

WHAT SIMPLE MEDIA TESTS CAN TELL YOU ABOUT FILTER PROBLEMS AND REHABILITATION

Samantha van Staden and Johannes Haarhoff

Department of Civil and Urban Engineering, Rand Afrikaans University, PO Box 524, Auckland Park, 2006, South Africa. Tel: +27 11 489 2148. Fax: +27 11 489 2148. E-mail: jh@ing.rau.ac.za

ABSTRACT

Rapid sand filters are expected to continuously produce clean, safe water for many years, during which time some of these filters will inevitably develop some problems. These problems are usually only apparent once the damage is already done, thereby causing expenditure and inconvenience due to rehabilitation. However, if the cleanliness of the media grains is routinely measured, the potential for some of the more serious problems could be detected at an early stage and measures taken to alleviate such problems before serious damage occurs.

In 2002 and 2003, the Water Research Group at the Rand Afrikaans University developed a number of tests to quantify filter media cleanliness in a simple yet standard manner. These tests provide information in two important areas. Firstly, they alert the operator when media does not meet an acceptable standard for cleanliness after backwashing. Secondly, they provide pointers to the nature of the residual deposit on the media, suggesting why the media have not been properly cleaned during backwashing.

These tests are currently being benchmarked by a series of trials at a number of South African water treatment plants. This paper will provide the details of these tests, together with practical limits for the different parameters. It should make a valuable contribution towards early detection and troubleshooting of filtration problems by operators and managers.

INTRODUCTION

This paper has its origin in the general observation that filters at many South African water treatment plants appear to be inadequately cleaned during the backwash cycle. In a companion paper presented at this conference (1), evidence was presented which suggests that this phenomenon may have its roots in an unusually high degree of biological activity, resulting in a sticky biofilm on the media grains, which is difficult to remove.

The single most important requirement of investigations of this type is to be able to measure and characterise media cleanliness in a standard, reproducible way. It is the purpose of this paper to provide the background and details of a proposed test procedure, which could be of benefit to operators and managers at all water filtration facilities. It covers the following points:

The procedure for stripping and measuring the deposits remaining in the grains after backwash. The development of the eventual method entailed a long and systematic screening process published elsewhere (2) – only the method finally adopted will be summarised here.

- The description of two methods for characterising the deposit on the media grains to gain some insight into the composition and thus the main reasons of the media fouling.
- The comparison of the proposed method with a different method, but with a similar objective reported from the USA, and the conversion of its guidelines for filter cleanliness.
- The application of the test to filters at eight local water treatment plants to verify the proposed procedures and to establish a local benchmark for filter media cleanliness.

ANALYTICAL PROCEDURES

Getting a Representative Media Sample

A tool referred to as a 'core sampler' was used if a combined sample through the entire bed was required. A core sampler is a steel tube with an internal diameter of 35mm, with depth markings on. A valve is welded at one end to close the tube after pushing it vertically into the media. This causes a negative pressure within the tube that prevents the media from 'spilling' during transfer to a suitable container.

Undisturbed samples were taken by careful excavation of the bed from top to bottom if media was required from a specific depth. In the case of the core sampler being unable to lift the sample from the bed, a number of such undisturbed samples were combined to form a representative sample per bed location. Due to the horizontal variance of filter deposits within a bed, it is necessary to sample at three or more locations in the bed and to make use of sample composites, as was done in this study. Following sampling, the composite sample had to be homogenised without premature stripping of the filter deposits present on the media grains. For this purpose, a riffle splitter (as used in standard engineering soils laboratories) was used to split the sample five consecutive times. Thereafter, the sample was sealed in a plastic bucket or bag and refrigerated until analysis, which was done as soon as possible after sampling.

Stripping the Residual Deposit from the Media Sample

After a number of extensive tests to determine an operator independent, yet simple test, that could be easily repeated in even the most limited of on-site treatment plant laboratories, the following procedure was determined to yield the most consistent results:

A homogenised 60m^l sample (approx. 50g dry weight) of filtration media was obtained.

A clean, dry 250m^l measuring cylinder was weighed and this value (CW) recorded in grams.

The sample was then placed in the cylinder, weighed and this value (CSW) recorded in grams.

The weight of the sample (SW) was determined using equation [1] below:

$$SW(g) = (CSW(g)) - (CW(g)) \quad [1]$$

A moisture content test was performed as follows:

A clean, dry evaporating dish was weighed and this value recorded in grams.

