Laboratory Testing Program for the Prediction of Rainfall Runoff from Soil Cover Systems

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ABSTRACT
Soil covers are commonly utilized to prevent Acid Rock Drainage (ARD). The design is governed by the net infiltration into the system. Infiltration prediction models require calibration using water balance controls. This requires rainfall runoff measurements, yet, such measurements are rarely available. Alternatively, accurate predictions of rainfall runoff for soil cover systems facilitate the calibration procedure.
A laboratory-testing program was developed to formulate a reliable model to predict rainfall runoff for soil covers. Both single layer and multi-layer soil profiles were tested in a specially designed rainfall simulator apparatus. Simulated precipitations of different intensities on different initial conditions were conducted. Runoff volumes were measured simultaneously with rainfall volumes. In addition, a number of instruments were installed to monitor changes in matric suction and volumetric moisture content as the wetting fronts propagated.
Results suggest that rainfall runoff rate is primarily governed by the applied rainfall intensity and saturated hydraulic conductivity in the case of saturated soil surfaces, whereas it is governed by the applied rainfall intensity and infiltration capacity for unsaturated soil profiles.

RÉSUMÉ
Les sols de recouvrement sont couramment utilisés pour prévenir et atténuer le drainage rocheux acide (ARD). La procédure de conception dépend en premier lieu de l'infiltration nette dans le système. Les modèles de prédiction de l'infiltration exigent un étalonnage précis. Cela nécessite que les mesures du ruissellement pluvial soient disponibles. Par contre, ces données sont rarement disponibles. Alternativement, les prévisions précises du ruissellement pluvial pour les systèmes de sols de recouvrement facilitent la procédure d'étalonnage. Un programme d'essai de laboratoire a été élaboré pour réaliser un modèle fiable permettant d'estimer le ruissellement pluvial pour les sols de recouvrement. Des sols à une et à plusieurs couches ont été testés dans un simulateur de précipitations spécialement conçu. Des précipitations de différentes intensités ont été simulées à différentes conditions initiales. Les volumes de ruissellement ont été mesurés simultanément avec les volumes de précipitations. De plus, un certain nombre d'instruments ont été installés pour contrôler les changements de succion matricielle et la teneur en eau volumétrique à mesure que le front d'humidité avance. Les résultats expérimentaux préliminaires montrent que le taux de ruissellement pluvial est d'abord contrôlé par l'intensité de précipitation appliquée et par la conductivité hydraulique dans le cas d'une surface de sol saturée, et qu'il est contrôlé par l'intensité de précipitation appliquée et la capacité d'infiltration dans les sols non saturés.

1 INTRODUCTION

Soil covers are designed as engineered barrier systems to restrict water and oxygen contact with sulphide minerals in mine waste. For the past few decades, these systems have proven efficiency in the following categories listed by O'Kane and Wels (2003): contaminant release control (through control of infiltration), establishment of a growth medium for landscaping purposes, chemical stabilisations of acid forming mine waste (through restricting oxygen diffusion), and dust and erosion control.

There are four well-known types of cover systems depending chiefly upon the climate regime in the prospect construction area and the nature of the waste. These types include water covers, 'conventional low hydraulic conductivity' covers, capillary barrier covers, and 'store and release' covers. According to the GARDGuide (The International Network for Acid Prevention (INAP) 2009), the last three types previously mentioned are referred to as 'dry covers'.

Generally, the design of dry covers is governed by the amount of net infiltration into the system, which is referred to as 'net percolation'. The design requires a detailed soil-atmosphere modelling to be completed using site-specific models to predict net infiltration into the system. Nevertheless, these models require proper calibration using water balance equations. Thereby, runoff measurements have to be available since rainfall runoff can be the largest component of the water budget that directly influences the amount of net infiltration.

Furthermore, in the case of soil atmospheric modelling, prediction of both evaporation (Penman 1948 and Wilson et al 1994), and infiltration (Green and Ampt 1911; Horton 1939; Philip 1957; Mein and Larsen 1978) are well addressed in the literature. Little attention, however, has been paid to predicting rainfall-runoff. Available models for predicting rainfall runoff at the field scale are rare and require improvements (Schmocker-Fackel et al. 2007, Benson, 2010 and Jubinville 2013).

In this paper, a laboratory-testing program was established to investigate the relationship between laboratory-induced rainfall and the subsequent runoff response in soil cover systems. The laboratory program aims to identify appropriate variables that control rainfall runoff for both saturated and unsaturated soil. Both a single layer (conventional low hydraulic conductivity covers) and multi-layer (capillary barrier covers) systems were investigated. The various types of instrumentations are described, and the experimental results of simulated rainfall runoff tests are presented and discussed.

2 DESCRIPTION OF THE LABORATORY MODEL

The laboratory study was conducted using a rainfall simulator apparatus that was specially designed and constructed for this study. The main components of the simulator were a water circulation system, a spraying system, and a flume to accommodate the soil and the measuring devices. The measuring devices were installed in the sidewalls of the flume in order to monitor changes in volumetric moisture content and matric suction.

