Solids Accumulation and Clogging

Solids accumulation (and production) occurs in all types of treatment wetlands and with time will lead to media clogging; the time it takes to clog depends on design and operation practises, with the effects of clogging will be more severe in systems where oxygen transfer is essential for their functioning.

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Abstract

Solids accumulation and clogging are known processes in constructed treatment wetlands, which can be mitigated by organic and solids loading management and resting periods. Unless there is solids withdrawal, the inorganic and refractory matter stored within the wetland will result in clogging, regardless of treatment type.

In French vertical flow systems, a freeboard enables the accumulation of solids for up to 10-15 years and this surface layer plays an important role in the treatment performance of mature systems. Indeed, temporary surface ponding in the first stage is critical for the distribution of flow and load across the surface of the bed. In horizontal flow wetlands clogging results in overland flow but not necessarily in changes in the effluent quality.

Clogging has detrimental effects on systems that depend on passive oxygen transfer for their functioning, such as secondary vertical flow wetlands. Where claims of “no clogging” have been made, these are typically because not enough time has elapsed to match the storage capacity of the system (e.g., due to very low loading rates) or other mechanisms of solids release have occurred (e.g., periodic loss of solids immediately following resting periods in vertical flow systems). Wetland failure due to clogging is rare as most designers understand the balance to be struck between loading rates, solids management, and overall asset management.

Main outcomes of the session:

- There are examples of clogging of wetland systems from across the world, but these represent a very small percentage of all systems built
- French first stage systems are designed to “pond”, which does not mean they are clogged or incorrectly operated or designed. The accumulation of solids is key in distributing the pollutant load across the surface of the bed and as this surface layer matures, the system performs better. This works because of the resting periods built in between feeding stages.
- There are instances where “sacrificial” horizontal flow beds have been designed and used to deal with high solids loading and high hydraulic loading rates, where refurbishing the HSSF wetland every 10 – 15 years is more economical than building the beds bigger to last longer
- The main cause of clogging in secondary vertical flow wetlands (generally filled with fine materials such as sands 0.1-3 mm) is typically poor solids management in the primary stage. These can include lack of routine emptying of septic tanks, poor septic tank design, and/or solids flushing from the upstream process. Clogging has a negative impact on these systems as it restricts oxygen transfer in a process designed to be aerobic to meet its treatment objectives.
- Clogging in systems that rely on chemical precipitation for functioning is also problematic and will require intervention. Design criteria for these are being developed.
- There is limited full scale data of the influent characteristics to the wetlands before they clog; the practitioner is usually called to assist after the systems have clogged and with limited information on what caused clogging.

Introduction

Clogging development in subsurface flow wetlands is the result of physical (settling, filtration), chemical (precipitation), and biological (plant detritus and biofilm accretion) processes within the treatment system. These can be affected by design, operation and maintenance practices, such as pore size of the selected media when compared against loading rates applied to the bed or degradability of the solids under the conditions within the bed. When retention rates exceed degradation rates, solids accumulate both on top of the surface of the bed and within the bed media, reducing infiltration rates and eventually leading to permanent ponding on top of the bed. Further information on the contributing factors to clogging can be found in the review articles of Knowles et al. (2011) and Nivala et al. (2012). In this session, whilst types of clogging were discussed, the focus was primarily on first stage vertical flow beds in French-type systems (VF CWs; Chazarenc and Merlin, 2005) and tertiary horizontal flow beds (HSSF) used in the UK for domestic wastewater treatment. The rationale for this is that both types of systems have similar media (gravel), and receive similar hydraulic loading rates and solids loading rates (Knowles et al., 2011), about 50 g TSS m^2/d for the 1st stage of the French VF CWs (considering the entire surface of the first stage, it generally represents 150 g TSS m^2/d on the fed bed) and up to 35 g TSS m^2/d in HSSF wetlands.

The available quantification tools, remediation strategies and their cost comparison are provided in Nivala et al. (2012). Briefly, options to quantify clogging include on-site permeability tests for horizontal flow wetlands and drain tests for vertical flow systems, plus the conventional solids characterisation both as surface sludge and sludge within the bed. To manage clogging on a proactive basis, the only strategies available are either lowering the loading rates or managing the resting or recovery periods for the beds. In practice, all of these are mitigation strategies and, unless a periodic removal of solids occurs either intentionally or unintentionally, the system will clog as it matures. The balance is then in designing a system that can cope with the loading rates, retains solids within the bed, and is the lowest whole life cost when considering the frequency needed for refurbishment or sludge removal.

