

Modeling the development and consequences of clogging for stormwater infiltration trenches

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Abstract

Stormwater infiltration systems are a means of restoring the natural hydrologic cycle where it has been disturbed by urbanisation. These systems help to increase soil infiltration, groundwater recharge and baseflows and reduce direct surface runoff. There is a strong correlation between the directly connected impervious area of a catchment and corresponding declining health of urban waterways due to changes in the hydrology and water quality. Stormwater infiltration systems help to disconnect impervious areas from waterways and protect the waterway ecosystem.

Stormwater infiltration basins and trenches are used around the world in the UK, Europe, Japan, Australia and the USA. Despite the widespread usage, most existing design methods make a number of simplifying assumptions, such as assuming one dimensional (1D) saturated flow. Many existing models have limited capacity to represent antecedent conditions and the effects of lateral flows, particularly from the underlying soils which may be significant for infiltration trench systems. To assess the benefits of stormwater infiltration systems in terms of modifying the hydrology of a catchment, it is preferable to simulate the system under a range of different storm events and intervening dry periods to evaluate measures such as the hydrologic effectiveness of the system (the proportion of the runoff volume captured) and the frequency of downstream overflows.

While stormwater infiltration systems can be very effective in reducing the volume and frequency of runoff into receiving waters, they are also potentially subject to sediment clogging, which can lead to reduced performance and eventually system failure. Clogging risks are typically managed with requirements for pre-treatment (a wise precaution) and the use of a 'clogging factor' or 'safety factor'. These factors are usually arbitrary and may not have a sound basis. They also do not allow for the progressive development of clogging with time or consider the expected lifespan of a system.

In this paper, an overview of a recently developed dynamic two dimensional (2D) variably saturated flow model with representation of the storage and development of clogging is provided along with results from application of the model. The model allows a stormwater infiltration trench with a porous media such as gravel to be simulated. It models soil moistures and flows through the surrounding soils to better represent antecedent conditions and their influence on system behavior. The model also simulates filtration of sediment particles by the storage media and the development of a clogging layer as sediment accumulates at the interface with the soil. The clogging module provides feedback to the flow modules to progressively influence the flow behavior over time. This allows the long term hydrologic effectiveness of an infiltration system throughout its lifecycle to be evaluated.

The model was applied to a number of scenarios including open basin and porous trench systems in Melbourne and Brisbane. Scenarios were simulated for two different soil types, sandy loam and sandy clay, both with and without clogging to evaluate the impacts of clogging on the performance of the system. Comparison was also made with existing guidelines for clogging factors to assess the adequacy of these factors.

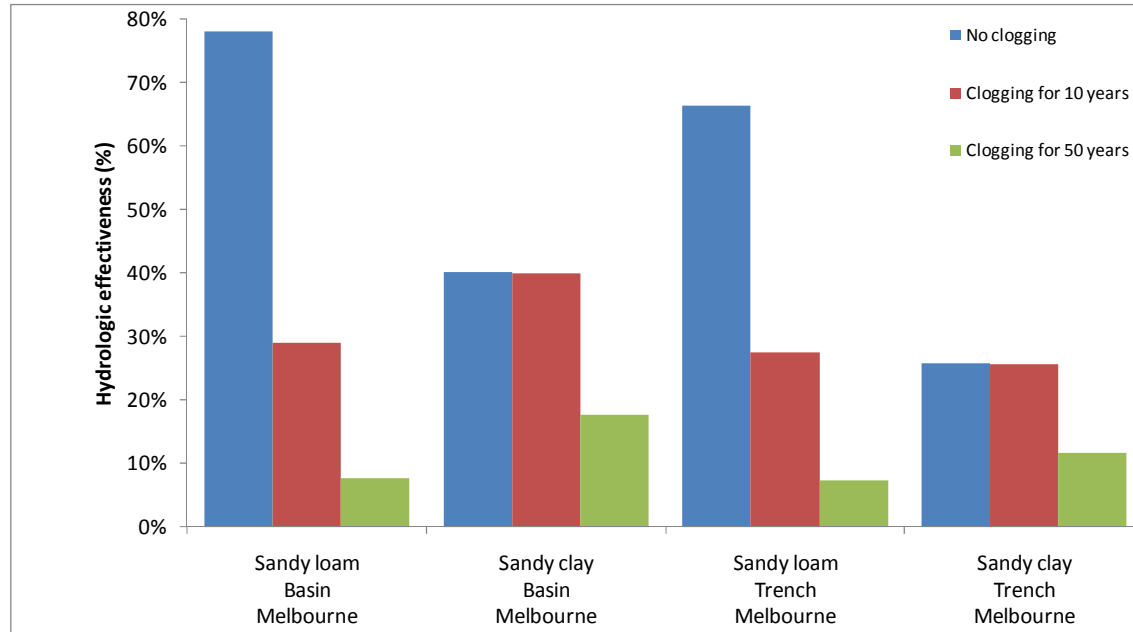


Figure 1 A comparison of the hydrologic effectiveness of a range of infiltration basin and trench systems in Melbourne with sandy loam and sandy clay surrounding soils with and without clogging

Some key observations from the results were as follows:

- Stormwater infiltration systems have substantial potential to improve the hydrology by reducing runoff volumes and also the frequency of downstream discharges.
- Comparing results with and without clogging clearly show that clogging significantly reduces the hydrologic effectiveness of these systems when they are not protected from sediment inflows and this can compromise the effectiveness of these systems
- Sandy loam obviously performed well without clogging. However once clogging was considered the sandy clay soil performed equally well or even better. Clogging has greater consequences for systems with a higher initial conductivity. Soils with a lower initial infiltration rate actually provide more consistent performance over time.
- The storage media plays an important role in filtering sediment to reduce the rate of clogging at the soil interface
- There are difficulties with the present use of ‘clogging factors’ to represent clogging as they usually provide a single factor. Firstly, some of these factors may actually not be conservative enough. Secondly, it is apparent that a more flexible approach allowing different factors for different soil types and other conditions is needed. This has important implications for the design of these systems.

