RECONSIDERING INFILTRATION POTENTIAL IN THE AUCKLAND REGION

Grace Wong, Auckland Council, CPEng, IntCPEng
Judy-Ann Ansen, Auckland Council, PhD

ABSTRACT (200 WORDS MAXIMUM)

Infiltration practices have the potential to 'return' excess stormwater runoff from developments back into the ground. Infiltration offers a multitude of benefits resulting in extensive implementation nationally and internationally and offers an opportunity to implement Low Impact Design (LID). This practice is frequently eliminated prematurely in the Auckland region in many stormwater management best practicable options (BPO) assessment due to the presumption that it is not feasible on the predominantly clayey Waitemata series. Other concerns include contaminant accumulation and mobilization; groundwater contamination; early clogging or failure; and accuracy of the minimum infiltration rate for determining the preliminary feasibility of infiltration devices.

These concerns are investigated and analysed to ascertain their weight; followed by approaches to manage these concerns, and a depth specific safety factor design chart for clogging. Engineering and economic analyses were conducted. A minimum infiltration rate of the surrounding soil was determined. The points of diminishing returns were ascertained from size of footprint and construction costs.

KEYWORDS

Infiltration, Low Impact Design (LID), Contaminant Mobilization, Clogging, Minimum Infiltration Rate, Safety Factor, Best Practicable Option Assessment (BPO)

PRESENTER PROFILE

Grace is a chartered professional engineer with the Stormwater Technical Services Team of Auckland Council. Her engineering experiences ranges from roading and airport design and construction management to stormwater modeling and design. She is the principle author of Guideline Document No 3 (Proprietary Devices Evaluation Protocol). Her current interest is in stormwater management.

1 INTRODUCTION

Infiltration is one of the many techniques to manage stormwater. This technique mimics nature's way of handling stormwater. Technical Publication No. 10 – Stormwater Management Devices: Design Guideline Manual (TP10) (ARC, 2003) establishes that 'infiltration practices direct urban stormwater away from surface runoff paths and into the underlying soil. The runoff then continues into groundwater. It is one of the few practices that reduces the overall volume of stormwater being discharged'. Construction Industry Research and Information Association (CIRIA) defines infiltration practices as a device to temporarily store runoff from a development and allow it to percolate into the ground (Woolds-Ballard et al, 2007).

This paper summarizes findings from the Technical Report for updating the Infiltration Practice chapter of the future Guideline Document 01: Stormwater Management Devices Guideline for the Auckland Region (GD01). GD01 will be updated to replace the current stormwater management devices design manual, TP10. Five common design challenges are summarized in this paper with the analyses of their weight. They are (1) feasibility of infiltration practices in the clay regions of Auckland; (2) contaminant accumulation and mobilization; (3) groundwater contamination; (4) early clogging or failure; and (5) accuracy of the minimum infiltration rate.

An infiltration practice allows a quantum of stormwater to enter and reside in the practice. It is either hollow in sites above basalt formation or otherwise usually filled with materials of higher infiltration capacity than the surrounding soils. The material in the practice is called the media, which can consist of either gravels or synthetic materials. The voids between the media of the infiltration practice will provide temporary storage during the design storm event, preventing stormwater overflows. The presumption of the lack of ability of sites on clayey soils in the Auckland region to ex-filtrate runoff from the practice into surrounding clayey soils is of the main reason these practices are eliminated in the BPO assessment for stormwater quantity management. This is analysed in detail in Section 2.1.

The captured stormwater then leaves the practice by percolating or 'ex-filtrating' into the surrounding soils. This reduces the total volume of stormwater runoff during any storm events while 'recharging' the groundwater. This feature makes it a commonly used technique for runoff quantity control, suitable for low impact developments (LID). The pollutants entering the media of the infiltration practice can be either transformed and/ or removed. (Hvitved-Jacobsen et al, 2010) There are also concerns that the runoff is still contaminated when ex-filtrating the device and hence polluting the groundwater. These concerns are analysed in detail in Section 2.2 and Section 2.3.

Concerns that infiltration practices will clog and fail prematurely is evident. This happens as fine particles settle on the base of the practice and form a layer that could potentially blind the base of the practice, with the water column compacting it from above. Research and good engineering design can manage this issue. This is analysed in detail in Section 2.4.

Several stormwater management design manuals were reviewed for the literature review and the names of the manuals and the country of origin is outlined in Table 1 below. The minimum infiltration rate is an order of magnitude higher than that recommended in Australian guidelines below; and 70% higher than those recommended in other New Zealand guidelines. Conversely, it is at least 300% lower than those recommended in the US guidelines reviewed. How does one determine the best practicable minimum infiltration rate for determining the feasibility of infiltration practices in the Auckland region? This is analysed in detail in Section 2.5.