30-40m^l homogenised sample was placed in the dish, weighed and this value was recorded in grams.

The evaporating dish, with sample, was then placed in an oven at 103-105°C, weighed when dry and this value recorded in grams.

Moisture content (MC) was determined using equation [2] below and the weight of the 60m^l sample corrected accordingly (as determined in step 4 above), using equation [3] below:

$$MC = \frac{\text{wet sample weight (g)} - \text{dry sample weight (g)}}{\text{wet sample weight (g)}} \quad [2]$$

$$\text{dry weight (DSW)}(g) = SW(g) \times (1 - MC) \quad [3]$$

100m^l clean tap water was added to the sample.

The end of the cylinder was sealed and inverted 20 times (as shown in figure 1 below), with pauses between inversions to allow the media to settle at the bottom:

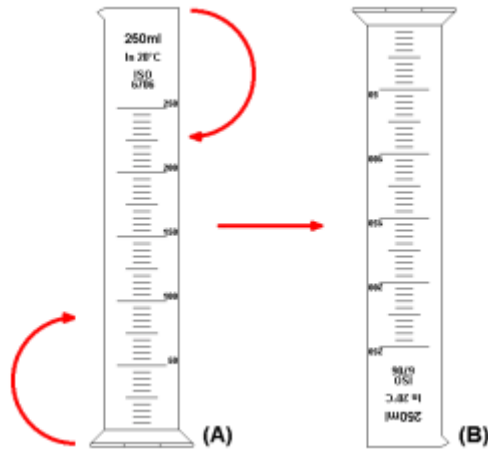


Figure 1. A single cylinder inversion, i.e. from position (A) to position (B).

The resultant suspension was then drained into a clean, dry 500mℓ Erlenmeyer flask.

Steps 6 to 8 were repeated four times until the flask contained a 500mℓ sample.

The sample was then sealed and refrigerated until further analyses could be performed.

Measuring How Much Deposit was Stripped

The first method used to determine how much deposit was stripped from the media was an indirect one, by measuring turbidity. Turbidity (expressed as nephelometric turbidity units or NTU/100g media) was measured using a HACH ratio turbidimeter (Model 18900 with a range 0-200 NTU). However, the samples produced by the above methodology presented two problems for turbidity measurement. Firstly, relatively large particles caused fluctuations in the turbidimeter reading and, secondly, the suspension settled fairly quickly in the sample cell. However, vigorous stirring and rapid transference of the sample into the sample cell and the turbidimeter overcame these problems. In addition, consecutive readings were recorded at 5s intervals, starting at 5s and ending at 30s, since significant settling and flocculation is not expected to occur over this time period. The average of the six readings was taken as the representative turbidity of the sample.

Some samples required dilution before they were within the measuring range of the instrument, therefore requiring the use of a dilution factor (DF) (see equations [4] and [5] below):

$$DF = \frac{m\ell \text{ sample} + m\ell \text{ clean water}}{m\ell \text{ sample}} \quad [4]$$

$$NTU/100g = \text{measured NTU} \times DF \times \frac{100}{\text{dry weight}} \quad [5]$$

The second method used to determine how much deposit was stripped from the media was based on mass of the solids in the suspension, i.e. the measurement of suspended solids. The sample obtained using the stripping method (as outlined above) was used to determine total suspended solids (TS) as follows:

Whilst vigorously stirring the resultant suspension, 20mℓ to 50mℓ was drawn off (depending on how “dirty” the sample was), and filtered through a weighed glass-fibre prefilter, using filtration apparatus.

Using *Standard Methods* (3) procedure 209C and equation [6] below, the TS of the sample was determined from this filtrate (A):

$$TS(\text{mg/l}) = \frac{(A - B) \times 1000}{\text{sample volume}(m\text{l})}$$

where A = weight of watchglass and filter with dried residue (mg) [6]

B = weight of clean filter (mg) + weight of watchglass (mg)

Acid Solubility and Volatility of the Stripped Deposit

The TS value (as determined above) was then quantitatively separated on the grounds of acid solubility as well as volatility at 550°C.