Introduction

It is well known that urbanisation and conventional drainage increases the frequency, volume and peak flow rate of stormwater runoff. It leads to more frequent and severe flooding, increased erosion and more frequent habitat disturbance. It has been shown that there is a strong correlation between the directly connected impervious area of a catchment and corresponding declining health of urban waterways [Walsh, *et al.*, 2005b]. Infiltration systems increase soil infiltration, groundwater recharge and baseflows while reducing direct surface runoff. They can be used to restore a more natural hydrologic cycle to urban areas by disconnecting impervious areas from waterways.

Stormwater infiltration basins and trenches are used around the world in the UK, Europe, Japan, Australia and the USA [CIRIA, 2007; Dechesne, *et al.*, 2004a; Galli, 1992; Mikkelsen, *et al.*, 1996; Wong, 2006]. Despite widespread usage, most existing design methods rely on simplifying assumptions such as one dimensional (1D) saturated flow and clogging factors. Many existing models have limited capacity to represent antecedent conditions and the effects of lateral flows, particularly from the underlying soils which may be significant for infiltration trench systems. To assess the benefits of stormwater infiltration systems in terms of modifying the hydrology of a catchment, it is preferable to simulate the system under a range of different storm events and intervening dry periods to evaluate measures such as the hydrologic effectiveness of the system (the proportion of the runoff volume captured) and the frequency of downstream overflows.

While stormwater infiltration systems can be very effective in reducing the volume and frequency of runoff into receiving waters, they are also potentially subject to sediment clogging, which can lead to reduced performance and eventually system failure. The consequences of clogging were vividly illustrated by studies in the US [Galli, 1992; Lindsey, *et al.*, 1991] which found that a high proportion of infiltration basins and trenches failed due to clogging. On the other hand, many systems in Europe and Japan appear to be operating as designed [Achleitner, *et al.*, 2007; Fujita, 1994] indicating that they can be used effectively.

Clogging risks are typically managed with requirements for pre-treatment (a wise precaution) and the use of a 'clogging factor' or 'safety factor' where the hydraulic conductivity is divided by this factor. A factor of 2 is commonly used in Australia [Wong, 2006], 1.23 in Japan [Imbe, *et al.*, 2002] and 1.4 in New Zealand [Auckland City Council, 2003] while in the UK the factor varies from 1.5 to 10 depending on risk [CIRIA, 2007]. These factors are usually arbitrary and may not have a sound basis. They also do not allow for the progressive development of clogging with time or consider the expected lifespan of a system.

There are few simple models representing clogging available. Furumai [2005] simulated a catchment containing infiltration systems and represented clogging by assuming 10% of the systems had no infiltration (which is similar to the clogging factor approach) to obtain a better fit to observed data although such approaches have limited predictive potential. Researchers at INSA have developed a model for infiltration basins [Dechesne, *et al.*, 2002; Dechesne, *et al.*, 2004b; Le Coustumer and Barraud, 2007] based on the Bouwer model of infiltration [Bouwer, 1969] and have successfully applied it. The model is effective for well established clogging although representation of antecedent conditions is limited. There is a need to be able to predict and understand the likely impacts of clogging on stormwater infiltration trenches with greater confidence.

Stormwater infiltration model

Infiltration systems typically consist of a trench or soakaway filled with gravel or an open basin. Water enters the system directly or through a pipe and fills the storage. Water then infiltrates through the bottom and side walls into the surrounding soils. For infiltration trenches, the flow patterns are complex with two dimensional (2D) variably saturated flows occurring into the surrounding soil and a saturated zone forming after prolonged ponding. Sediment is filtered from the water as it passes through the storage media and forms a clogging layer along the bottom and side walls of the system, reducing the infiltration capacity of the system.

A dynamic 2D variably saturated flow model with representation of a porous storage and development of a clogging layer was developed. The model allows a stormwater infiltration trench or soakaway with a porous media such as gravel or an infiltration basin to be simulated. It models the antecedent soil moistures and flows through the surrounding soils to represent the influence of antecedent conditions on system behavior. The model also simulates filtration of sediment particles by the storage media and the development of a clogging layer as sediment accumulates at the interface with the soil. The clogging and filtration modules provide feedback to the flow modules to progressively influence the flow behavior over time. This allows the long term hydrologic effectiveness of an infiltration system throughout its lifecycle to be evaluated.

The model contains five main blocks representing the significant processes:

- Storage
- Saturated soil zone
- Unsaturated soil zone
- Filtration
- Clogging layer

A diagrammatic representation of the model is shown in Figure 2. It is assumed that the system is symmetrical and can be represented by simulating half of the system. The equations used in each of the above blocks are summarized in Figure 3, while their origins are discussed below.