Table 1: Stormwater Management Design Manuals reviewed in the literature review for the update GD01.

Country	Organisation	Document
New Zealand	Auckland Regional Council	Design Guideline Manual: Stormwater Treatment Devices (1992)
	Auckland Regional Council	Technical Publication No 10 – Stormwater Management Devices (2003)
	New Zealand Water Environment Research Foundation	On-Site Stormwater Management Guideline (2004)

	Auckland City Council	Soakage Design Manual (2002)
	Department of Building and Housing	Compliance Document for New Zealand Building Code: Clause E1-Surface Water
Australia	Environmental Protection Agency (EPA) Victoria	Water Sensitive Urban Design Engineering Procedures: Stormwater
	Stormwater Trust and Upper Parramatta River Catchment Trust	Water Sensitive Urban Design: Technical Guideline for Western Sydney, Australia.
United State of America	Maryland Department of the Environment, Water Management Administration	Maryland Stormwater Design Manual Volumes I & II (2000) (Revised 2009)
	Department Of Environmental Protection, Bureau of Watershed Management	Pennsylvania Stormwater Management Manual
England	CIRIA	The SUDS (Sustainable Drainage Systems) Manual

2 SOLUTIONS TO DESIGN CHALLENGES OF INFILTRATION PRACTICES

2.1 FEASIBILITY IN CLAYEY REGIONS IN AUCKLAND

Infiltration in the Auckland region is traditionally regarded as a mechanism to dispose stormwater runoff rapidly via an aquifer. This ideology has resulted in the failure to consider infiltration practices which ex-filtrate in many potentially feasible sites. In the revised design guideline, these two infiltration applications will be differentiated. Rapid soakage refers to infiltration through fissures in the basalt formation; while infiltration refers to infiltration through the practice media, storage in the interstices within the media and ex-filtration to surrounding soil.

2.1.1 TOO CLAYEY GROUP C WAITEMATA FORMATION

The general industry presumption is that most soils in Auckland are of the Waitemata Formation, which has poor permeability and is classified as Hydrological Group C soils. Recent studies by Landcare Resesarch concluded that granular and allophonic soils, which have Group A permeability, occurs as minor inclusions in landscapes dominated by Group C permeability Ultic Soils on Waitemata Formation sedimentary rocks in the Auckland region (Ross, 2007). They have poor compaction and soil strength characteristics, making these pockets feasible for infiltration. However, the identification of areas of Hydrological Group A soils in landscapes on Waitemata Formation dominated by Group C soils is yet to be carried out.

Infiltration practices should also be widely used on sites above peat soils. They recharge the underlying groundwater and prevent soil subsidence.

2.1.2 NON-REPRESENTATIVE PRELIMINARY INFILTRATION RATES

The infiltration rates published for soils for different textural classes are readily available. They are not necessarily representative of the soil at a site. These published rates are measured from homogeneous soils, while homogeneous soils are rarely found in the field. Field measurements have demonstrated that these values are conservative. Hence, it is recommended that these values be used for preliminary sizing and refined during detailed design with field measurement of infiltration rates on site.

2.1.3 TEMPORARY STORAGE IN INFILTRATION PRACTICES

Stormwater runoff for a design storm can be stored in a depression sized and infilled with the optimum media. This runoff can be temporarily stored within the interstices before ex-filtrating to surrounding soils. The constraint will be the rate of infiltration of the surrounding soils. This can be managed by optimizing the design with routing of the stormwater runoff through the practice as a function of stage-volume-discharge. The GD01 will simplify this optimization by developing design charts for various footprint of the infiltration practice based on a range of infiltration rates of the surrounding soils.

2.2 CONTAMINANT ACCUMULATION AND MOBILIZATION

2.2.1 DEPTH OF CONTAMINANT ACCUMULATION

Concerns about the accumulation and mobilization of the contaminants captured and retained within infiltration practices were investigated in a field study consisting of four infiltration practices (10-21 years old) by Dechesne et al. in 2004. The findings indicated a rapid decrease of concentration with depth. (Figure 1) The figure depicts a reduction of pollutant concentration at depths between 40-80cm. This depth is measured from the base of the infiltration practice.

Most hydrocarbons are trapped in the first few centimeters of soil of the base of infiltration practices. (Barraud et. al., 1999; Dierkes & Geiger, 1999) The type of hydrocarbon appears to affect the fate; Dierkes and Geiger (1999) found that 'mineral oil' type hydrocarbons (MOTHS) were more likely to be captured in soil and degraded than polycyclic aromatic hydrocarbons (PAHs).