Solids release from subsurface wetlands can occur under: (a) high flow conditions, when an overflow system is in place (Figure 1), (b) immediately following a drying or rest period on the first stage of a French system (Molle, 2003) , and (c) when operating a horizontal subsurface flow system with surface flow, as it enables less dense particles to travel through the top of the bed until they reach the effluent point, where it is only filtered by a thin column of gravel (Dotro et. al., unpublished data). The extent of solids loss through these routes remains to be quantified.

Accumulation of water on top of subsurface flow wetlands is only problematic for some HSSF, as it can enable solids carryover across the length of the bed, and in VF wetlands if ponding remains between batches. Temporary surface water accumulation in VF CWs is part of normal operation (Figure 2) and, as such, fundamentally different from clogging. Surface water in HSSF can also occur due to poor operational practices where water level is poorly regulated (i.e., kept above the surface on purpose) and in some cases, unrelated to clogging as well. In both of these cases, there were only positive effects (VF CWs) or no effect (HSSF) on overall performance of the beds.

Figure 1: Example of subsurface flow wetlands with surface flow during high flow conditions. The water flows preferentially over the top of the bed and will result in partially treated water exiting through the overflow pipe and blending with the treated effluent at the final collection point.

Figure 2: Example of 1st stage VF Wetland with ponding during feeding. The water flow preferentially over the top of the bed around inlet points and the percolates.

Experiences with Positive and No Treatment Impact

In French VFCWs, solid accumulation expressed in terms of dry matter accumulation rate can range between 5 -10 kg DM/m^2/year on the surface of the first stage (Prigent et al., 2013; Chazarenc and Merlin, 2005). The accumulation rate is variable and linked to several operating and seasonal parameters, with the amount of sludge accumulated being higher during fall and summer than in winter time (Chazarenc and Merlin, 2005). The quantity of solids accumulated is more homogenous in older system with a surface layer covering the entire beds 2-3 year after the commission period (Figure 3), which results in improved treatment performance in terms of organic matter and ammonia removal.

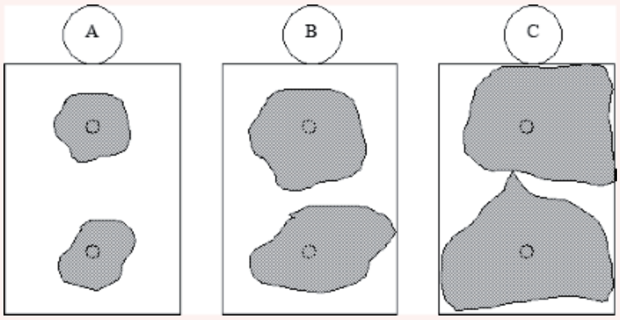

Figure 3: Plan view of surface layer area evolution in a bed of Glandieu during 12 day assay. Circles represent feeding points, from no surface layer at day 0 to (a) day 2; (b) day 4; and (c) day 12. Adapted from Chazarenc and Merlin (2005).

An example of ponding on secondary horizontal flow wetlands with no impact on treatment performance was reported by Nivala and Rousseau (2009) from the USA, showing persistent ponding in the inlet area four years after installation. The wetland was designed to treat the wastewater from a residential development to produce an effluent compliant with BOD and TSS concentrations of 30 mg/L each, prior to discharge into soil infiltration systems. The treated water exiting the wetland was well below the consented values, with effluent BOD and TSS at <5 mgO_2/l and <15 mg/l, respectively. However, areas of open water where the water is partially treated sewage were considered a health risk, which meant the system required intervention to rectify this clogging.

There are over 640 tertiary horizontal flow wetlands in the UK owned and operated by Severn Trent Water, a major utility company which pioneered this particular use of the technology. The main purpose of the tertiary beds is to trap any residual solids and particulate organic matter remaining from upstream settling and biofilm processes, and provide flow attenuation during storm events. As such, the wetlands are designed to operate as subsurface flow but have 25 cm on top of the gravel for additional storage of water and an additional 25 cm above that before reaching the top end of the bed (Knowles et al., 2011). The rationale is that, in the event of extreme flows (or severe clogging), partially treated water will bypass the wetland system and will blend with the tertiary treated effluent at the wetland exit point. Because the systems are for a tertiary application, the hydraulic loading rates can be high ranging from 0.2 to 0.8 m/d (Knowles et al., 2011). This, combined with the surface feeding strategy favoured by UK operators results in surface sludge accumulation over the top of the gravel, which will restrict permeability and eventually lead to ponding. One such case was observed by the authors at a small sewage works serving 13,700 pe, and fed with effluent from a trickling filter. The site was designed to meet a consent of 20, 25, and 5 mg/L of BOD, TSS and ammonia, respectively. The wetlands, however, were severely undersized, as they were based on available land and influent biochemical oxygen demand (BOD) concentrations rather than hydraulic load. When the site was visited in early 2013, after five years of operation, the three wetlands were fully flooded to the extent that they were hydraulically linked (Figure 4). The effluent quality, however, was again well below the consent discharging < 2, 4, and 1 mg/L for BOD, suspended solids, and ammonia representing 75%, 80% and 95% removal