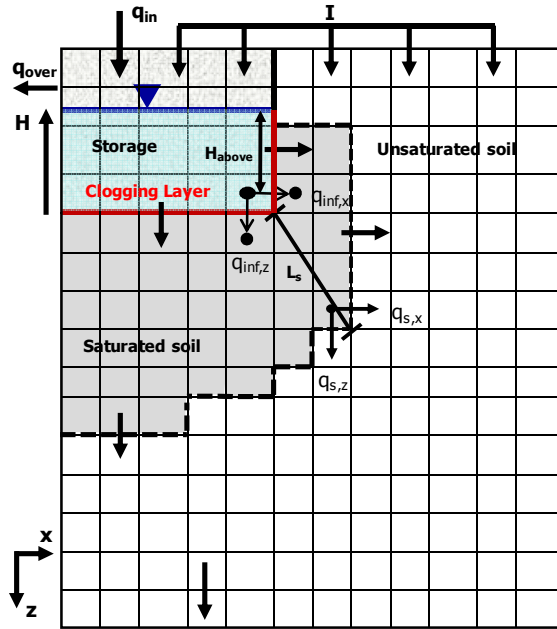


Figure 2 Diagrammatic representation of the stormwater infiltration model

| | |
|--|---|
| <p style="text-align: center;">Storage</p> $\frac{dH}{dt} = \frac{q_{in} + I - q_{inf} - E - q_{over}}{\phi}$ $q_{inf,pot,x} = -c_{clog} K(\theta) \frac{\partial \psi}{\partial x} \quad \text{horizontal}$ $q_{inf,pot,z} = -c_{clog} K(\theta) \frac{\partial \psi}{\partial z} + K(\theta) \quad \text{vertical}$ $q_{over} = \frac{c_w (H - H_w)^{3/2} \times L_w}{A_{storage}}$ <p style="text-align: center;">Saturated Soil</p> $q_{s,x} = -K(\theta) \frac{\partial \psi}{\partial x} \quad \text{horizontal}$ $q_{s,z} = -K(\theta) \frac{\partial \psi}{\partial z} + K(\theta) \quad \text{vertical}$ <p style="text-align: center;">Unsaturated Soil</p> $\frac{\partial \theta}{\partial t} = -\frac{\partial q_x}{\partial x} - \frac{\partial q_z}{\partial z}$ $q_x = -D(\theta) \frac{\partial \theta}{\partial x} \quad \text{horizontal}$ $q_z = -D(\theta) \frac{\partial \theta}{\partial z} + K(\theta) \quad \text{vertical}$ | <p style="text-align: center;">Filtration</p> $C_{out}^{clean} = C_{in} \exp \left[\frac{-3(1-\phi)\eta\beta H_{above}}{2d_m d_p} \right]$ $\eta = 0.9 \left(\frac{KT}{\mu d_p d_m v_i} \right)^{2/3} + \frac{3}{2} \left(\frac{d_p}{d_m} \right)^2 + \frac{g(sG_p - 1)d_p^2}{18\nu v_i}$ <p style="text-align: center; font-size: small;">Diffusion Interception Sedimentation</p> $C_{out} = F_{correction} + \sum_1^{N_{fractions}} C_{out,fraction}^{clean}$ $F_{correction} = F_1 H + F_2 PV_{cumulative}$ $PV_{cumulative} = \frac{V_{cumulative}}{\phi H_w}$ $Mass_{out} = C_{out} \times q_{inf} \times \Delta t$ $Mass_{cumulative,out} = C_{out} \times q_{inf} \times \Delta t$ <p style="text-align: center;">Clogging Layer</p> $C_{clog} = \left[\frac{100 c_1}{c_1 + (Mass_{cumulative,out})^2} \right]$ |
|--|---|

Figure 3 Model equations after Browne [submitted 2010]

Storage

The storage is represented using a reservoir model accounting for stormwater inflows, direct rainfall, infiltration, evaporation (for open basins) and weir overflows. The storage may be an open pond with porosity of 1 or a storage media. A porosity of about 0.4 is typical for gravel.

Saturated zone

The saturated soil zone is determined using a wetting front tracking algorithm and used to represent the area surrounding the storage with positive pressure heads. Following ponding, the wetting front expands out from the storage with nodes becoming part of the saturated zone once they reach a threshold saturation. If the ponding level recedes, outer areas of the saturated zone may also retract and when ponding ceases the saturated zone ceases to exist and all nodes are simulated as part of the unsaturated soil zone.

Unsaturated zone

The unsaturated soil zone is represented using Richard's equation expressed in the soil moisture based form.

Filtration model

The filtration model is based on the Yao model of filtration [Yao, *et al.*, 1971]. The Yao model predicts the effectiveness of a packed bed of media for removing sediment particles. It relies on the single collector efficiency and a collision efficiency factor which is the proportion of collisions resulting in adhesion. The collision efficiency factor depends on the chemistry of the system and must be determined by calibration. Newton [Newton, 2005] proposed a modification to use the interstitial rather than macroscopic velocity. In a parallel study of clogging by Siriwardene [Siriwardene, 2007; Siriwardene, *et al.*, 2007a; c], a single collision efficiency divided by the sediment particle diameter was added. Siriwardene extended the model for use in stormwater infiltration systems, proposing the use of a correction factor to account for remobilisation of accumulated sediment.

In this study, the Siriwardene model was adapted for use with nodal fluxes and concentrations for nodes at the storage/soil interface. Calculations were undertaken for two fractions, clay (<2 μm) and fine silt (2-6 μm).