Prior to the design of the apparatus, a comprehensive literature review was conducted to obtain the sufficient dimensions of the flume, the most appropriate location of instruments, and the appropriate soils for the capillary barrier system. Furthermore, the literature review investigated the factors that govern the runoff phenomenon when tested using rainfall simulators. These include, precipitation characteristics, initial conditions, slope gradient effects, vegetation cover, material properties, and scale effects.

2.1 Water Circulation System

The water circulation system consisted of a water reservoir of one cubic meter capacity. Inside the reservoir, a submersible constant-rate pump directed the water from the reservoir to the spraying arm by a set of PVC pipes one inch in diameter. The pump had to provide adequate constant pressure to overcome both head losses and friction losses in the pipes, and to operate the nozzles properly.
In order to ensure proper functioning of the pump, when the rainfall intensity is less than the capacity of the pump, an overflow system was designed to direct drainage back to the water reservoir. The water circulation system is illustrated in Figure 1.

2.2 Spraying System

The spraying system consisted of a number of nozzles of different orifices. Each set of nozzles produced different rainfall intensity. The configuration of the spraying system is shown in Figure 2. The following components are shown: a control valve to regulate inflow into the system, a pressure gauge to monitor water pressure, a flowmeter to measure volume and rate of applied rainfall, a set of manifolds that have several appropriate openings for the intended nozzles, and a release valve at the end of the arm for de-airing the system.

The most appropriate type of nozzles for this study was the type that provides an even distribution of medium-sized raindrops throughout a rectangular spray pattern. The height of the spraying arm was obtained by iteration trials to achieve the correct spray pattern, the optimum rainfall coverage of the plot, and the maximum uniformity of simulated rainfall. Similarly, the spacing between the nozzles was obtained to eliminate overlapping of raindrops and to ensure concordant coverage of the plot.

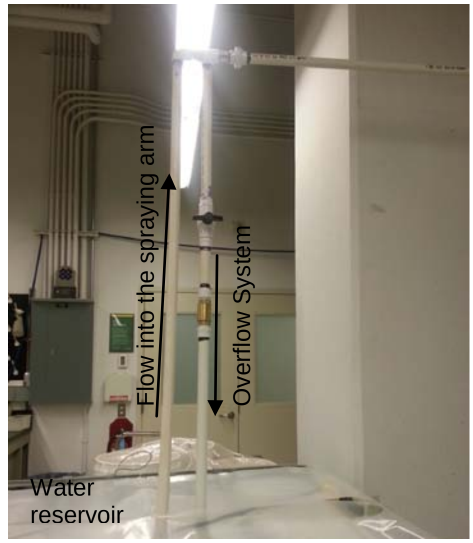

Figure 1. A view of the water circulation system and overflow system.

Figure 2. A view of the spraying system: A: controlling valve; B: pressure gauge; C: flowmeter; D: nozzles; E: de-airing valve.

2.3 Flume and Measuring Devices

The soil was accommodated inside a specially designed flume, which was constructed of 10 mm thick Plexiglas® sheets to enable observing the propagation of the wetting-fronts as tests progressed. The dimensions of the box were 90 cm in length, 30 cm in width, and 35 cm in height. The flume had a runoff collection outlet at the top, and a one-inch drainage opening equipped with a regulating valve at the toe as illustrated in Figure 3. The flume was at one percent slope at all times during the tests.

Figure 3. A view of the flume.

A number of openings were drilled along the sidewalls of the flume in order to allow for instrumentation. The instruments used in this study included Time Domain Reflectometry (TDR) (Cambell-CS640) probes and (UMS-T5) Tensiometers for measuring volumetric moisture content and matric suction, respectively. Instruments were distributed evenly at two elevations in the flume. A schematic of the arrangement of measuring devices is illustrated in Figure 4.

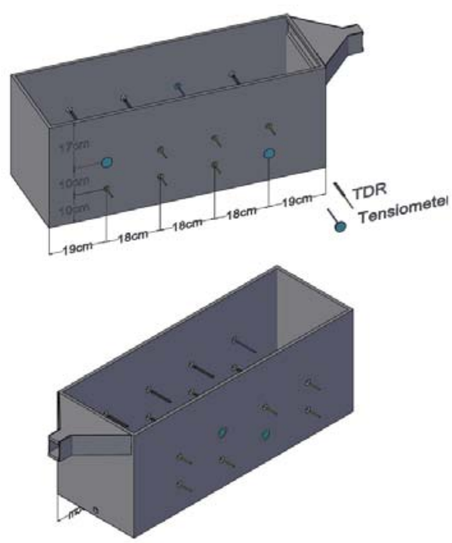

Figure 4. Arrangement of measuring devices.

Measuring devices were installed and secured in place through the openings in the sidewalls of the flume before placement of soil. These sensors (TDR probes and tensiometers) had to be in good contact with the soil in order to produce good quality measurements.

