Effectiveness of infiltration galleries in reduction of surface runoff and flooding in urban areas

Conference Paper · July 2019

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Efficacité des galeries d'infiltration dans la réduction des eaux de ruissellement et des inondations en milieu urbain

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RÉSUMÉ

Plusieurs fois, la conception des ouvrages de drainage pour la gestion des eaux pluviales (GDS) suit l'approche classique consistant à acheminer les écoulements en aval aussi rapidement que possible. Par conséquent, les zones basses et principalement urbaines pauvres souffrent de problèmes d'inondation. En guise de solution, les terres en amont peuvent être utilisées au maximum de leurs possibilités en intégrant des pratiques d'infiltration permettant à l'eau de s'infiltrer avant d'être rejetée en aval. Cet article est basé sur un projet de recherche d'études de cas réalisé à l'échelle d'une parcelle sur la colline de Makerere, à Kampala, en Ouganda. Il s'est concentré sur l'étude de l'efficacité de galeries d'infiltration bien conçues pour la réduction du ruissellement. Les résultats indiquent que l'utilisation de galeries d'infiltration peut entraîner une réduction de 40% du ruissellement généré. Les résultats suggèrent en outre que cette réduction dépend de la perméabilité du sol, de la taille du terrain disponible et de la taille et du nombre de tuyaux perforés encastrés utilisés pour la structure d'infiltration.

ABSTRACT

Many times the design of drainage structures for storm water management (SWM) follows the conventional approach of conveying flows downstream as quickly as possible. Consequently, low lying and mostly urban poor areas suffer flooding problems. As a solution, the land upstream can be utilized to its maximum potential by incorporating infiltration practices that allow water to infiltrate before it is released downstream. This paper is based on a case study research project carried out at a plot scale on Makerere hill, Kampala, Uganda focused on investigation of the effectiveness of appropriately designed infiltration galleries on reduction of surface runoff. Results indicated that use of infiltration galleries can result into a 40% percentage reduction in the generated runoff. The results further suggested that this reduction is dependent on the soil permeability, size of available land and the size and number of perforated embedded pipes used for the infiltration structure.

KEYWORDS

Infiltration galleries, soil permeability, surface runoff, urban flooding

1 INTRODUCTION

1.1 Background

Tropical countries like Uganda experience climate which is characterized by periods of short duration and high intensity rainfall during the wet season (Mugume & Butler, 2016). Rainfall is a major contributor of runoff waters that can cause flash floods in cities and urban areas due to insufficient capacity of existing drainage systems, uncontrolled urban development, inadequate solid waste management and climate change impacts among others. Mostly, the management of storm water in urban areas has adopted the conveyance-oriented approach that is focused on collection and rapid transportation of runoff to downstream receiving waters. However, storm water management could adopt a storage-oriented approach through detention and retention systems and engineered waterways such as infiltration trenches, swales, and storage basins among others. With this approach, storm water is stored, allowed to infiltrate, and slowly released into conventional drains or receiving waters. Fletcher, et al. (2014) stated the objectives of adopting sustainable drainage systems (SuDs) that is; quantitative control of surface runoff; improvement of runoff water quality; conservation of natural characteristics of bodies of water; and balance of hydrological variables in watersheds. Other advantages of incorporating infiltration structures within the SWM system include, space economy, minimizing disruption and damage to the downstream areas of urban centers and reduced cost and size of any downstream constructed conveyance facilities (Poleto & Tassi, 2012). However, these emerging approaches to stormwater management have not be extensively studied in tropical developing country cities.

1.2 Aims

The main aim of the study was to assess the impact on surface runoff reduction using infiltration galleries using a case study area in Kampala City, Uganda. The specific objectives included the following:

(i) Assessment of soil suitability for infiltrating water.
(ii) Investigation of land proportions (paved and unpaved) in relation to runoff generated and that available for infiltration respectively.
(iii) Design of an infiltration gallery
(iv) Estimating the resulting impact on reduction of surface runoff