Clogging model

Clogging typically occurs at the interface between the storage and the soil where a layer of sediment accumulates. It has been found [Siriwardene, 2007; Siriwardene, *et al.*, 2007a; b; c] that clogging for stormwater infiltration trenches mostly depends on sediment particles with a diameter less than 6 μm . A clogging model was developed to determine a factor for clogging using the cumulative mass of fine sediment less than 6 μm at the storage/soil interface. The factor is applied to the unclogged potential flow. The Siriwardene model assumes a constant depth or the average of a regularly varying depth. Calibration to laboratory experiments with constant depth and regular filling and draining provided good results.

In this study, the Siriwardene model was extended by applying it to the instantaneous potential nodal outflow rate at each node. The model uses depth from the flow modules and provides feedback in the form of nodal clogging factors allowing changing conditions to be continuously updated. This allows the model to be used in a dynamic 2D environment with irregularly varying depths. The use of nodal fluxes in the filtration and clogging models also allows for differential development of the clogging layer along the bottom and side walls depending on flow volumes and the length of overlying filter.

Numerical model

The model is discretised using a Godunov-type finite volume scheme. An explicit non-iterative variable-timestep is used. The resulting model handles rapid infiltration and sharp wetting fronts into dry and freely draining soils such as sands without difficulty which is

important as these conditions are common for infiltration systems. The method allows rapid simulation of the intervening dry periods between events while it is slower for continuously saturated conditions such as clay soils with restricted drainage. Further details of the model have been published previously [*Browne*, submitted 2010; *Browne, et al.*, 2008].

The model represents the main physical processes relevant for stormwater infiltration systems. The model simulates variably saturated 2D flows, antecedent moisture conditions and the progressive development of clogging to allow prediction of the long term hydrologic effectiveness of a system as a clogging layer develops. The flow model has been tested using commonly used cases for variably saturated flow models and laboratory data and found to produce good results [*Browne, et al.*, 2008; 2009].

Experiments

The model was tested for clogging conditions using data from experiments conducted at Monash University in collaboration with Nilmini Siriwardene [2007]. The experimental rig represents a 2D slice of an infiltration trench and was 2.15 m wide, 2.1 m high and 0.25m deep. It was constructed in a steel frame with removal perspex segments at the front and wood walls for the rear and sides. In this paper we will discuss one of the four experiments, (2DE4) [*Browne*, submitted 2010]. The rig was filled with loamy sand compacted with a mechanical vibrator. A gravel storage of width 0.5m and height 0.8m representing an infiltration trench was formed in the top left corner. Pressure sensors were used to monitor positive pressures in the soil and depth in the storage while Time Domain Reflectometry (TDR) probes were used to monitor soil moisture. During the experiment the storage was filled to a depth of 74cm and allowed to drain repeatedly to a depth of 7-10cm for 7 hours each weekday. Initially clean water was introduced to obtain data to calibrate the soil parameters of the model and establish a benchmark. Sediment was then mixed into the water in the supply tank with a target concentration of 150 mg/L to simulate the introduction of typical sediment-laden stormwater. The experiment was continued until the flow rate had reduced by 90% after 30 days. The model was calibrated by varying the soil parameters for a single day of clean inflows using PEST [*Doherty*, 1994], a popular optimisation software. The model was then calibrated to the experimental clogging data through adjustment of the clogging and filtration parameters. Further details of the experiments can be found in the theses prepared for this study, [*Browne*, submitted 2010] and [*Siriwardene*, 2007].

Applications

The model was applied to a number of scenarios including open basin and porous trench systems providing filtration. Climate conditions for Melbourne and Brisbane which respectively have moderate oceanic and humid subtropical climates respectively with rainfall as shown in Table 1 were simulated. A climate time-series from July 1996 to June 2006 was selected, representing decreased future rainfall as anticipated with climate change [*Jones, et al.*, 2004]. Inflows and concentrations to the stormwater infiltration systems were predicted using MUSIC Version 3 [*Wong, et al.*, 2005] assuming a catchment area of 100m², impervious fraction of 100% and a unit infiltration system sized at 1% of the catchment area or 1m². It was assumed that 1% of the total suspended solids would be less than 2 µm and 2% within the range 2-6 µm as assumed by Siriwardene .

Table 1 Mean annual rainfall volume and intensity for Melbourne and Brisbane

| Parameter | Melbourne (086017) | Brisbane (040223) |
|---|--------------------|-------------------|
| Mean annual rainfall 1950-1999 (mm) | 653 | 1172 |
| 1996-2006 rainfall (mm) | 525 | 927 |
| 1 in 1 year, 6 minute duration rainfall intensity (mm/hr)** | 44 | 110 |
| 1 in 1 year, 1 hour duration rainfall intensity (mm/hr)** | 14 | 36 |

Scenarios were simulated for two different soil types, sandy loam and sandy clay with saturated hydraulic conductivities of 36 mm/hr and 1.2 mm/hr respectively. Simulations with and without clogging were undertaken to evaluate the impacts of clogging on the performance of the system. The model was first run using the 10 year dataset with no clogging to create a benchmark. Clogging was then modeled with 50 years of data (five repetitions of the data set) to calculate the impacts of clogging after 10 and after 50 years relative to the benchmark.

Comparison was made with existing guidelines for clogging factors to assess the adequacy of these factors. This was achieved by rerunning the scenarios for Melbourne with 'no clogging' and the hydraulic conductivity of the surrounding soil reduced by a clogging factor of 2 as suggested by Australian Runoff Quality [Wong, 2006].