Prior to installing the measuring devices, each device was carefully calibrated in order to ensure accuracy of data. Similarly, the uniformity of each set of simulated precipitations was assessed based on Christensen Uniformity coefficient CU[1]. The results for CU ranged between 74% and 85%.

A cuboid enclosure (made of 2 mm thick Plexiglas® sheets) was placed directly on top of the flume in order to ensure a complete water budget during the tests. Water tightness was a high priority; hence, the entire structure was conservatively designed and constructed in order to avoid leakage. All seams and joints between the flume and the closure sheets were carefully sealed with silicone and allowed to cure before testing took place. A view of the overall setup is illustrated in Figure 5.

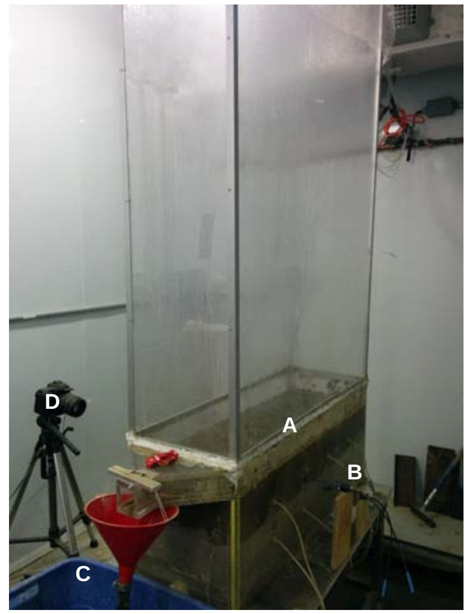

Figure 5. A view of laboratory setup for the experiments: A: flume and water closure; B: measuring devices; C: runoff collection tank above weight balance; D: camera for recording wetting front propagation through unsaturated profile.

3 MATERIALS

Two types of soil were chosen for testing the simulated rainfall runoff responses; namely, Devon silt and Suncor Tailings Beach sand. The corresponding particle size distribution for each soil is illustrated in Figure 6. Two different profiles were considered; a single layer profile of Devon silt (low hydraulic conductivity cover) and two-layer profile of silt overlaying sand (capillary barrier cover). According to Fredlund et al 2012, the contrast in hydraulic properties between the fine and the coarse material in the capillary barrier system forms hydraulic impedance at the interface, thereby, limits downward infiltration into the coarse layer.

Prior to conducting the simulated rainfall runoff tests, hydraulic characteristics of both soils were thoroughly investigated. Eight column tests were prepared for each type of soil in order to determine the soil infiltration capacity and the corresponding saturated hydraulic

[1] Christensen Uniformity Coefficient =100* $\left[1-\frac{\Sigma|\bar{x}-x_i|}{\Sigma x_i}\right]$

$\bar{X}$ is the arithmetic mean of all equally measured observations of magnitude x_i

conductivity at different densities. A summary of soil characteristics for each type of soil is presented in Table 1

Table 1 Soil characteristics

Characteristics	Dry density (g/cm^3)	Devon Silt (m/s)	Sand (m/s)
Saturated hydraulic conductivity (m/s)	1.46	6.12E-08	2.22E-03
	1.5	3.80E-08	1.25E-03
	1.54	3.69E-09	9.60E-04
	1.6	1.93E-09	9.54E-04
Infiltration Capacity[2] (m/s)	1.46	1.04E-07	2.00E-04
	1.5	4.80E-08	1.95E-04
	1.54	3.20E-08	1.90E-04
	1.6	2.40E-08	1.81E-04

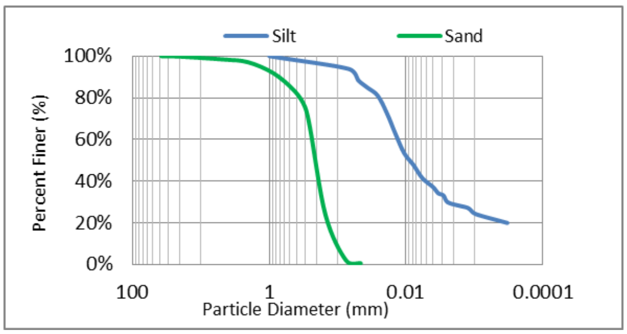

Figure 6. Particle size distribution of the tested soils.

In order to maintain homogeneity of each profile, the soil was placed using 'funnel deposition' method. A specially designed funnel was raised by a mechanical movement using a wall mounted hand winch and a set of double pulleys as illustrated in Figure 7.

Placement of soil inside the flume was performed by initially placing the spout of the funnel at the bottom of the flume. The funnel was filled with soil, and then slowly raised along the flume's axes of symmetry. This placement procedure ensured that the soil was deposited in a low-energy state without any drop height.

The velocity of raising the funnel controlled the density of the soil. The faster the funnel was raised, the denser the soil got (although still without a drop height). In order to eliminate any bias in placement of soil the velocity of raising the funnel was sustained the same throughout all tests as much as possible.