Acid Soluble and Non-Soluble Fractions

“Non-soluble solids” is the term applied to the residue of total, suspended, or dissolved solids that remain after treatment with an acid solution. The procedure used to determine these two fractions is outlined below:

A 32% dilution of hydrochloric acid (HCl) was further diluted by 20%, i.e. 25mℓ of 32% HCl was thoroughly mixed with 100mℓ distilled water

10mℓ of the resultant acid (strength = 6.4%) was mixed with 100mℓ of the sample.

The same procedure as used for the TS determination and equation [7] below were then used to determine the total non-soluble solids (NS) of the sample from the filtrate (**B**):

$$NS(\text{mg/l}) = \frac{(A - B) \times 1000}{\text{sample volume}(m\text{l})}$$

where A = weight of watchglass and filter with dried acid residue (mg) [7]

B = weight of clean filter (mg) + weight of watchglass (mg)

The acid soluble fraction is, therefore, the difference between TS and NS (see Table 1 below).

Volatile and Non-Volatile Fractions

“Non-volatile solids” is the term applied to the residue of total, suspended, or dissolved solids remaining after ignition for a specified time at a specified temperature. The mass loss on ignition is called “volatile solids”. However, the determinations of non-volatile and volatile solids do not distinguish between organic and inorganic matter, as the loss on ignition cannot be confined to organic matter, but also includes losses due to decomposition or volatilisation of some mineral salts (3).

Standard Methods (3) procedure 209D was applied to the TS and NS filtrates, obtained using the above procedures, and using equations [8] and [9] below, the total non-volatile solids (NV - **C**) and the total non-soluble non-volatile solids (NSNV - **D**) of the sample were determined:

$$NV(\text{mg/l}) = \frac{(A - B) \times 1000}{\text{sample volume}(m\text{l})}$$

where A = weight of watchglass and filter with dried residue
before ignition (mg) [8]

B = weight of watchglass and filter with dried residue
after ignition (mg)

$$\text{NSNV}(mg/l) = \frac{(A - B) \times 1000}{\text{sample volume}(ml)}$$

where A = weight of watchglass and filter with dried acid residue before ignition(mg) [9]

B = weight of watchglass and filter with dried acid residue after ignition(mg)

The volatile fraction is, therefore, the difference between TS and NV, whilst the acid-soluble non-volatile fraction is the difference between NV and NSNV (see Table 1 below).

Converting Mg/l to Mg/G

In order to make further sense of the numbers obtained using the above equations, it was decided that it would be best to relate the quantity of "dirt" determined to the quantity of media within the bed. As a result, the above values for TS, NS, NV and NSNV (in mg/l) were converted into mg/g using the result of equation [3] above and equation [10] below:

$$mg/g \text{ sand} = \frac{mg/l}{200} \times \left(\frac{100}{\text{dry weight}(g)} \right) \quad [10]$$

Using the values (in mg/g) determined using the above methods (A , B , C and D), the unknown values in Table 1 below could be determined, thereby, characterising the filter media residue in terms of four values, which can be interpreted as shown in the table.

Table 1. Suspended solids composition matrix.

| | soluble | non-soluble | Total |
|--------------|--|---|---------------------------------------|
| Volatile | SV decomposition or volatilisation of some mineral salts (A - B - C + D) | NSV bacterial and algal biomass, organic detritus (B - D) | (A - C) |
| Non-volatile | SNV originates from the carry-over of chemical precipitates (C - D) | NSNV Equation [9] corresponds to inorganic particles present in the raw water D | NV Equation [8] C |
| Total | (A - B) | NS Equation [7] B | TS Equation [6] A |

Elemental Composition of the Stripped Media

Analyses of between 16 and 18 elements were performed using inductively coupled plasma optical emission spectroscopy (ICP-OES). This analysis works on the principle that the sample to be analysed (in liquid state) is fed into a plasma produced within the instrument. Atoms in this plasma then emit light (photons) with characteristic wavelengths for each element. This light is recorded by one or more optical spectrometers providing a quantitative analysis (in mg/l) of the original sample (4).