Dierkes and Geiger (1999) also found that concentration of pollutants decreased rapidly with depth. Daltry et al. (2004) concluded that since heavy metals and hydrocarbons were either not detected or below reference concentrations in groundwater and aquifer sediments they remained adsorbed onto stormwater sediments stored in the infiltration practice. Daltry et. al. (2004) also suggested that elevated concentrations of phosphate and Dissolved Organic Carbon (DOC) in groundwater below the infiltration basins monitored are most probably caused by mineralization of organic sediments.

Most of the literature reviewed agrees that the concentration of the contaminants reduce with depth, and the consensus is around 50cm from the base of the infiltration practice.

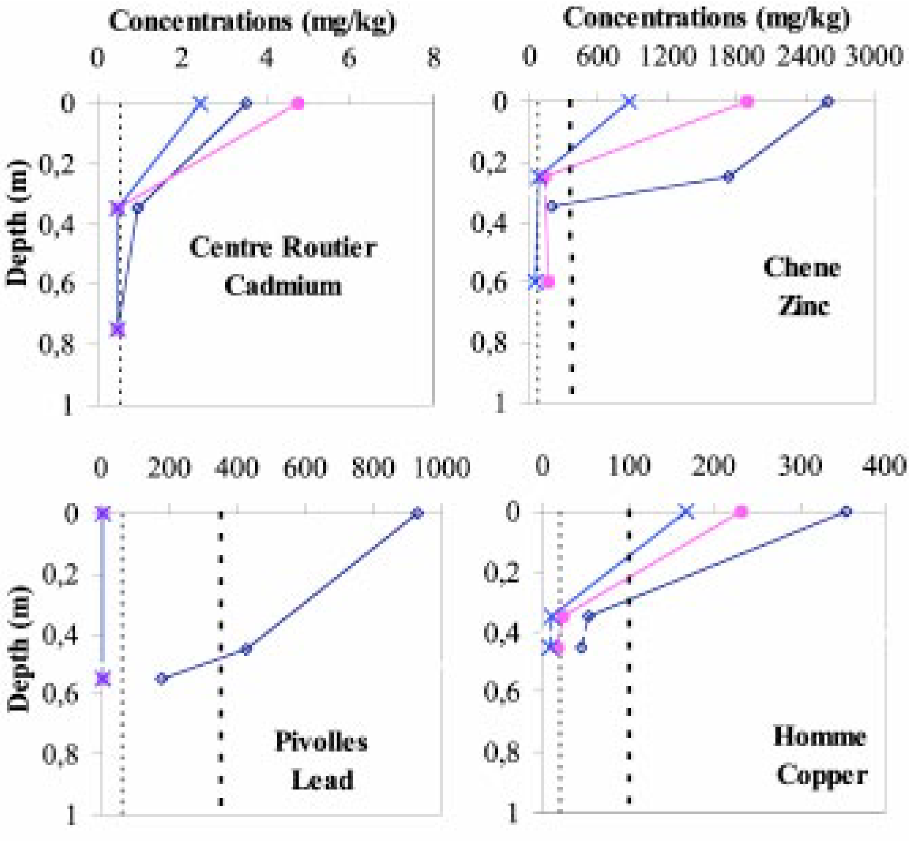

Figure 1: Pollutant Concentration of selected pollutants at various depths for different basins. (Source: Dechesne et al., 2005)

2.2.2 CONTAMINANT MOBILIZATION

Heavy metal retention is high provided sedimentation is used upstream of an infiltration practice. Soil conditions such as pH may release metals and this is heavy metal specific (Pitt et. al., 1995)

Contaminants are generally trapped and absorbed in the practice but have the risk of mobilizing either with interactions within urban runoff constituents and concentrations of dissolved organic material, or mineralization of organic sediments. This can be optimized and resolved by specific details and appropriate routine maintenance.

2.3 GROUNDWATER CONTAMINATION

2.3.1 LITERATURE REVIEW

Properly constructed infiltration practices percolating runoff into the surrounding soil and/ or groundwater does not necessarily pollute the receiving environment. The most common urban runoff pollutant is usually suspended sediments. During infiltration of stormwater into the practice, almost all solids are removed by filtration and adsorption in the initial centimetres of soil (Chebbo et al., 1995; Mason et al., 1999; Baveye et al., 2000). Groundwater tends to be nearly free of suspended solids because of the filtrative and adsorptive properties of soil (Bianchi and Muckel, 1970, cited in Fergusson, 1994). Studies by Nightingale (1987) confirmed the trapping ability and effectiveness of infiltration basins that have been operational for up to 20 years. It was found that concentrations of monitored constituents in the groundwater under the basins were similar to those in groundwater elsewhere in Fresno, California (Fergusson, 1994). Mikkelsen et.al. (1994) researched soil and groundwater contamination of infiltration sites due to stormwater contaminated with PAHs and found that they readily sorb to soil particles. The authors concluded that these contaminants (PAHs) posed little risk of groundwater contamination.