Figure 7. A view of the placement procedure setup.

4 METHODS

The testing program included a series of experiments in order to investigate the rainfall runoff response of different types of engineered soil barriers under initial conditions, and different precipitation rates.

A fundamental point to identify is the difference between saturated and unsaturated profiles in both nature and engineering response. Therefore, separate series of tests were carried out for each type of initial saturation state of the soil.

Although both saturated and unsaturated profiles were deposited using the same funnel instrument mentioned earlier, the primary difference was that the saturated profiles were deposited as slurry while the unsaturated profiles were deposited dry. The boundary conditions were maintained the same in both scenarios. In addition, the propagations of the wetting-fronts in the unsaturated profiles were monitored.

The criteria for experiments carried out on both silt profiles and capillary barrier profiles were identical. Overall, six different precipitation rates were applied for three days (eight consecutive hours each day) on each profile. Table 2 summarizes the different stages and controlling parameters in the testing program.

During each test, the volumetric moisture content and matric suction within the soil profiles were recorded at two-minute interval. Furthermore, cumulative volume and rate of both rainfall and runoff were measured simultaneously every 15 minutes. Using these measurements, plots of rainfall, runoff, and infiltration cumulative volumes versus time were established.

The volume of infiltration was concluded using equilibrium equation for the water balance components, which can be expressed as follows:

$$\text{Surface Infiltration} = P - R - AE \qquad [1]$$

[2] The value presented here, as Infiltration capacity is the value at which the infiltration capacity function reached a constant value with time.

The main components of water balance equation are cumulative precipitation P, cumulative runoff R, and actual evaporation AE. Complete water budget calculation were possible during each test since the tests were conducted in a controlled environment where no evaporation or leaks of any kind were allowed, thus Equation 1 can be reduced as follows:

$$\text{Surface Infiltration} = P - R \quad [2]$$

Table 2 Stages of the testing program applied on both silt profile and capillary barrier profile.

Initial Condition	Stages					
	40 mm/hr	55 mm/hr	90 mm/hr	140 mm/hr	190 mm/hr	260 mm/hr
saturated silt	55 hrs	33 hrs	33 hrs	130 hrs	80 hrs	33 hrs
Unsaturated silt	55 hrs	103 hrs	103 hrs	33 hrs	33 hrs	33 hrs
Unsaturated CB profile	103 hrs	55 hrs	55 hrs	55 hrs	55 hrs	55 hrs

5 RESULTS AND DISCUSSION

The results of the laboratory experiments presented in this paper can be grouped into the following categories: water balances, rate statistics, and volumetric moisture content and matric suction profiles.

5.1 Water Balance

Typical measured components of the water balance equation in the saturated silt profiles, unsaturated silt profiles, and unsaturated capillary barrier profiles are presented in Figure 8, Figure 9, and Figure 10, respectively. In the saturated silt profiles, results were consistent for all precipitation rate scenarios. In all cases, about 95%-98% of the entire applied rainfall volume eventually converted into runoff with very little infiltration.

Nevertheless, lower percentages of runoff were observed in the unsaturated silt profiles, where 60-80% of the entire applied rainfall eventually converted into runoff. It was observed that the increase in runoff percentage was proportional to the precipitation rate.

In contrast to the unsaturated silt profiles, higher percentages of runoff were observed in the unsaturated capillary barrier profiles. Measured cumulative runoff volumes ranged between 70% and 80% of the overall applied rainfall. Similarly, the increase in runoff percentage was proportional to the increase in precipitation rate.

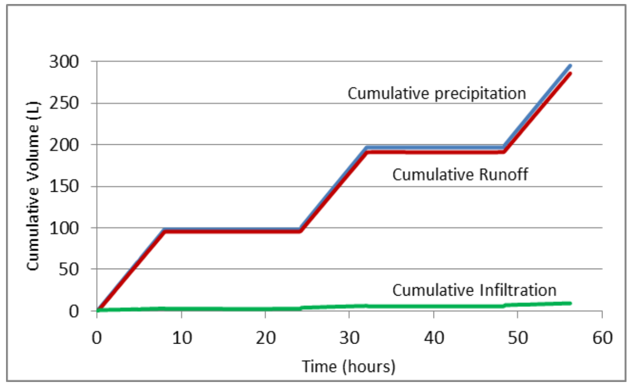

Figure 8. The measured components of water balance versus time in the saturated silt profile at 40 mm/hr rainfall intensity.