The elements analysed are listed in Table 2 below, along with their quantitative detection limits (the values below which detection becomes inaccurate):

Table 2. Elements and limits for the ICP-OES analysis of this study.

| Element | Limit (mg/ℓ) | Element | Limit (mg/ℓ) | Element | Limit (mg/ℓ) |
|-----------------------|--------------|-----------------------|--------------|--------------|--------------|
| Calcium (Ca) | 0.05 | Cobalt (Co) | 0.10 | Sodium (Na) | 0.10 |
| Barium (Ba) | 0.05 | Cadmium (Cd) | 0.05 | Zinc (Zn) | 0.05 |
| Strontium (Sr) | 0.05 | Nickel (Ni) | 0.05 | Lithium (Li) | 0.10 |
| Magnesium (Mg) | 0.05 | Manganese (Mn) | 0.02 | Lead (Pb) | 0.10 |
| Copper (Cu) | 0.02 | Iron (Fe) | 0.05 | Bismuth (Bi) | 1.00 |
| Aluminium (Al) | 0.10 | Chromium (Cr) | 0.05 | Boron (B) | 0.05 |

Each suspension obtained from the stripping procedure was analysed using the ICP-OES method, and equation [10] and the result of equation [3] above were used to convert the values obtained into mg/g sand. In addition, the water used to strip the media was analysed and the values obtained per element for the water was subtracted from the values obtained for the suspension in order to determine the composition of the stripped deposits only.

Filtration problems are usually caused by the precipitates of four well-known cations, namely calcium (Ca), magnesium (Mg), Manganese (Mn), and iron (Fe) (as highlighted in the table). For the purposes of this study these four elements were focused on to help provide further insight into the composition of the media deposits.

THE AWWA MEDIA CLEANLINESS TEST

The American Water Works Association (AWWA) also suggested that the routine measure of media grain cleanliness would result in early detection of the potential for serious problems within filters and, thereby, allow for evasive action to be taken to arrest such problems. This routine measure took place in the form of a 'floc retention test' (5).

This test is simply described as taking approximately 50g of filter sand, adding 100 ml of water, shaking it vigorously and decanting the resultant suspension into a beaker. After five repetitions, the turbidity of the suspension is measured, multiplied by two and reported as NTU (nephelometric turbidity units)/100g of sand.

The turbidity, according to AWWA, allows the media to be assigned to one of the following four categories:

- A value of 30 to 60 NTU (threshold A) indicates a clean bed
- 60 to 120 NTU (threshold B) indicates a slightly clogged bed
- 120 to 300 NTU (threshold C) indicates a clogged filter with mudball formation potential
- and values above 300 NTU indicate a serious problem with highly probable mudball formation

The procedures used in this investigation allowed for the determination of both turbidity (in NTU/100g) and suspended solids (in mg/g). In this way the AWWA guidelines could be expressed in terms of suspended solids, which is considered to be a more meaningful measure.

Translation from Turbidity to Suspended Solids

By using the values obtained for TS and turbidity, graphs were plotted per plant sampled, with a trendline forced through the origin. The equation of this trendline was then used to determine what the corresponding TS value would be for each plant at each corresponding turbidity guideline value. The results of the interpretations are summarised in Table 3 below, with the average values representing the translated TS value for the AWWA guidelines:

Table 3. Equations, r^2 values and TS (in mg/g) values per plant, with min., max. and ave. values.

| | Trendline equation | R^2 value | TS (mg/g) compared to NTU/100g | | | |
|-------------|-------------------------------|-------------|--------------------------------|-------------|-------------|-------------|
| | | | 30 | 60 | 120 | 300 |
| Plant #1 | $TS = \frac{NTU / 100g}{84}$ | 0.56 | 0.36 | 0.71 | 1.43 | 3.57 |
| Plant #2 | $TS = \frac{NTU / 100g}{141}$ | 0.89 | 0.21 | 0.43 | 0.85 | 2.13 |
| Plant #3 | $TS = \frac{NTU / 100g}{80}$ | 0.93 | 0.37 | 0.75 | 1.49 | 3.73 |
| Plant #4 | $TS = \frac{NTU / 100g}{113}$ | 0.92 | 0.27 | 0.53 | 1.06 | 2.65 |
| Plant #5 | $TS = \frac{NTU / 100g}{99}$ | 0.97 | 0.30 | 0.61 | 1.21 | 3.03 |
| Plant #6 | $TS = \frac{NTU / 100g}{135}$ | 0.83 | 0.22 | 0.45 | 0.89 | 2.23 |
| Plant #7 | $TS = \frac{NTU / 100g}{242}$ | 0.75 | 0.12 | 0.25 | 0.50 | 1.24 |
| Plant #8 | $TS = \frac{NTU / 100g}{193}$ | 0.85 | 0.16 | 0.31 | 0.62 | 1.55 |
| min. | | | 0.12 | 0.25 | 0.50 | 1.24 |
| max. | | | 0.37 | 0.75 | 1.49 | 3.73 |
| ave. | | | 0.25 | 0.50 | 1.01 | 2.52 |