2.3.2 LIKELIHOOD OF POLLUTANT CONTAMINATING GROUNDWATER

The likelihood of a particular pollutant, ranging from pesticides to heavy metals, contaminating groundwater has been investigated in great depth by Pitt et al. (1999). Pitt et. al. (1994) examined the interaction of various factors, such as mobility in the worst soil comprising sandy or low organic soils, and the pollutants' abundance in stormwater. The results were tabulated and adapted in this paper as Table 2: Groundwater contamination potential from stormwater pollutants in infiltration devices with sedimentation adapted from Groundwater Contamination Potential for Stormwater Pollutants as reported by Pitt et al. (1994).

Table 2 shows that of the 28 potential pollutants of groundwater investigated, only one, enteroviruses demonstrate a high contamination potential of groundwater, however with a high filterable fraction. This translates to a high proportion of the enteroviruses being filtered when the runoff passes through a device which has filtration mechanism, namely an appropriate pre-treatment device or mechanism. The remaining pollutants have low to moderate contamination potential.

2.3.3 IS PRE-TREATMENT USEFUL FOR PREVENTING GROUNDWATER CONTAMINATION?

The reduction of groundwater contamination potential with the addition of some form of upstream pretreatment, referred to as sedimentation in Table 2, is minimal for most pollutants. The improvement is only observed for 8 out of the 28 pollutants listed. One can conclude from Table 2 that pretreatment is not highly effective for the purpose of preventing groundwater contamination, with the possible exception of the eight identified above.

However, values in Table 2 are only appropriate for initial estimates. For runoff containing higher than usual levels of contaminants, such as those on a highly industrialised catchment; behaviour and decay of the pollutants through an infiltration practice needs to be investigated specifically for each site.

2.3.4 GROUNDWATER CONTAMINATION POTENTIAL EVALUATION MODELS

Clark and Pitt (2008) proposed two evaluation methodologies for predicting groundwater contamination potential from stormwater infiltration practices. The first is a simplified method, utilizing information contained in Table 2 below. The second is a detailed method, which is to develop a computer model to predict vadose zone contaminant transport. This is only required if the risk of groundwater contamination is high or if groundwater is used as a potable water source.

However, designers and decision makers should note that areas with high contaminant loading such as recycling centres, gas stations, or brownfields with high soil contamination, may not be appropriate for infiltration, due to increased risk of contaminating the groundwater (Dietz, 2007).

Certain pollution risks are associated with infiltration practices, but many pollution risks are associated with the status-quo method, which is discharging to surface water bodies without any water quality control at all. Moreover, the benefits of infiltrating the rainfall-runoff into the ground and recharging the soils are profound. This practice is accepted widely as a Low Impact Design component.

Table 2: Groundwater contamination potential from stormwater pollutants in infiltration devices with sedimentation adapted from Groundwater Contamination Potential for Stormwater Pollutants adapted from Pitt et al. (1994).

	Compounds (Pollutants)	Mobility (worst case: sandy/ low organic soils)	Abundance in stormwater	Fraction filterable	Contamination potential for surface infiltration and no pretreatment	Contamination potential for surface infiltration with sedimentation
Nutrients	Nitrates	Mobile	Low/moderate	High	Low/moderate	Low/moderate
Pesticides	2, 4-D	Mobile	Low	Likely low	Low	Low
	*g-BHC (lindane)	Intermediate	Moderate	Likely low	Moderate	Low
	Malathion	Mobile	Low	Likely low	Low	Low
	Atrazine	Mobile	Low	Likely low	Low	Low
	* Chlordane	Intermediate	Moderate	Very low	Moderate	Low
	Diazinon	Mobile	Low	Likely low	Low	Low
Other organics	VOCs	Mobile	Low	Very high	Low	Low
	1,3-dicholorobenzene	Low	High	High	Low	Low
	Anthracene	Intermediate	Low	Moderate	Low	Low
	* Benzo(a)anthracene	Intermediate	Moderate	Very low	Moderate	Low
	* Bis (2-ethylhexyl) phthalate	Intermediate	Moderate	Likely low	Moderate	Low
	* Butyl benzyl phthalate	Intermediate	Moderate	Likely low	Moderate	Low
	Flouroranthene	Intermediate	High	High	Moderate	Moderate
	Flourene	Intermediate	Low	Likely low	Low	Low
	Naphthalene	Low/intermediate	Low	Moderate	Low	Low
	* Penta-chlorophenol	Intermediate	Moderate	Likely low	Moderate	Low
	* Phenanthrene	Intermediate	Moderate	Very low	Moderate	Low
	Pyrene	Intermediate	High	High	Moderate	Moderate
Pathogens	Enteroviruses	Mobile	Likely present	High	High	High
	Shigella	Low/intermediate	Likely present	Moderate	Low/moderate	Low/moderate
	Pseudomonas aeruginosa	Low/intermediate	Very high	Moderate	Low/moderate	Low/moderate
	Protozoa	Low/intermediate	Likely present	Moderate	Low/moderate	Low/moderate
Heavy metals	Nickel	Low	High	Low	Low	Low
	Cadmium	Low	Low	Moderate	Low	Low
	* Chromium	Intermediate/very low	Moderate	Very low	Low/moderate	Low
	Lead	Very low	Moderate	Very low	Low	Low
	Zinc	Low/very low	High	High	Low	Low