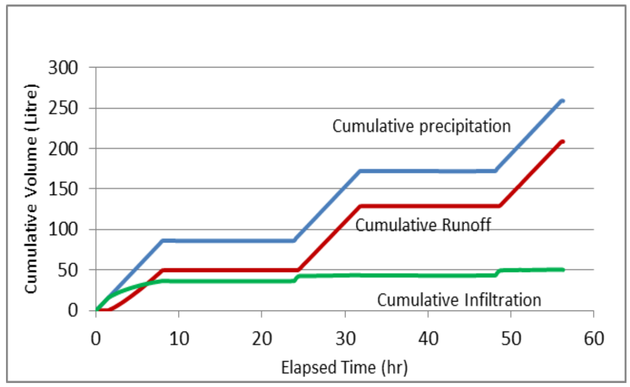

Figure 9. The measured components of water balance versus time in the unsaturated silt profile at 40 mm/hr rainfall intensity.

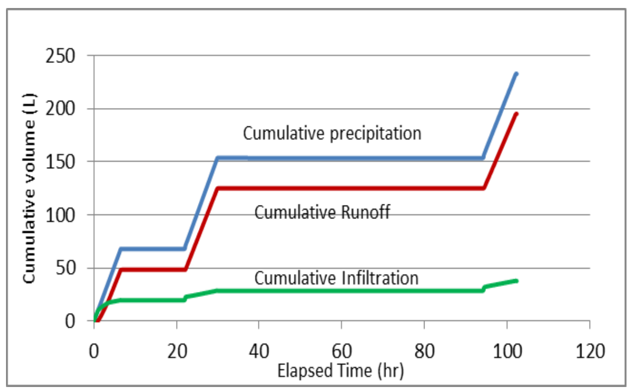

Figure 10. The measured components of water balance versus time in the unsaturated capillary barrier profile at 40 mm/hr rainfall intensity.

5.2 Rate Statistics

Typical variation in the rate of precipitation, runoff and infiltration with time are illustrated in Figure 11, Figure 13, and Figure 14 for saturated silt profile, unsaturated silt profile, and unsaturated capillary barrier profile, respectively.

In the saturated silt profiles, the infiltration rate remained almost unchanged as the time progressed during each test as seen in Figure 11. This observation holds true in all scenarios of various precipitation rates. Nevertheless, the infiltration rate seemed to increase slightly as the precipitation rate increased (as seen in Figure 12).

The runoff rate, on the other hand, appeared to remain constant throughout each test (Figure 11). However, upon comparing different sets of tests (different rainfall intensities) to each other, the runoff rate increased from one experiment to another in accord with the applied rainfall intensity (Figure 12).

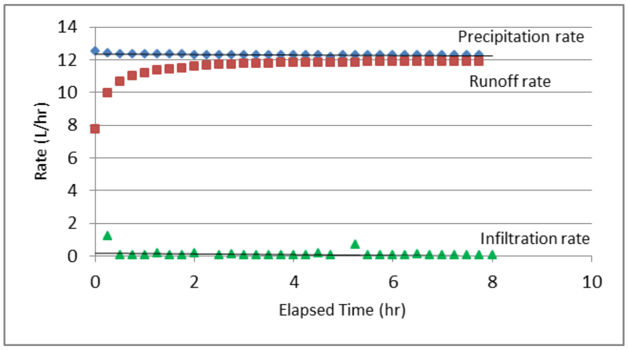

Figure 11. The measured rate of precipitation, runoff, and infiltration versus time for the saturated silt profile at 40 mm/hr rainfall intensity.

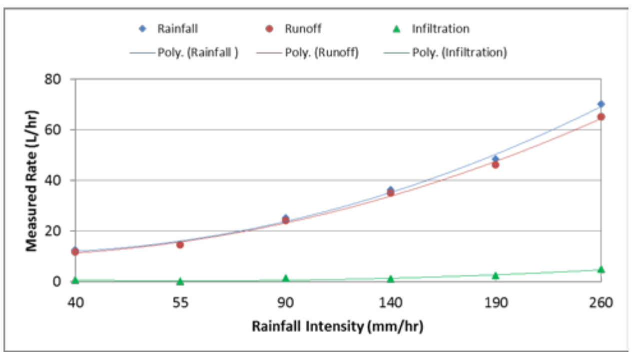

Figure 12. Change in infiltration rate with the change in applied precipitation rate for the saturated silt profile.

Conversely, in the unsaturated profiles, initially, the entire amount of precipitation infiltrated into the soil (in both silt and capillary barrier scenarios). Once runoff was produced, the rate of infiltration decreased non-linearly with time as seen in Figure 13 and Figure 14 for unsaturated silt and unsaturated capillary barrier profiles, respectively. This pattern is consistent with the infiltration capacity function of the soil. Furthermore, this observation was a common scheme in all of the experiments conducted on unsaturated profiles. In other words, the infiltration curve remained almost the same regardless of the precipitation rate. However, the runoff rate increased from one set of tests to the other in accord with the applied rainfall intensity. In addition, the 'time to runoff' decreased as the rainfall intensity increased from one set of tests to the other.