1.3 Case study

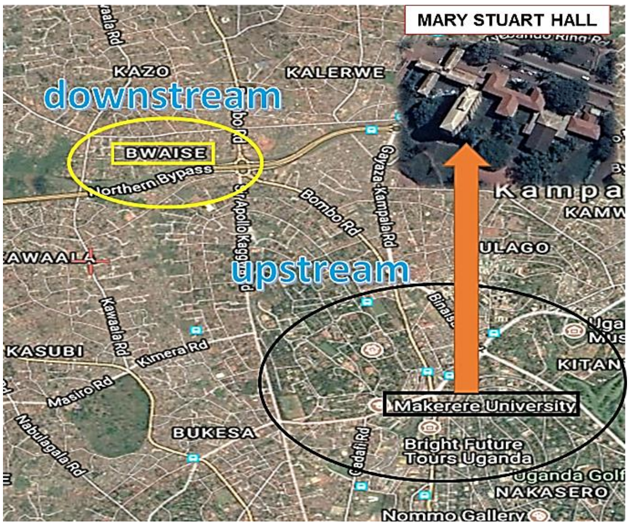

Figure 1-1 Entire study area (Google Maps)

Figure 1-1 presents the study area which consists of a building plot comprising a students' hall of residence (Mary Stuart Hall) in Makerere University. The university is one of the settlements on Makerere Hill, located upstream of a major flood hotspot (Bwaise) in Kampala. The student's hall of residence as shown is a series of detached buildings, where the total roof catchment of the buildings and total unpaved area, formed the basis of the case study.

2 METHODS

In order to meet the specific objectives stated in section 1.2 above, soil, land use and rainfall data was collected and analyzed. The collected and analyzed data was then used in the design of the infiltration structure.

2.1 Data Collection

3 test pits were dug to collect soil samples whose permeability was obtained through laboratory analysis. Land use data was obtained using ArcGIS software to obtain proportions of impermeable land (paved) that would be used to estimate the surface runoff, and permeable land (unpaved) for land requirement assessment for the infiltration gallery. Rainfall information was obtained from rain gauge records for the gauge stationed at the university. The gauge records were thereafter used in the estimation of runoff volume.

2.2 Data Analysis

The collected soil samples were analyzed using the Constant Head Test according to BS1377: Part 7: 1990. Rainfall data collected was used together with the area to estimate the peak volume of surface runoff (Q) using the rational method (Rugumayo, 2012).

Rainfall intensity (I) was obtained using Intensity Duration Frequency Curves (IDFs) by the Watkins and Fiddes procedure (Watkins and Fiddes, 1984) and a suitable time of concentration (T_c) for roofed areas was estimated using a procedure detailed by R.W.P May (2003) and calculated using Kirpich formula (Rugumayo, 2012).Following this procedure, the hall of residence was considered as a series of detached buildings, with each building having an independent roof catchment. The time of concentration for each was assessed considering total distance travelled from the remotest part of the roof area to the inlet of the infiltration gallery, through a gutter running from the roof and sides of the building. The highest value of time of concentration was thereafter adopted.

2.3 Design of infiltration structure

The design of the infiltration gallery followed a step by step procedure as reported in the Virginia Department of Transportation's BMP Design Manual of Practice (2013). The main design parameters as seen in *figure 3-1* include, storage volume, infiltration rate, trench depth and trench bottom area. For this type of structure, the maximum allowable time for infiltration is a constant limited to **72 hours**, and the recommended void ratio for the stone trench according to AASHTO specification measured by ASTM C-29, is **0.4** or 40%.