Figure 4: Examples of clogged horizontal flow wetlands (a) Hydraulically linked UK tertiary wetland cells and (b) Surface ponding and hydrogen sulfide generation in secondary wetland in Italy. Picture (b) courtesy of IRIDRA Srl.

efficiencies, respectively. Like in the USA example, the site was refurbished due to health and safety concerns, that is, to ensure the water remained within the wetlands rather than due to deterioration in treatment performance.

Two examples of clogging of horizontal flow wetlands were supplied by IRIDRA Srl. In their 20 years of experience, these are the only systems that have resulted in clogging and required intervention. The first one, reported by Masi et al. (2013), consists of a system located in the municipality of Dicomano, Italy, and has been in operation for over 12 years. It comprises a primary settling stage in the form of an Inhoff tank, followed by a horizontal flow wetland (secondary treatment), a vertical flow wetland (tertiary treatment), another horizontal flow system and a final stage with a surface flow wetland for polishing and habitat creation purposes, for a total surface area of 6,080 m^2 for 3,500 pe. The secondary HF wetland was designed as a sacrificial bed, designed to trap the majority of the solids exiting the primary treatment stage and protect the VF wetland where most of the organics and ammonia removal would take place. The wetland started to show ponding in the first 3 meters of the influent after 4 years, and within 9 years ponding covered half the surface of the bed, which had a distinct white colouring (sulphide production). The hydraulic loading rate used in this secondary HF was 0.52 m/d with an organic loading rate of 0.105 $kgCOD/m^2/d$, which was an order of magnitude greater than the organic loading applied to the subsequent VF wetland. There was no deterioration in effluent quality from the overall treatment flowsheet but there were concerns of odour production once new housing was developed within 200 m of the treatment plant (F. Masi, pers comm.). The use of “sacrificial” HSSF wetlands, i.e., systems that will require solids removal or refurbishing within 8 – 10 years of operation, has been shown to be more cost-effective in some cases, such as this case study, and in tertiary HSSF wetlands in small treatment works in the UK (Figure 5).

A second example of a multi-stage or hybrid system that resulted in clogging of secondary horizontal flow wetlands was reported by IRIDRA during the workshop. The system was designed to treat 35 m^3/d of winery wastewater in 2001 but by 2007, the production at the winery had increased and was resulting in 100 m^3/d of water to be treated by the wetlands. The system comprised an Imhoff tank, followed by a horizontal flow wetland and a surface flow wetland. Ponding in the HF wetland started to appear in the middle of the bed and reed growth shifted so that they only grew in the perimeter (Figure 6). Sulphide formation was evidenced by a white colour in the wastewater inside the HF bed and exiting the bed, with odour being generated. The treatment performance was, again, within the consents in spite of the system overload but the smell issues resulted in the entire facility being re-built in 2009. The treatment flowsheet now comprises an equalisation tank, a French type first stage VF, followed by a refurbished HF wetland, a refurbished surface flow wetland and a final filter stage.

Experiences with Negative Impact on Treatment

Examples of wetlands that have suffered from clogging and this has impacted effluent water quality are rare. The workshop was a good place for practitioners to share their experiences and as such, a total of six systems with data and two anecdotical reports were compiled. In general, the issues were associated with wetlands that relied on oxygen transfer for achieving their treatment objectives where surface clogging developed and prohibited this. This could be the result of hydraulic, organic or solids overloads; uneven flow and load distribution; and media that did not meet the design specifications when the systems were actually constructed. As a result, the clogging in these wetlands impacted their treatment ability and resulted in the necesary interventions to rectify the issues. An additional special case of clogging