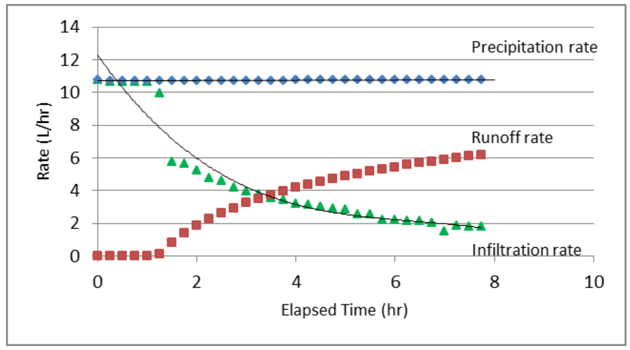

Figure 13. The measured rate of precipitation, runoff, and infiltration versus time for the unsaturated silt profile at 40 mm/hr rainfall intensity.

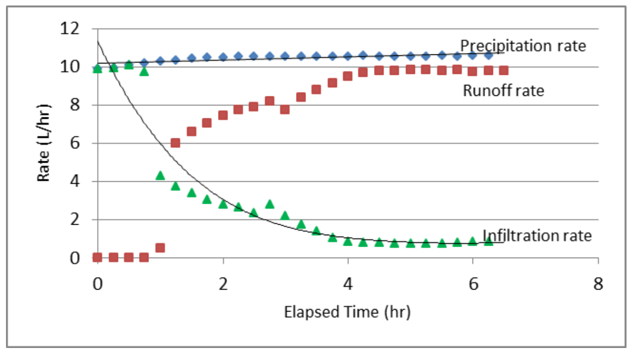

Figure 14. The measured rate of precipitation, runoff, and infiltration versus time for the unsaturated capillary barrier profile at 40 mm/hr rainfall intensity.

5.3 Changes in Volumetric Moisture Content and Matric Suction

Typical measured changes in volumetric moisture content as a function of time in unsaturated silt profiles and unsaturated capillary barrier profiles are illustrated in Figure 15 and Figure 16, respectively. Similarly, the changes in matric suction as a function of time in unsaturated silt and unsaturated capillary barrier profiles are presented in Figure 17 and Figure 18, respectively.

The volumetric water content variations in the silt profiles (Figure 15) and the capillary barrier profile (Figure 16) obtained at the same precipitation rate (40 mm/hr), clearly demonstrate the capillary barrier effect. This is manifested in two distinct manners: First, the time required for the wetting front to propagate into the lower elevation (sand layer) in the capillary barrier profiles is considerably longer than that in the silt profiles. Secondly, the total water storage in the lower elevation (sand layer) is considerably less than that of silt profiles at the same elevation (please refer back to Figure 4 for reference).

Similarly, upon comparing Figure 17 to Figure 18, this 'capillary barrier' effect is much more pronounced when considering the matric suction measurements[3]. These figures show clearly that the time required for the wetting front to propagate into the sand layer in the case of capillary barrier profiles was triple the time required in the case of silt profiles (although the same precipitation rate was applied).

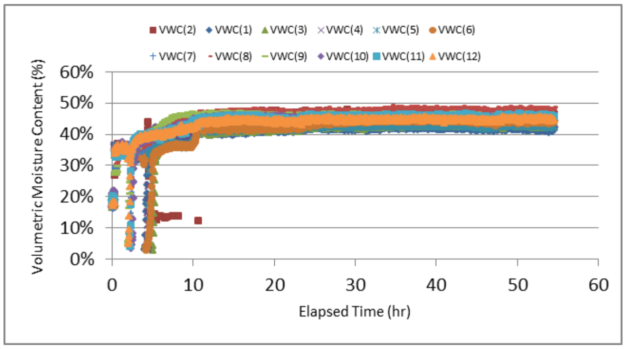

Figure 15. The volumetric moisture content[3] variation with time in the unsaturated silt profile at 40 mm/hr rainfall intensity.

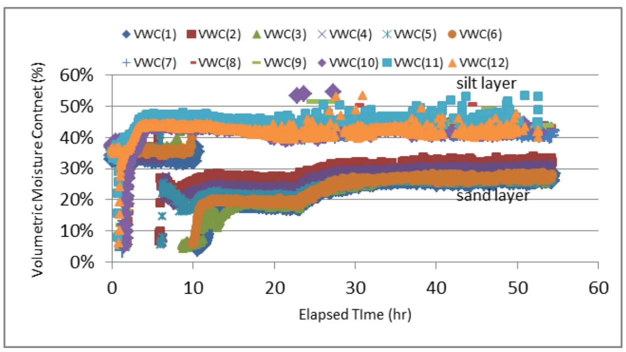

Figure 16. The volumetric moisture content[3] variation with time in the unsaturated capillary barrier profile at 40 mm/hr rainfall intensity.