* Eight compounds/ pollutants which respond to sedimentation (pre-treatment)before infiltration

2.4 SAFETY FACTOR TO ACCOUNT FOR EARLY CLOGGING OR FAILURE

Safety factors are usually applied to a design equation to account for an unquantifiable known factor, like clogging; or to manage the risks of known effects, like damage from overflows or flooding. This paper only discusses the development of the safety factor to account for clogging.

2.4.1 INFILTRATION RATE OF CLOGGED LAYER

Infiltration practice footprint designs are usually optimized by increasing the depth of the practice and utilizing side walls for infiltration. If they are designed as deep practices, it decreases the design life span of the device. Fine sediments are anticipated to buildup at the base on the practice. As this limiting layer develops, it is compressed by the hydraulic load/ pressure imposed by the ponded water. The effective stress across the limiting layer is increased, and could further compress it, increasing its bulk density, hence further reducing its hydraulic conductivity (Bouwer, 1989). Bouwer et al.'s (1989) research emphasized the need to ensure that depth of infiltration practices are within an infiltration depth envelope.

Although the appropriate depth for infiltration practices was important, Bouwer and Rice (1989) did not develop this envelope. This paper also presents the envelope developed with Bouwer and Rice's (1989) equation. It characterizes the range of practice depth to ensure optimum flow through the practice. It also provides a limitation to prevent the compression of the clogging area at the base of the practice.

The depth of a practice versus the reduction of the infiltration rate is analysed to determine the reduction of infiltration rate as a result of the compression of the clogging layer which forms at the base of the practice. The method of computation is outlined equation 1 below (Bouwer & Rice, 1989).

$$Z = \Delta Pi \frac{L}{E} \qquad (1)$$

Where

Z = Vertical compression of the clogging layer

ΔP_i = Increase in inter-granular pressure between the top and base of the clogging layer

L = Thickness of the clogging later prior to compression

E = Elasticity Modulus of the clogging layer, taken as 1 kg/cm^2 - 10 kg/cm^2 for this analysis to assess its effects on the results

From equation (1) above, the difference in the thickness of the potential clogging layer before and after compression is computed for depths of 100mm to 2000mm. This value is then used to compute the reduction in the infiltration rate. The computed safety factor is a function of the initial infiltration rate, and the infiltration rate when the clogged layer is formed. These safety factors were computed for the development of a clogging layer consisting of fine particles similar to fine clay with the Elasticity Modulus ranging from 1 kg cm^{-2} to 10 kg cm^{-2}. The reason for deriving the chart for fine clay only is that fine clay particles have the smallest modulus of elasticity. This means that a layer consisting of fine clay particles would have the highest degree of compression based on the equation (1) above, causing the worst case clogging. This is reinforced with the curve in figure 2 below. The blue line is the worst case envelope derived from using a Young's Elasticity

Modulus of 1 kg cm^{-2}. The clogged layer is assumed to be 100mm as a most conservative scenario.

2.4.2 DESIGN FOR EARLY CLOGGING OR FAILURE

Equation (1) was computed for infiltration practice depths ranging from 100mm to 2000mm. Figure 2 below correlates the safety factor to account for clogging and the depth of the practice.