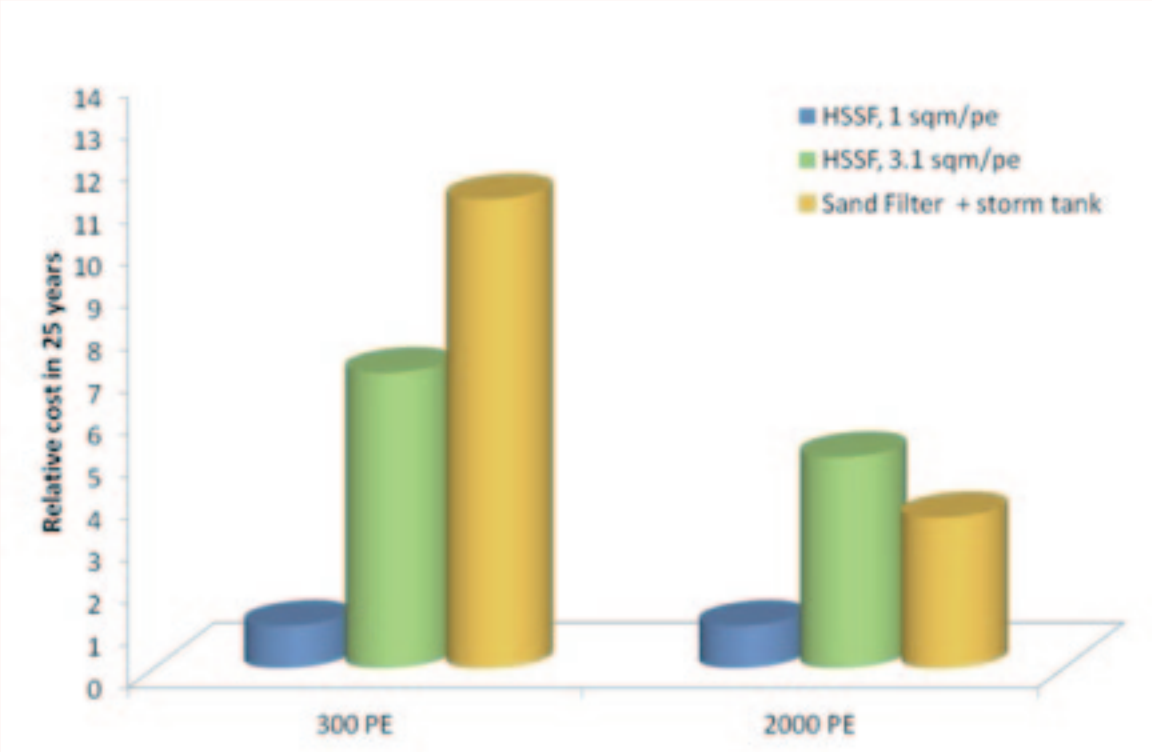

Figure 5: Relative cost comparison for a conventional tertiary HSSF sized at 1 m^2/pe (assumed asset life is 8 years), a wetland designed at 3.1 m^2/pe (designed for 18 years) and a conventional sand filter plus storm tank for an example small works serving 300 pe and 2000 pe. The difference between the two wetlands are the refurbishment intervals vs capital cost of a bigger wetland. All costs calculated based on Severn Trent Water's standards for 2010-2015. Adapted from Dotro et al. (2012).

Figure 6: Winery horizontal flow wetland (a) before and (b) after clogging developed. The loading rate onto the wetlands was three times the design load by the time clogging became permanent. Images courtesy of IRIDRA Srl.

ocurs in systems where chemical reactions are the main mechanism for the removal of phosphorus. Examples of clogging were shared where steel slag resulted in clogging at laboratory scale (France) and mixing of iron particules with the sand in a VF wetland resulted in clogging at full scale (Belgium).

From over 2,000 VF CWs in France used for domestic wastewater treatment, there have only been a few reports on clogging and hydraulic failures of the first stage beds. However, several cases can be highlighted, as the main indicator of a clogging of the first stage is the permanent ponding leading to reduced conditions and plants die-off (Figure 7).

The bed fed in the first stage can receive up to 300 g COD/m^2/d during one week, before 2 weeks of rest enabling the accumulated solids to be mineralized. When the amount of COD and TSS is above this load, the risk of clogging is higher especially during non-vegetative seasons. If a system is properly designed (Molle et al., 2005) clogging appears mostly as a consequence of inappropriate operating conditions. In most of the cases, the COD overload can be linked to sewer cleaning operations, unusual rainfall patterns (very low flows followed by very high flows, leadings to release of accumulated solids), or the discharge of low biodegradability compounds (xenobiotics, mineral oils, etc).

Figure 7: Example of 1st stage clogging in a VF CWs system.