Experimental Results

The experimental results show that outflows decrease with time and the system drains more slowly as clogging develops as shown in Figure 4 and Figure 5. The drainage time increases from less than 2 hours initially to 4 hours by Day 19 and more than 7 hours by Day 30. As the clogging layer begins to dominate, soil moistures decrease. It can be seen that while there are variations at the instantaneous level, the model represents the clogging patterns quite well.

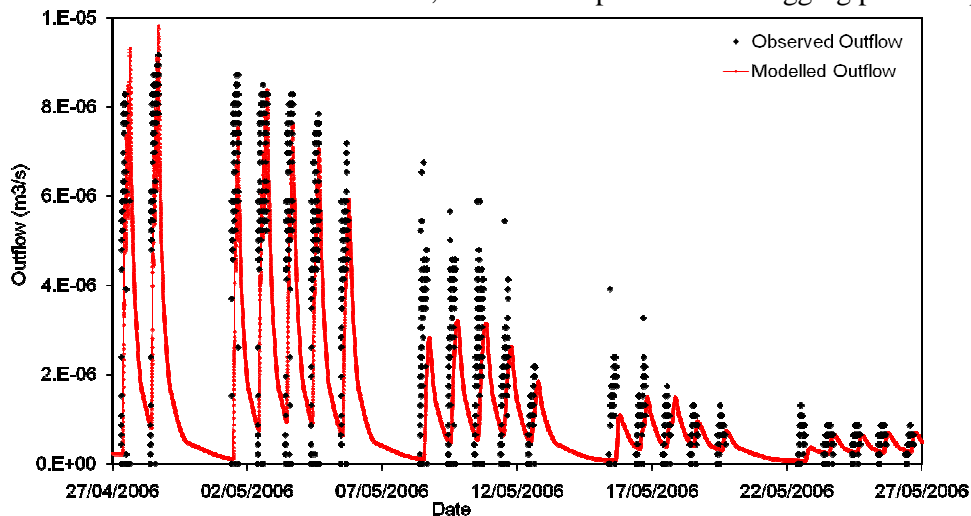
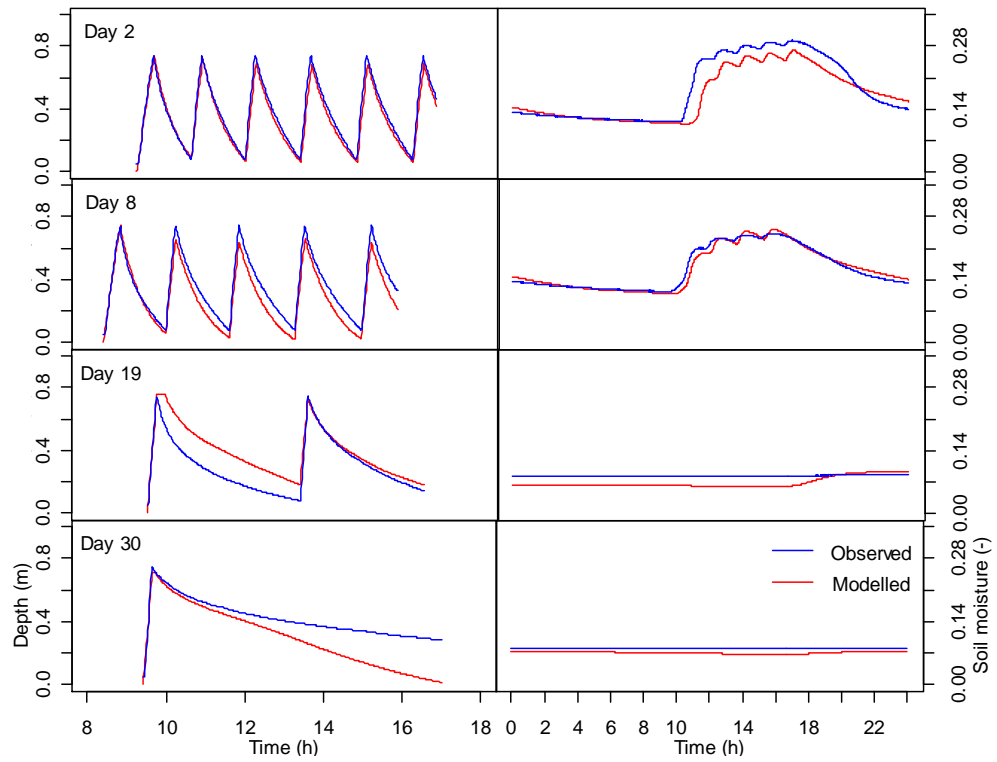


Figure 4 Modeled and experimental instantaneous outflows showing the decline as clogging occurs