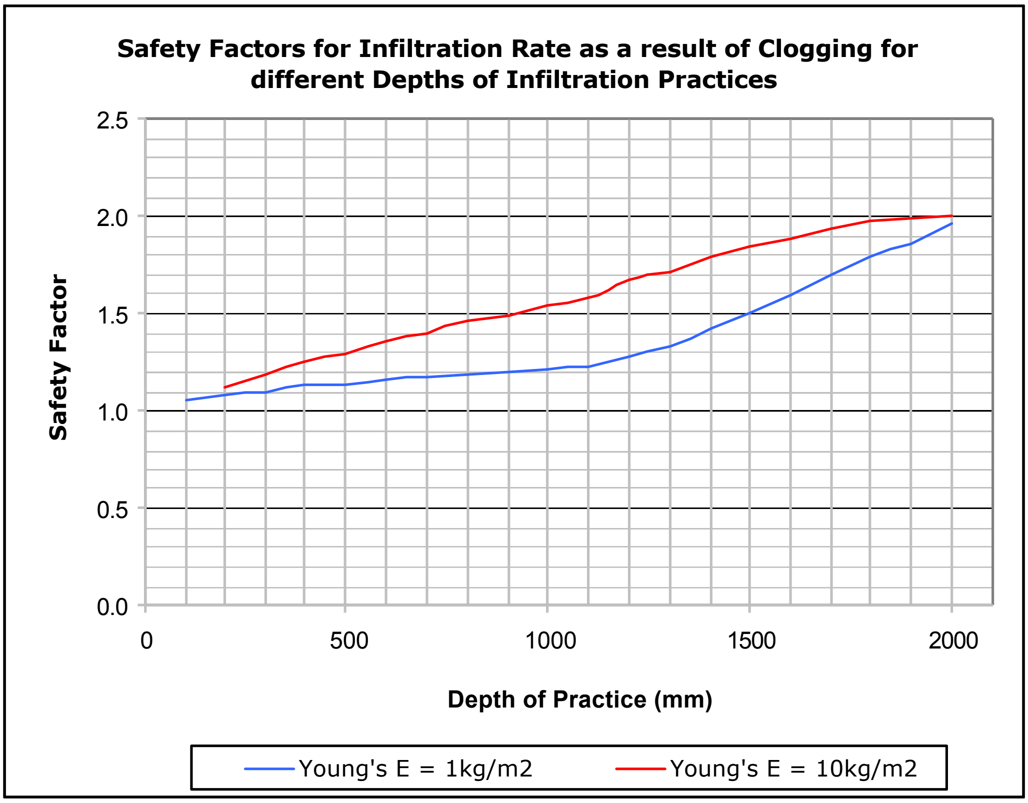

Figure 2: Safety Factors for Infiltration Rate as a result of Clogging for different Depths of Infiltration Practices

This chart shows a positive proportional relationship between the safety factor for the infiltration rate and the depth of the practice. This chart is limited to use on sites where fine particles, such as fine clays and fine silts are the predominant soil type. The risk of this magnitude of clogging at these depths is reduced on sites with a coarser particle size distribution.

The safety factor varies between 1.0 and 2.0. This indicates that on a site where fine particles are in abundance in the topsoil, infiltration practices should be designed with a safety factor of up to 2 to account for clogging. This safety factor envelope would be slightly different with different topsoil particle sizes. This has to be evaluated to account for the increase of particle sizes, which results in an increase in the Young's Elasticity Modulus.

The designer can first calculate the depth of the practice preliminarily and then use the design chart in Figure 2 to determine the safety factor for the infiltration rate. It is then used to re-calculate the final depth of the practice after substituting the preliminary depth in the sizing equation.

2.5 MINIMUM INFILTRATION RATES

2.5.1 EXISTING TP10 VALUES

The minimum infiltration rate is the smallest feasible rate which is used preliminarily to determine the feasibility of the practice on the site and also to preliminarily design the practice. This does not replace the design infiltration rate which represents the long-term resultant infiltration rate of the surrounding soil.

The minimum infiltration rate suggested in TP10 (2003) is 3mm hr^{-1}, which is 73% higher than those recommended in other New Zealand guidelines reviewed; and at least 300% lower than those recommended in the US guidelines reviewed. Refer to Table 1 for details of the reviewed guidelines.

2.5.2 DESIGN CAPACITY FOR FOUR CATCHMENT SIZES

The large variation in the minimum infiltration rates prompted an investigation to determine the appropriate minimum infiltration rate. Several analyses were carried out by varying size of footprint, size of catchment and cost of construction. The results of the analyses as illustrated in the following figures.

Figure 3 illustrates the variation of the footprint of an infiltration practice with different infiltration rates of the surrounding soil for four different catchment sizes.