Second stage clogging in the French VFCW system is more frequent as finer material are employed (coarse sand). The failure are mostly linked to problems including poor treatment in the first stage which bring more solids on the second stage, poor distribution and drainage systems, and poor organic solids degradation. These are similar to issues encountered in conventional secondary VF CWs and present a problem as they limit oxygen transfer into the bed matrix.

A secondary vertical flow wetland that clogged and resulted in deterioration of the effluent quality was reported by Nivala and Rousseau (2009), in Geel, Belgium. The system was built in 1996 on a milk farm and was designed to treat a mixture of primary settled domestic wastewater and settled rinse water from the milking parlour. With time, the farm operation grew and so did the load onto the beds. The wetland received, in addition to the design loads, a number of shock loads coming from the milking operations during its history. This resulted in permanent ponding on the surface of the VF wetland, which did not percolate between feeding batches. When the site was visited in 2007, there were between 2 and 8 cm of sludge on top of the media and permanent ponding. As a result, the effluent quality markedly deteriorated, moving from the normal average effluent BOD, COD, TSS and NH_4-N of 5, 41, 6 and 1 mg/L to 865, 1200, 105 and 62 mg/L, respectively. The clogging was so severe and the wetland so undersized under the new farm operation that, in the end, the system was abandoned and a new, larger wetland was built instead. The main factor believed to have influenced effluent quality was the reduced oxygenation of the bed matrix, thus shifting the microbial metabolism from aerobic to anaerobic, which meant slower degradation rates and an inability to treat the waste under the loading rates applied with the area and design configuration available.

Two examples of VF systems that clogged as a direct result of inadequate solids handling in the primary treatment and incorrect media used in the construction of the wetlands were reported by Kilian Water, from Denmark. They reported that out of 450 secondary VF systems designed for onsite tretment two presented clogging. The first system had an old septic tank which allowed too many solids to pass through to the VF bed, which, in addition, had sand that was too fine (i.e., non compliant with the Danish guidelines published by Brix and Arias in 2005) and uneven flow distribution. The combination of sand with low permeability and organic and solids loading in excess of the assumptions made for the design resulted in premature clogging of the surface of the VF wetland. In the second system, the effluent from a septic tank was connected to the VF wetland through a 160 mm pipe without slope and a tipping bucket. When the pipe was full, the tipping bucket discharged a pulse of septic tank effluent onto the VF bed. Unfortunately, this arrangement also meant that solids would accumulate in the pipe and be washed out in the tipping bucket pulse directly onto the surface of the VF wetland. This accumulation of solids on the surface was unplanned in the design, and so oxygen transfer was insufficient to provide the treatment quality required of the system with the designed footprint.

A separate case of clogging due to accumulation of solids from chemical reactions (i.e., precipitates) is found in some wetlands used for phosphorus removal such as slag filters or VF wetlands where the sand has been mixed reactive media (slag or iron). In the case of slag filters, the effect of calcium phosphate precipitates was assessed in column experiments. These showed clogging was mostly linked to the reduction of void space and an increase of dispersion within the filter; however, the full scale slag filters presented normal conductivities (i.e., no clogging) in the first two years of operation (Barca et al., 2013). In terms of iron-containing media, an example was reported at the workshop by Rietland, from Belgium. When phosphorus removal is required, a layer of approximately 30 cm of sand is mixed with iron scaling from steel manufacturing. When the ratio of iron scaling to sand by mass is less than 5%, the systems have presented no issues; if the ratio is above this value, or if the sand is not throughouly mixed with the iron media, clogging can develop. In this case, clogging is a result of high concentrations of iron hydroxides which created a crust that encouraged the accumulation of organic matter (black sludge) and lead to ponding. The issue was rectified by breaking the impermeable layer with an excavator and re-mixing (Figure 8).

Opportunities

A few items were highlighted during the workshop that offer opportunities for future research:

- More cost-effective solutions to clogging management than digging out the sludge layer every decade or so when the surface of the wetland ponds permanently and negatively impacts treatment performance.

Figure 8: Chemical precipitation within wetland media leading to clogging (a) sand and iron clusters from a VF wetland, (b) media cementation from a steel slag pilot wetland in the UK. Images courtesy of (a) D. Van Oirschot and (b) Flint Walters.

- Better design/ failsafe for oxygen input to the - bed when the system clogs
- Resting periods in horizontal flow beds

Earthworms

- Better records of operating conditions that could have lead to clogging.
- Improved design (and proof) for ventilation pipes
- Simple indicators of early signs of clogging to enable operators to report issues at an early stage.
- Design criteria for wetlands with reactive media to ensure good treatment performance and permeability is maintained for the life of the asset.

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