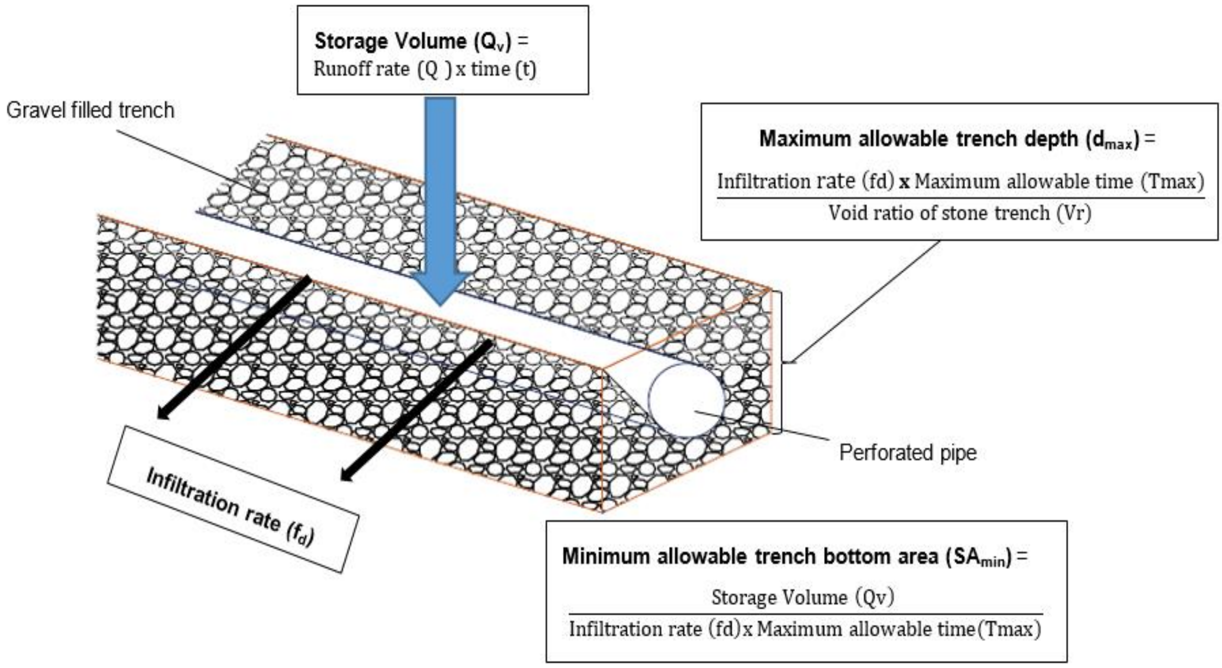

Figure 2-1 Design of Infiltration gallery

The trench depth and width of the land available guide the sizing of the pipe(s), in terms of diameter and length respectively. The pipe size should be chosen such that at least 75% of the embedded pipe depth is covered by the gravel backfill.

3 RESULTS AND DISCUSSION

3.1 Results

From *section 2* and *figure 2-1* above, below were the results obtained from the analysis and design;

Table 3-1 Table of results

Soil permeability	Sample 1: 2.35×10^{-7} m/s Sample 2: 4.98×10^{-7} m/s Sample 3: 4.56×10^{-7} m/s **Average:** 3.98×10^{-7} m/s
Roof catchment area (A)	2765.03 m^2
Unpaved/Lawn area	8637.18 m^2
Time of concentration (T_c)	1.5mins = 90s
Rainfall Intensity (I)	164 mm/hr
Runoff coefficient (C)	0.95
Rate of runoff (Q)	0.12 m^3/s
Storage volume (Q_v)	10.8 m^3
Design infiltration rate (f_d)	3.98×10^{-7} m/s
Maximum allowable trench depth (d_{max})	0.3 m

3.2 Discussion

Consider a plot of land measuring 10m by 10m. Assuming that 8, 0.25m diameter perforated pipes of length 10m spaced at 1m intervals are used for the proposed infiltration gallery, and assuming that volume of water stored by the pipes and allowed to infiltrate into the soil, is equivalent to the volume of pipes.

The volume of pipes, is therefore the cut off volume and is presented as;

Volume cut off = volume of pipes = n. $V_{pipe} = 8 \times \pi \times (0.25/2)^2 \times 10 = \underline{4\ m^3}$

In comparison to the storage volume (10.8 m^3), this system will reduce the generated roof runoff by at least 40%.

One of the key findings of this study was, presence of low permeability soils and in spite of this, a significant percentage reduction in generated roof runoff is achievable.

Another finding was with regard to the relationship and interaction among the design parameters which also has an effect on the overall percentage runoff reduction. The value can go even higher with soils having good infiltrability, because the depth requirement increases, implying that bigger sized pipes can be adopted, leading to more runoff stored within the infiltration structure. In addition, with good infiltrability, the area requirement reduces, which has a cost saving effect.

The relationship among these factors is summarized in the figure below.