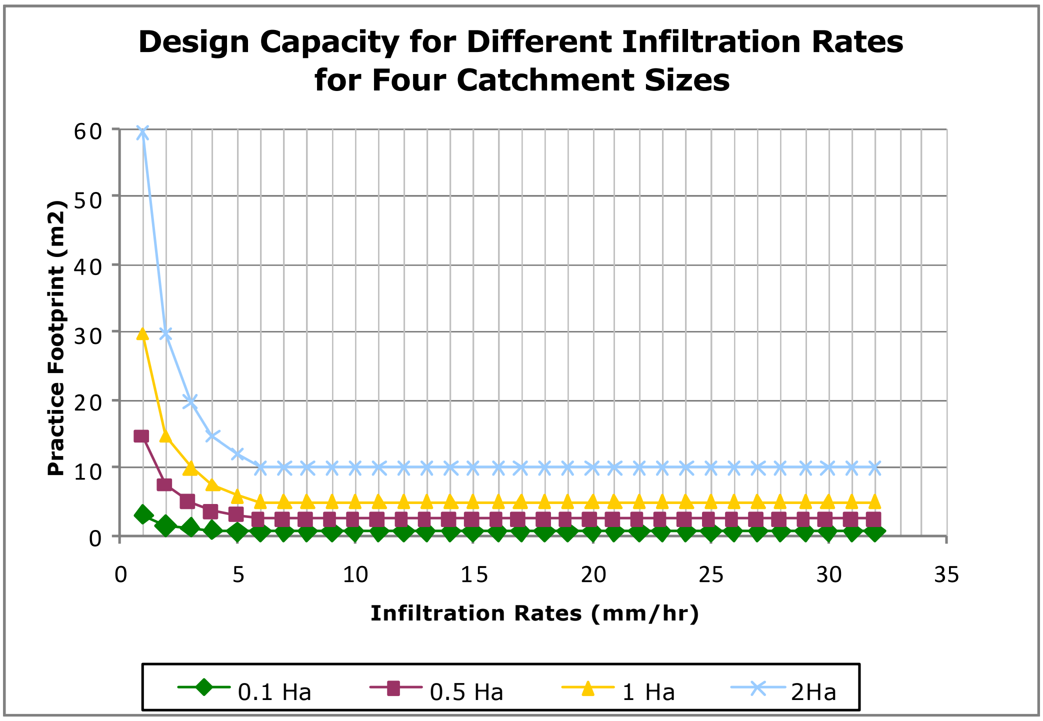

Figure 3: Variation of the design capacity with different infiltration rates for four catchment sizes (0.1Ha, 0.5Ha, 1Ha & 2Ha)

The gradient of each line changes between infiltration rates of 2-3 mm hr^{-1}. This point of inflection is known in the industry as the point of no economic return. This is the range where designing infiltration practices on sites with infiltration rates less than that of the range would cost more due to the size of the footprint required. This is also identified is most stormwater management design guidelines as the minimum infiltration rate. The estimated cost of infiltration practices for the same range of infiltration infiltration rates and four catchment sizes were analysed to validate this assumption. The results are graphically illustrated in Figure 4 below.

