in continuing the backwash cycle beyond five bed volumes per wash.
- On the average, there is a substantial benefit to repeat a wash (using both the consecutive air and water again), as more solids can be removed. At the treatment plants surveyed, a third wash, on average, removed between 50% and 100% of what was removed during the second wash.
- However, the use of multiple backwash cycles should be investigated at plants on a individual basis. At some plants, the benefits are very significant, while the advantages at other plants are marginal.
- Where multiple washing may be beneficial, it may be a good strategy to use say three consecutive wash cycles – the first two using 2 bed volumes, and the third 4 bed volumes. In this way, the total volume of washwater remains at 8 bed volumes, which seems to be a typical values for the conventional way of washing filters with air and water consecutively. If, for example, such a strategy had been used at Plant D during August 2003 (see Figure 6), about the total specific deposit removed could be doubled.

ACKNOWLEDGEMENT

The authors would like to express their thanks to the Water Research Commission for the financial contribution to this project, and to Dr. Gerhard Offringa, in particular, for his consent and encouragement given for the publication of this paper. Many thanks also to the personnel that assisted in the sampling of the filters at the various treatment plants visited over the last five years.

REFERENCES

(1) AWWA, Standard Methods for the Examination of Water and Wastewater (18th edn.), American Public Health Association, Washington, DC, USA (1992).

(2) SJ van Staden and J Haarhoff, A Standard Test for Filter Media Cleanliness, Water SA 30 (1), p.81-88 (2004).

(3) J Haarhoff, The disturbance of sand filter supporting layers by air scouring, Unpublished M Eng thesis: University of Stellenbosch (1982).