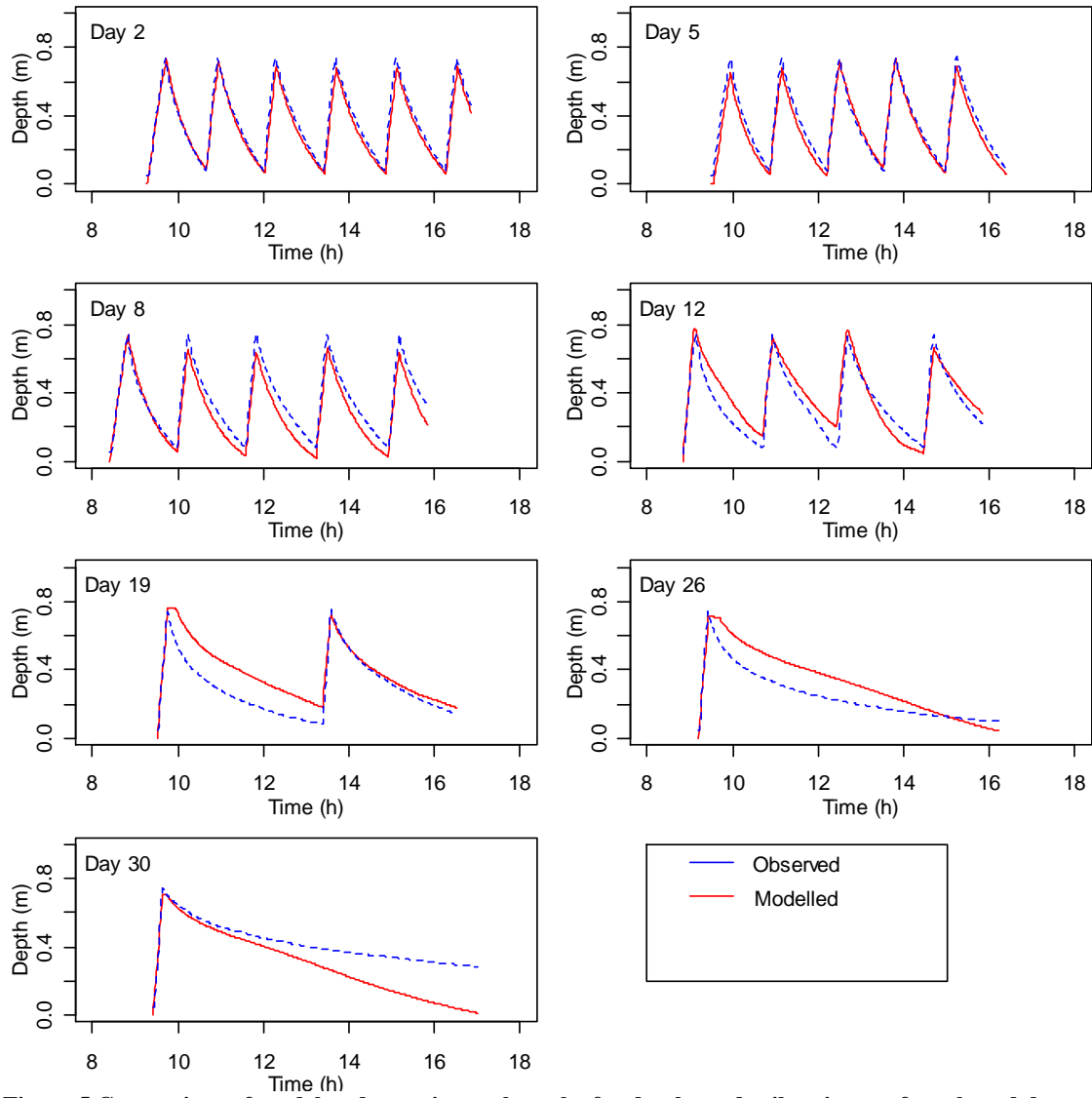


Figure 5 Comparison of model and experimental results for depths and soil moistures for selected days

Application Results

The results from the scenario models were compared to evaluate how clogging may impact on the potential for a stormwater infiltration system to effectively infiltrate water and reduce flows to downstream waterways. Two measures were considered, the hydrologic effectiveness or proportion of water captured and the frequency of overflow, see Figure 6 and Figure 7.

The results show that infiltration systems can potentially significantly reduce both the volume and frequency of stormwater runoff. Prior to clogging, the hydrologic effectiveness ranges from 20% to 80% while frequencies are reduced by at least a third and down to as low as 10 days per year. These changes would likely result in significant benefits for downstream waterways.

However, the potential consequences of clogging are also clear. The basin and trench systems constructed in sandy loam show a rapid decline in infiltration performance with the hydrologic effectiveness falling by half within 10 years. This is in stark contrast with the

systems in sandy clay which declined more slowly and ended up with similar performance to the systems in sandy loam after clogging, particularly for reducing overflow frequency. These results indicate that not only is it *possible* to construct systems in less rapidly draining soils, but that it may even be *preferable* in the long term. Such systems will achieve more stable and consistent performance with time and will have less difference between the predicted design performance (based on measured infiltration rates during design) and the real performance. Over the long term of 50 years, it can be seen that the hydrologic effectiveness of all systems declines to a comparable low level of around 10% by which time most systems would have failed to meet their design objectives.