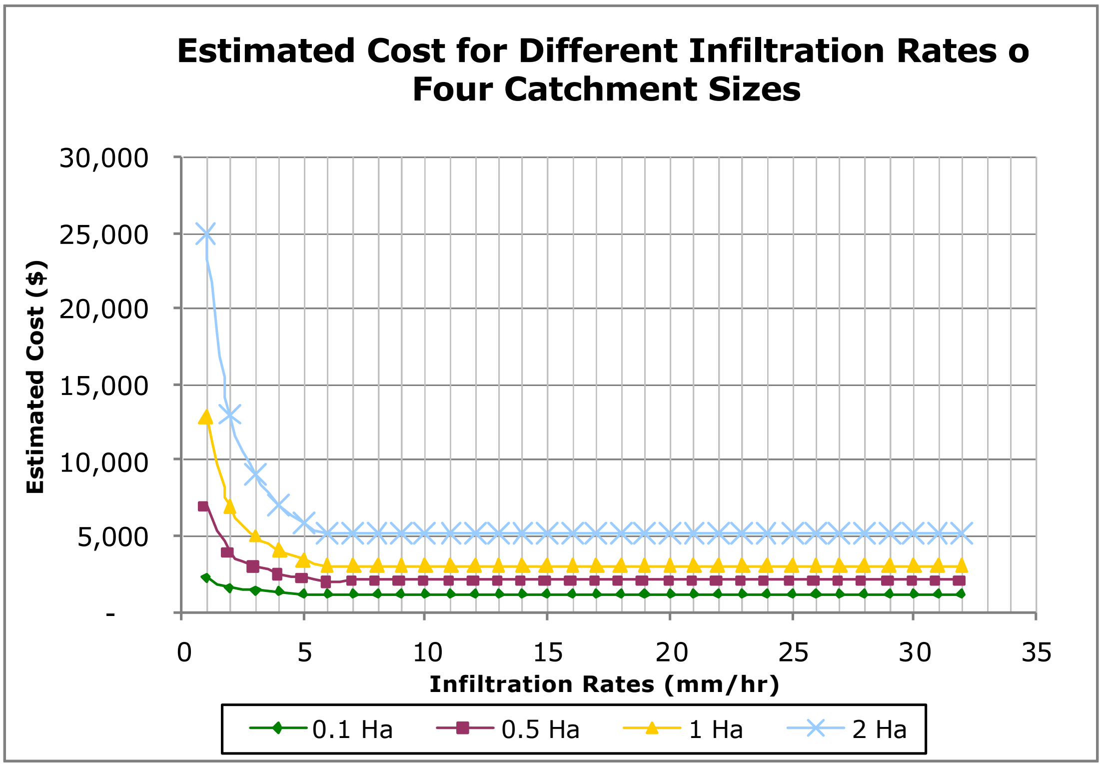

Figure 4: Estimated Cost of Infiltration Practice for different infiltration rates for four catchment sizes (0.1Ha, 0.5Ha, 1Ha & 2Ha)

The relationship is similar between design capacity and estimated cost for different infiltration rates of the four catchment sizes investigated. The relationships have a change in the gradients and then tapers to an asymptote. Both figures 3 & 4 demonstrate an obvious inflection point, which is between 2-3 mm hr^{-1}.

This point of no economic return increases as the size of catchment increases. This point is 2 mm hr^{-1} for the catchment up to 1.0 hectares. It increases to 3 mm hr^{-1} for the catchment of 2.0 hectares. This is the same on Figure 3 and 4. Hence, the minimum infiltration rate increases as the size of catchment increases.

This departs from the conventional assumption that the minimum infiltration rate constraint is only one value regardless of the size of the catchment draining into the infiltration practice. This analysis indicates that the minimum infiltration rate constraint increases as the size of the catchment increases. For catchments up to 1.0 hectares, the minimum infiltration rate is 2 mm hr^{-1}; while it increases to 3 mm hr^{-1} for the catchment of 2.0 hectares. The degree of increase was not investigated in this paper.

3 CONCLUSIONS

Infiltration in the clayey soils of the Waitemata formation is sometimes feasible as there are minor inclusions of Hydrological Group A permeability granular and allophonic soils. Auckland Council plans to identify areas of Hydrological Group A soils in landscapes on Waitemata Formation dominated by Group C soils.

Infiltration practices should also be widely used on sites above peat soils. They recharge the underlying groundwater and prevents subsidence.

Infiltration practices can often be used for disposal or reduction of stormwater runoff in clayey regions of Hydrological Group C soils by utilizing the void created. Temporary storage provided by the voids between the media in the practice can be utilized while it ex-filtrates to the surrounding soils. This size optimization will simplified on new design charts of GD01.

With the knowledge of contaminants fronts generally being located at the top 50cm of infiltration practices; it is practical to allocate at least 50cm between the base of the practice to the groundwater table to avoid remobilization of these contaminants into the surrounding soil and/or groundwater; and to ensure the longetivity of the infiltration practice's performance.

Groundwater contamination is unlikely for the common pollutants of stormwater runoff, with the exception of enteroviruses. Pre-treatment benefits are minimal except for eight pollutants. For runoff containing higher than usual levels of contaminants, such as those on a highly industrialised catchment; behaviour and decay of the pollutants through an infiltration practice needs to be investigated specifically for each site. Infiltration practices may not be appropriate for use on areas with high contaminant loading such as recycling centres gas stations, or brownfields with high soil contamination, due to increased risk of contaminating the groundwater.

Certain pollution risks are associated with infiltration practices, but many pollution risks are associated with the status-quo method, which is discharging to surface water bodies without any water quality control at all. Moreover, the benefits of infiltrating the rainfall-runoff into the ground and recharging the soils are profound.

Safety factor to accommodate for clogging has an upper limit of 2 on sites with fine particle size distribution. The design chart for refining this safety factor will be published in GD01.

The minimum infiltration rate for determining the feasibility of infiltration practices varies according to the size of the contributing catchment. The design and economic analyses carried out for a range of infiltration rates of four catchment sizes indicated that the minimum infiltration rate for catchments up to 1.0 hectares is 2 mm hr^{-1}; while it increases to 3 mm hr^{-1} for the catchment of 2.0 hectares.

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