APPLYING THE PROCEDURE TO LOCAL FILTRATION PLANTS

Plant Survey

A total of eight plants were sampled (six plants were sampled once each and two were sampled twice each) between May 2002 and October 2003. These plants were scattered in four provinces of South Africa, with the majority of samples taken in the spring-summer months. The types of media sampled varied between sand and sand-anthracite combinations. The types of raw waters supplying the plants sampled varied from eutrophic through turbid to low-turbidity waters.

Stripping and Measuring the Deposits

During the site visits the backwashing procedures and general condition of each filter sampled was observed and visually assessed in terms of “dead-spots”, existent mudball problems and overall effectiveness of backwashing. These assessments were qualitative rather than quantitative and assisted in the classification of each plant according to the AWWA four-point classification. Each plant was classified as (1) a clean bed, (2) a slightly soiled bed without cracks, mudballs and dead spots, (3) a filter with evidence of small mudballs, or (4) a filter with a obvious bed problems and high incidence of mudball formation.

Following this classification step, each media sample was stripped according to the above procedure, with three replicates for each sample to minimise error. The TS was then measured for each sample (in mg/l) and corrected for sample weight and moisture content to yield a value in mg/g. Table 4 below is a summary of these results.

Comparing these three threshold values to the equivalent AWWA guidelines, it can be seen that the threshold values proposed are much higher than those of AWWA, i.e. in the order of four – six times greater. This can partially be explained by the fact that AWWA does not allow for moisture content correction. In the South African survey, the measured moisture content varied between 5% and 28% with an average of 13%.

Table 4. Average TS and visual classification of filter beds after a single backwash cycle, with suggested classification limits.

| | Classification | TS |
|----------|-----------------------------------|--------|
| | | (mg/g) |
| Plant #6 | Media appeared clean | 0.9 |
| Plant #7 | Media appeared clean | 1.7 |
| Plant #3 | Media appeared clean | 2.0 |
| Plant #8 | Media somewhat dirty, no mudballs | 4.5 |
| Plant #2 | Media somewhat dirty, no mudballs | 4.7 |
| Plant #1 | Small mudballs | 7.2 |
| Plant #5 | Small mudballs | 11.5 |
| Plant #4 | Definite mudball formation | 19.5 |
| Min. | | 0.9 |
| Max. | | 19.5 |
| Ave. | | 6.5 |

← Set threshold A at 3 mg/g

← Set threshold B at 6 mg/g

← Set threshold C at 10 mg/g

Composition of the Deposits

Acid Solubility and Volatility

Using the values obtained from equations [6] to [9] (after conversion to mg/g) and the four fractions determined as shown in Table 1, average compositions could be determined as a percentage of the TS per plant. These results showed that the SV (soluble and volatile) fraction was not very significant (ave. 5%) and it is speculated that this fraction is probably biological in origin. Therefore, for the purposes of this interpretation, the NSV and SV fractions are added together to get a single total volatile fraction (V), which represents the biological fraction of the deposits. The three values (NSNV, SNV, and V) are summarised in Table 5 below:

Table 5. Average composition of deposits per plant (expressed as mg/g and %).

| | Ave. TS (mg/g) | Composition per fraction characterisation | | | | | |
|----------|-------------------|---|-----|------|-----|------|-----|
| | | NSNV | | SNV | | V | |
| | | mg/g | % | mg/g | % | mg/g | % |
| Plant #6 | 0.9 | 0.15 | 16% | 0.43 | 47% | 0.34 | 37% |
| Plant #7 | 1.7 | 0.58 | 34% | 0.10 | 6% | 1.02 | 60% |
| Plant #3 | 2.0 | 1.47 | 73% | 0.02 | 1% | 0.53 | 26% |
| Plant #8 | 4.5 | 0.82 | 18% | 1.74 | 39% | 1.95 | 43% |
| Plant #2 | 4.7 | 0.38 | 8% | 3.68 | 79% | 0.60 | 13% |
| Plant #1 | 7.2 | 2.11 | 29% | 0.94 | 13% | 4.16 | 58% |
| Plant #5 | 11.5 | 2.24 | 20% | 8.05 | 70% | 1.16 | 10% |
| Plant #4 | 19.5 | 14.71 | 75% | 0.47 | 2% | 4.34 | 22% |
| Min. | 0.9 | 0.15 | 8% | 0.02 | 1% | 0.34 | 10% |
| Max. | 19.5 | 14.71 | 75% | 8.05 | 79% | 4.34 | 60% |
| Ave. | 6.5 | 2.81 | 34% | 1.93 | 32% | 1.76 | 34% |