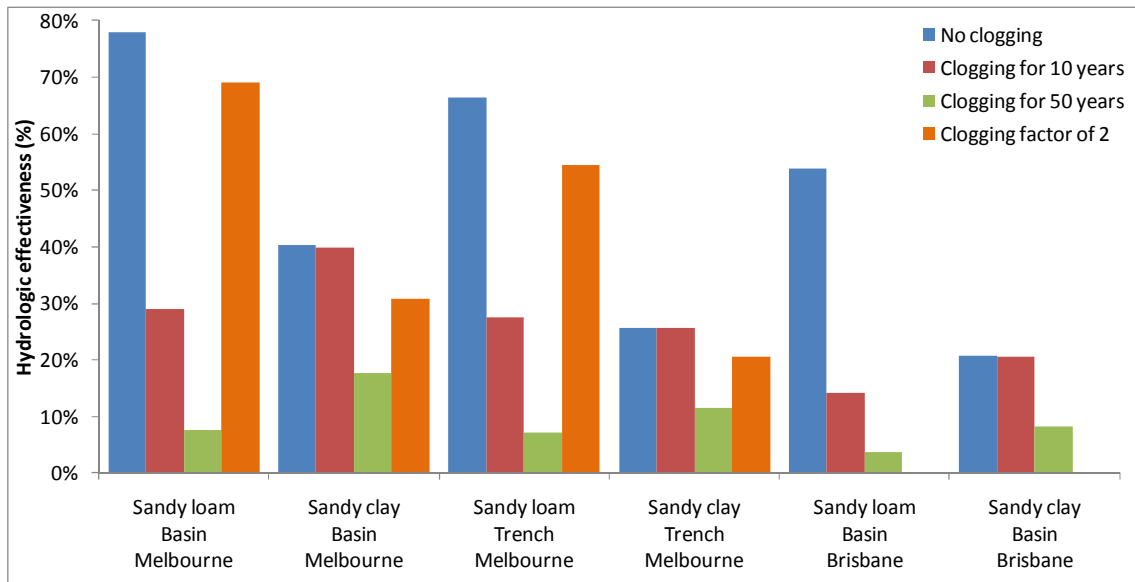


Figure 6 A comparison of the hydrologic effectiveness of a range of infiltration basin (porosity 1) and trench systems ($n = 0.4$) in Melbourne and Brisbane with sandy loam and sandy clay surrounding soils with and without clogging

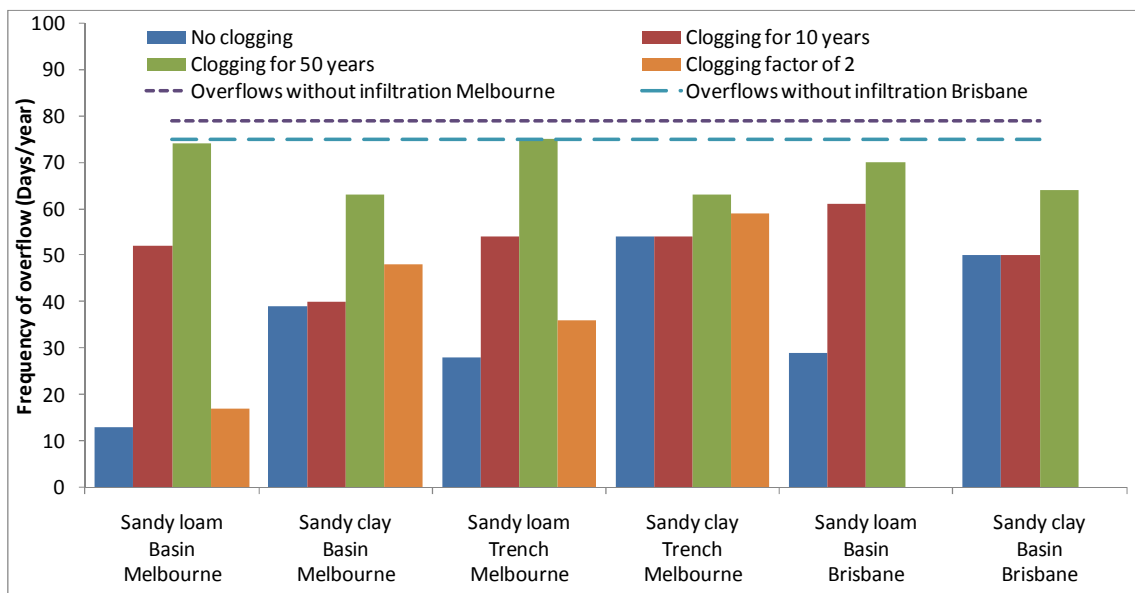


Figure 7 A comparison of the number of overflow days for a range of infiltration basin and trench system

The importance of the storage media is apparent for the sandy loam systems. While the trench has just 40% of the volumetric capacity of the basin, the hydrologic effectiveness results after

10 and 50 years of clogging are comparable for the two systems. This indicates that while a system with gravel will have less storage volume, it will also clog more slowly and over the long term will have similar performance. This has important implications for the development of proprietary storage media where the emphasis has historically been on increasing the proportional storage volume but not filtration efficiency.

The results above paint a somewhat depressing picture, and it is easy to see why some systems, particularly basins, have failed early in their lifespan [Galli, 1992; Lindsey, *et al.*, 1991]. However, the modeling here has assumed the worst case of untreated stormwater. Most guidelines recommend or require the use of pre-treatment and it is readily apparent why this is necessary for stormwater. Furthermore, some systems only receive relatively clean rainwater, are over-sized for their catchment or in Japan are cleaned. Therefore, we could hypothesise that the actual performance of most systems will fall somewhere between the clogged and unclogged results shown above.

The performance results with the proposed clogging factor of '2' are significantly better than the models with clogging for a sandy loam and between the 10 and 50 years clogging results for sandy clay. This indicates that these guidelines are probably not conservative enough for freely draining soils, while they would be reasonable for a system with slowly draining soils and a lifespan of perhaps 10-20 years. If a system were subjected to significant clogging, performance would be far worse than would be predicted. However, most guidelines also have recommendations to provide pre-treatment. Clearly such pre-treatment will need to be quite effective if the predicted performance levels are to be achieved and it would appear that guidelines should likely be more conservative where soils with high infiltration rates are used or the capability of pre-treatment systems to remove fine clay and silt particles is uncertain.