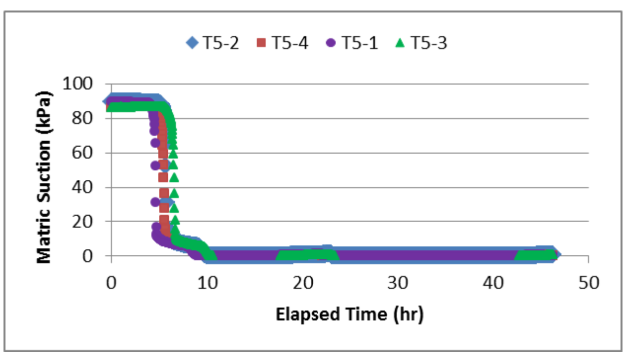

Figure 17. The matric suction[3] variation with time in the unsaturated silt profile at 40 mm/hr rainfall intensity.

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[3] TDR probes 1 through 6 and Tensiometers T5-1 and T5-4 are located in the silt layer in the capillary barrier profile, whereas TDR probes 7 through 12 and TensiometersT5-2 and T5-3 are located in the sand layer.

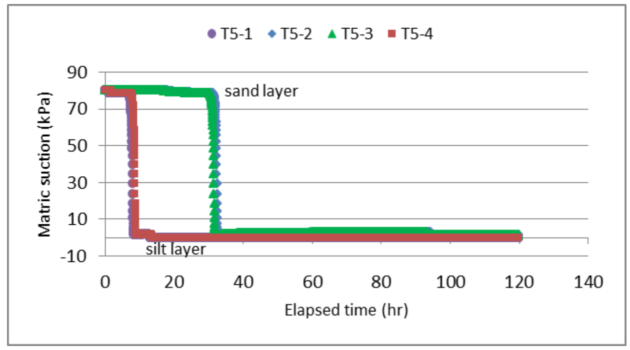

Figure 18. The matric suction[3] variation with time in the unsaturated capillary barrier profile.

5.4 Relationship between Rainfall and Runoff Volumes

Results suggest a linear positive correlation between the applied rainfall volume and the subsequent runoff volumes regardless of the applied precipitation rate in all of the profiles tested as seen in Figure 19, Figure 20, and Figure 21.

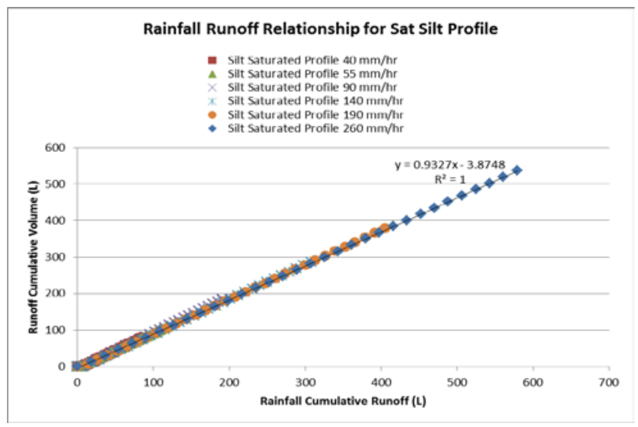

Figure 19. Rainfall Runoff relationships in the saturated silt profile for each precipitation rate.

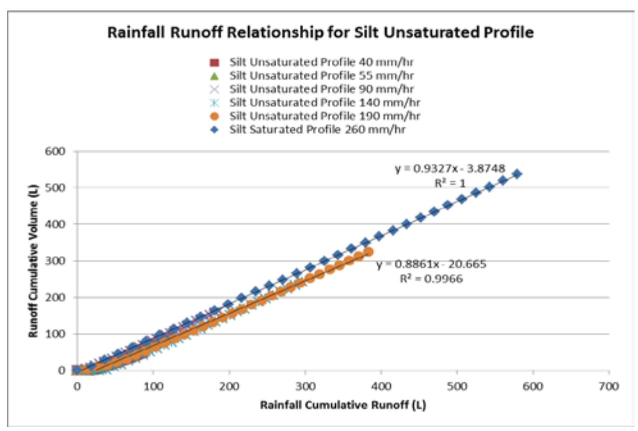

Figure 20. Rainfall Runoff relationships in the unsaturated silt profile for each precipitation rate.

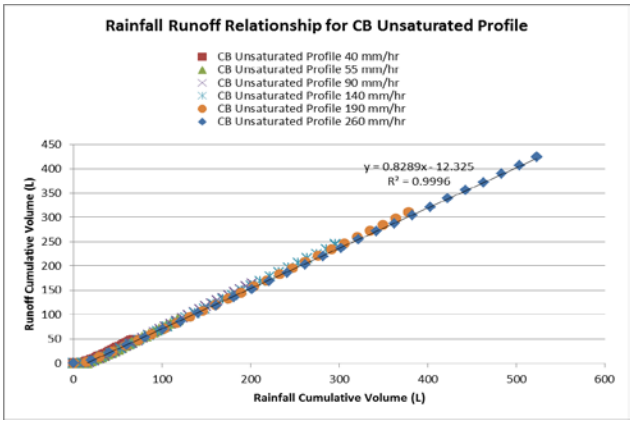

Figure 21. Rainfall Runoff relationships in the unsaturated capillary barrier profile for each precipitation rate.