From this summary it can be seen that, although the average compositions appear to be the same for all three fractions, the composition of filtration media deposits varies greatly between plants. Some plants, e.g. plants 3 and 4, have high inorganic compositions and others, e.g. plants 2 and 5, have deposits consisting mostly of chemical precipitates. Plants 1 and 7 have high biological compositions, though the inorganic content of these deposits is still significant. Media from plants 6 and 8, however, yield deposits with relatively little difference between the three fractions.

Elemental Composition

Once the elemental analysis was performed and the values converted into mg/g, the percentage composition of each of the four identified 'problem' elements was determined, by simply expressing it as a fraction of the sum of the mg/g of elements measured per sample. These results are summarised in Table 6 below.

Table 6. Composition of the stripped deposits in terms of the four usual problem elements (in mg/g).

| | Total suspended solids (TS) (mg/g) | Elements (mg/g) | | | |
|----------|---------------------------------------|-----------------|-------|-------|-------|
| | | Ca | Mg | Mn | Fe |
| Plant #6 | 0.92 | 0.194 | 0.051 | 0 | 0.003 |
| Plant #7 | 1.70 | 0.309 | 0.069 | 0 | 0 |
| Plant #3 | 2.02 | 0.120 | 0.059 | 0.006 | 0.011 |
| Plant #8 | 4.50 | 0.391 | 0.078 | 0 | 0 |
| Plant #2 | 4.67 | 0.182 | 0.055 | 0 | 0 |
| Plant #1 | 7.21 | 0.246 | 0.080 | 0.007 | 0 |
| Plant #5 | 11.45 | 0.262 | 0.057 | 0 | 0 |
| Plant #4 | 19.52 | 0.154 | 0.072 | 0.220 | 0.047 |

As expected, the results show that calcium and magnesium are present in high quantities for all the plants. These results, therefore, do not have a correlation with amount of solids (TS) deposited on the media. These two elements represent the harder scale-like precipitates present in the media deposits that are not easily removed by the stripping method used.

There are, however, large differences in the quantities of manganese and iron in the samples. This correlates with known manganese and iron problems in the raw waters of the plants in which these elements were detected. Although the stripping method used was able to strip these deposits from the media, the normal backwash procedures did not. Therefore, the backwash procedures for these plants are currently inefficient and need to be more aggressive.

DISCUSSION AND CONCLUSION

This investigation led to a number of conclusions regarding the sampling of media and it's testing to yield meaningful results:

A standard test was developed that proved to work well in practice:

- It provided a method of stripping media of deposits that was reproducible.
- Its results were based on a mass concentration rather than a visual one, thereby providing a better measure of filter media cleanliness.
- It allows for the correction of the media sample moisture content.
- The sample yielded by the test could be used to provide information about the nature of the deposits on the media.

Based on the survey of this investigation, new tentative threshold guidelines were suggested (see summary table 7). These guidelines are significantly higher than the comparable AWWA guidelines:

Table 7. Tentative threshold guidelines suggested by this survey.

| | Interpreted AWWA guidelines | Suggested guidelines |
|--------------------|--------------------------------|-------------------------|
| Threshold A | 0.50 mg/g | 3 mg/g |
| Threshold B | 1.01 mg/g | 6 mg/g |
| Threshold C | 2.52 mg/g | 10 mg/g |

The fractionation of the deposits suggests that large variations in the composition of the deposits are found at different treatment plants.

This finding could suggest a media rehabilitation strategy as follows:

- If the deposits are mostly biological (V), the media could be treated in situ with chlorine (Cl₂).
- If the deposits consist mostly of chemical precipitates (SNV), acid could be used to treat the media in situ.
- If the deposits consist mostly of natural silts (NSNV), mechanical cleaning methods would need to be employed to clean the media.

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