Conclusions

A stormwater infiltration system model for infiltration basins and trenches was developed. The model is a continuous simulation model that represents 2D variably saturated flows through the surrounding soils and filtration and clogging processes. The model allows the long-term performance of a system to be predicted, taking into account the effects of filtration and development of a clogging layer.

The model was calibrated to experimental data and shown to be able to predict storage depths and soil moistures for a stormwater infiltration system throughout the development of a clogging layer.

The model was applied to a range of scenarios considering different treatment configurations (open storage basin and gravel trench), climate conditions for Melbourne and Brisbane and sandy loam and sandy clay soils with and without clogging.

The results indicate that stormwater infiltration systems have substantial potential to improve the hydrology by reducing runoff volumes and also the frequency of downstream discharges. However, clogging significantly reduces the hydrologic effectiveness of these systems when they are not protected from sediment inflows and this can compromise the effectiveness of these systems.

Infiltration systems constructed in sandy loam obviously performed well without clogging. However once clogging was considered the slower draining sandy clay soil performed equally

well or even better. It can be concluded that clogging has greater consequences for systems with a higher initial infiltration capacity. Soils with a lower initial infiltration capacity actually provide more consistent performance over time.

It was found that the storage media plays an important role in filtering sediment to reduce the rate of clogging at the soil interface. The trench system in sandy loam soil outperformed the basin system with a relatively larger storage volume due to filtration and reduced clogging.

There are difficulties with the present use of 'clogging factors' to represent clogging as they usually provide a single factor. It appears that in some cases these factors may not be conservative enough. It is apparent that a more flexible approach allowing different factors for different soil types and other conditions is needed. This has important implications for the design of these systems.

The model developed can be used to predict the effectiveness of stormwater infiltration systems for mitigating the impacts of urbanisation on the hydrology of urban streams, taking into account the likely impacts of clogging over the lifespan of the system.

It would be beneficial for further research to be undertaken to understand the effects of pre-treatment on clogging and performance. In particular, while concentrations can readily be predicted, the particle size distribution is also important, particularly for fine particles less than 6 μm and there is a need to be able to predict the effectiveness of treatment systems to capture these fine particles and the corresponding outflow proportions. Further work could also be undertaken on the effectiveness of cleaning systems and the combined impact of stormwater infiltration systems and rainwater/stormwater reuse on hydrologic effectiveness.

Notation

$A_{storage}$ (m²) is the plan area of the storage
 C_{out}^{clean} (g/m³) is outflow concentration for a clean filter for a given fraction
 c_1 (g/m²) and c_2 (-) are calibration coefficients for the clogging model
 c_{clog} (-) is the outflow rate as a fraction of the instantaneous potential unclogged outflow rate
 C_{in} (g/m³) is inflow concentration
 C_{out} (g/m³) is concentration of sediment for all given fractions at the soil interface
 c_w (-) is the weir coefficient
 d_m (m) is equivalent particle diameter of the storage/filter media
 d_p (m) is median particle diameter of the inflow sediment fraction
 $D(\theta)$ (m²/s) is diffusivity defined as $D(\theta) = K(\theta) \partial(\psi) / \partial\theta$
 E (m/s) is evaporation rate from the storage
 F_1 (g/m³/m) and F_2 (g/m³) are calibration constants for $F_{correction}$
 $F_{correction}$ (g/m³) is correction factor for a clogged filter
 g (m/s²) is acceleration due to gravity
 H (m) is depth of water in storage (assumed to be 'wet' component in filtration model)
 H_w (m) is the level of the weir above the bottom of the storage
 I (m/s) is rainfall intensity
 K (J/K) is Boltzmann's constant
 L_w (m) is the length of the weir
 $Mass_{out}$ (g/m²) is mass of sediment for all given fractions reaching the soil interface at a given timestep
 $Mass_{cumulative,out}$ (g/m²) is cumulative mass of sediment for given fractions reaching the soil interface
 $PV_{cumulative}$ (-) is cumulative pore volumes that have passed through the storage/filter
 q is Darcy flux (m/s) in the direction of the coordinate
 $q_{available}$ (m/s) is maximum infiltration rate if all available water infiltrated within the timestep
 q_{in} (m/s) is stormwater inflow rate
 q_{inf} (m/s) is nodal soil infiltration rate
 q_s (m/s) is saturated flow rate
 q_{over} (m/s) is weir overflow rate from the storage
 SG_p (-) is specific gravity of the sediment particles
 t (s) is time
 T (K) is absolute temperature
 $V_{cumulative}$ (m³/m² of storage area) is cumulative flow volume that has passed through the storage/filter
 x and z (m) are the horizontal and vertical coordinates respectively

 β (-) is universal collision efficiency factor
 Δt (s) is timestep length
 η (-) is single collector efficiency (sum of diffusion, interception and sedimentation efficiencies)
 θ is soil moisture (-), $K(\theta)$ (m/s) is hydraulic conductivity
 ϕ (-) is porosity of the storage media
 ψ (m) is pressure head
 μ (kg.ms) is dynamic fluid viscosity
 v_0 (m/s) is macroscopic velocity
 $v_i = v_0 / \phi$ (m/s) is interstitial flow velocity [Newton, 2005]
 ν (m²/s) is kinematic fluid viscosity

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