6 CONCLUSIONS

Surface runoff can be the most critical component of the water cycle that directly influences infiltration into soil covers systems, thus controlling their design. In this paper, the rainfall runoff phenomenon was studied in a laboratory program conducted, separately, on saturated and unsaturated soil profiles. Six different precipitation rates were applied on both low hydraulic conductivity (silt) covers and capillary barrier covers systems.

In summary, in all saturated silt profiles, about 95%-98% of the entire applied rainfall volume eventually converted into runoff with very little infiltration. The rates at which runoff occurred were found to remain constant with time throughout each test. However, as precipitation rate increased from one test to the other the runoff rate seemed to follow that increase. Overall, runoff rate seemed to be primarily governed by precipitation rate and the saturated hydraulic conductivity of the soil.

On the other hand, in unsaturated silt profiles, between 60 and 80% of the applied rainfall eventually converted into runoff. Higher runoff percentages correspond to higher applied precipitation rates. Furthermore, runoff rates seemed to increase nonlinearly with time, proportional to the applied precipitation rate. The measured infiltration rates were consistent with the soil infiltration-capacity function. Overall, in unsaturated silt profiles runoff rate seemed to be chiefly governed by the precipitation rate and the infiltration capacity. Furthermore, Capillary barrier unsaturated profiles seemed to promote higher runoff total volumes (and less infiltration) compared to the corresponding silt profiles at the same conditions. About 70% to 80% of the overall applied rainfall converted to runoff. Moreover, the rate of runoff was found to be higher than that in the silt profiles. Similarly, the runoff rates seemed to increase non-linearly with time in each test, though at higher rates compared to those in the corresponding unsaturated silt profiles.

In essence, the data obtained in this study were found to be both consistent and adherent to saturated and unsaturated soil behaviour. Furthermore, these data suggest a linear correlation between the applied precipitation volume and the subsequent runoff volume in a rather predictable. Therefore, it is possible to develop a model to predict rainfall runoff based on precipitation data and measurable soil properties. Additional research to formulate such model, with the help of numerical simulations, is currently being developed.

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REFERENCES

Benson, C.H. 2010. Prediction in geoenvironmental engineering: Recommendations for reliable predictive modeling. In GeoFlorida 2010: Advances in Analysis, Modeling and Design, Reston, VA, USA., pp. 1-14.

Beven, K., J. 2012. Rainfall-runoff modelling: The primer. Jon Wiley & Sons Ltd., Oxford, UK.

Fredlund, D.G. and Rahardjo, H. 1993. Soil mechanics for unsaturated soils. John Wiley & Sons Inc., USA.

Fredlund, D.G. Rahardjo, H. and Fredlund M. D. 2012. Unsaturated Soil mechanics in engineering practice. John Wiley & Sons Inc., USA.

Green WH, Ampt G. 1911. Studies on soil physics, 1. The flow of air and water through soils. The Journal of Agricultural Science 4: 1–24.

Jubinville, S. K. 2013. Prediction of Rainfall Runoff for Soil Cover Modelling. M.Sc., University of Alberta, Canada.

Horton, R. 1935. Surface Runoff Phenomena. Horton Hydrologic Laboratory Publication, USA.

Mein, R.G. and Larson, C.L. 1973. Modeling infiltration during a steady rain, Water Resources Research, 9(2): 384-394.

O'Kane, M., and Wels, C. 2003. "Mine Waste Cover System Design – Linking Predicted Performance to Groundwater and Surface Water Impacts." 341-350.

Penman, H.L. 194 Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London A(194), S. 120-145.

Philip, J.R. 1957. The theory of infiltration: 1. the infiltration equation and its solution. Soil Science, 83: 345-357.

Schmocker-Fackel, P. and Naef, F. and Scherrer, S. 2007. "Identifying runoff processes on the plot and catchment scale." Hydrology and Earth System Sciences, 11 891- 906.

Stone, J.J., Paige, G.B., and Hawkins, R.H. 2008. "Rainfall intensity-dependent infiltration rates on rangeland rainfall simulator plots." Transactions of the ASABE, 51(1): 45-53, 51(1)

Tami, D., Rahardjo, H., Leong, E., and Fredlund, D. G. 2004. "Design and laboratory verification of a physical model of sloping capillary barrier." Canadian Geotechnical Journal, 41 814-830.

The International Network for Acid Prevention (INAP). 2009. Global acid rock drainage guide (GARD guide) [online]. Available from http://www.gardguide.com/ [cited 02 2015].

Wilson, G.W., Fredlund, D.G., and Barbour, S.L. 1994. Coupled soil-atmosphere modelling for soil evaporation. Canadian Geotechnical Journal, 31(2): 151– 161. doi:10.1139/t94-021.

Wilson, G.W. 2006. The application of cover systems for mine closure - are we doing it right? In First International Seminar on Mine Closure, Perth, Australia, pp.17.045631-42.