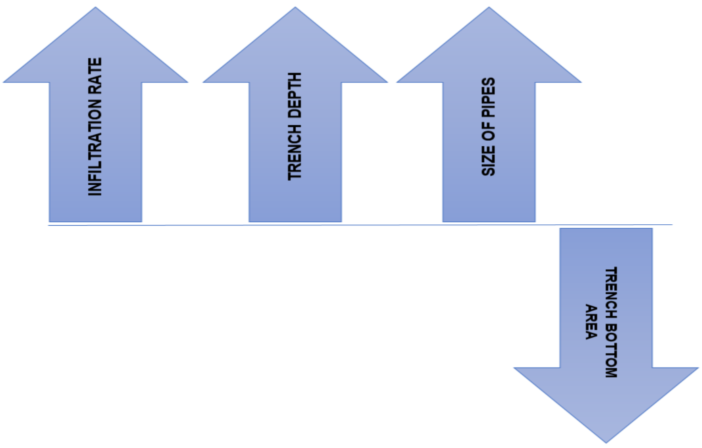

Figure 3-1 Relationship between the factors

3.2.1 Applicability and Layout

Figure 3-2 below, shows how the infiltration structure can be incorporated at plot scale, whereas *figure 3-3* shows a typical layout.

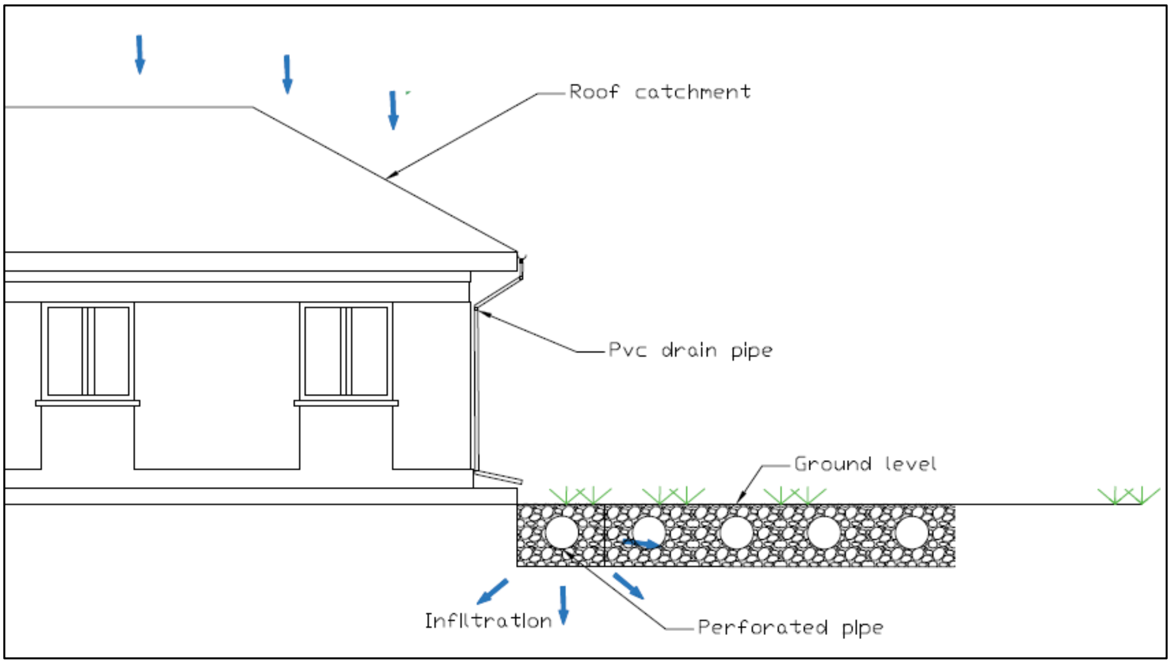

Figure 3-2 Application on plot scale

Figure 3-3 A perforated pipe system layout installation (New York City Department of Environmental Protection, 2012)

4 CONCLUSION

Infiltration galleries have traditionally been used below surface waters to divert water from rivers, creeks, and streams, or below the water table to collect ground water. Additionally, in storm water management on small scale, use of gravel filled trenches is often adopted, but without embedded perforated pipes. The significance of these pipes is to increase on the storage volume. Therefore, incorporating infiltration galleries in SWM systems on plot scale can significantly cut the runoff generated and subsequently reduce flooding downstream.

The results of the study show that for a significant percentage reduction of surface runoff, the soils should infiltrate easily, and the utilizable area should be greater than the runoff generating area. These are also the limiting factors of infiltration galleries. It is therefore a recommendation that infiltration galleries, especially in cases of low permeability soils be supplemented with other non-infiltration based technologies on plot scale such as, water harvesting (runoff capture and reuse), vegetated roofs, among others. Other recommendations to include improvement of low permeable soils with compost, and design for detention where it may be difficult to retain water.

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