Simplified Hydraulic Conceptual Model for Stormwater Treatment Bioretention Basin

by Isri Ronald Mangangka

Simplified Hydraulic Conceptual Model for Stormwater Treatment Bioretention Basin

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Abstract: A bioretention basin performs as a pollutant removal device using filtration as the main mechanism, supported by evapotranspiration, absorption and biotransformation. This is in addition to attenuation of runoff peak flow and reduction of runoff volume through detention and retention [1]. Past studies have reported that pollutant concentration reduction in bioretention basins is poor for a range of pollutant species particularly for nutrient species [1][2][3][4]. However, a substantial reduction in outflow volume can lead to significant reduction in pollutant loads [5].

A range of studies have been conducted for assessing bioretention basin performance and hydraulic and pollutant removal processes [6][7][8][9][10][11][12]. However, most of the past field studies have been conducted to evaluate the long term treatment performance while most of the studies which focused on developing an in-depth understanding of processes have been conducted using laboratory-scale models [13][14][15]. This has resulted in knowledge gaps relating to field performance and associated pollutant removal processes in relation to bioretention basins.

As a part of this study, a selected operating bioretention basin was evaluated for its hydraulic processes. This paper focuses on the development of bioretention basin hydraulic conceptual model. The model utilises a range of conceptual approaches and empirical equations. The model replicates the infiltration processes through the filter media and water movement within the system from the inlet to the outlet. The model was successfully calibrated using on-site recorded inflow and outflow data.

Keywords: Bioretention Basin, bioretention model, hydraulic conceptual model

1. INTRODUCTION

Hydraulic processes play an important role in stormwater pollutants removal by bioretention basins. As pointed out by numerous researchers (for example [6] and [8]), hydraulic factors such as residence time and outflow discharge are the most critical. These factors can be obtained using design configurations in event-based assessment. However, in-depth assessments which require variation of these factors within an event require a modelling approach to generate the relevant hydraulic factors. Due to this reason, a conceptual model was developed to estimate hydraulic factors in short time steps. The developed model contains a range of conceptual approaches and empirical equations. The model was developed to replicate stormwater infiltration through the filter media, and water movement from the drainage layer exiting the bioretention basin through the perforated pipes.

2. THE PRINCIPLES AND ASSUMPTIONS ADOPTED FOR THE MODEL

Hydraulic characteristics of a bioretention basin are primarily based on infiltration and percolation of stormwater through the filter media and can be classified as typical subsurface flow. Subsurface flow can be best replicated by 3-dimensional flow models, which are very complex and often requires numerical analysis [16]. To reduce this complexity, a range of assumptions was made, primarily to convert a 3-dimensional flow system to a 1-dimensional flow system. In the conceptual model, the bioretention basin was divided into a number of equal zones. A trial and error process used suggested that 10 equal zones were suitable for the model (see Figure 1). The stormwater movement over the surface was as a flow from zone 1 where the inlet structure was located to zone 10 where the outlet structure was located. Each zone with 24.8 m2 surface area was considered to be a soil column in which the water flows downward to replicate the infiltration process. When the stormwater flows on the surface of the assumed soil column exceeds the infiltration capacity of the soil, the excess runoff was assumed to be surface flow to the next zone.

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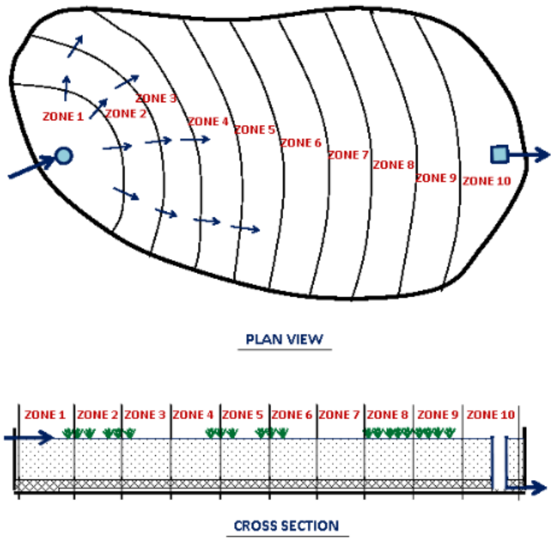

Fig. 1. Simplifying 3-dimensional flow into 1-dimensional column based flow

The stormwater flow within the bioretention basin (see Figure 2) was modelled according to the processes described in the following steps:

- Stormwater runoff enters the bioretention basin through the inlet structure in zone 1 which is assumed as a soil column (1).

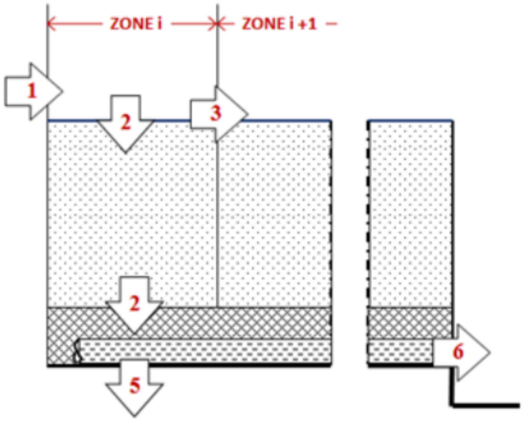

Fig. 2. The schematic of stormwater flows in the bioretention basin

- The stormwater runoff then infiltrates into the soil column (2). This is replicated using the infiltration model.
- When the inflow rate is higher than the soil column infiltration capacity, the excess runoff becomes surface flow to the next soil column (3).
- The infiltrated water then percolates until it reaches the drainage layer in which the stormwater is temporarily stored (4).
- Part of stormwater stored in the drainage layer percolates to the original soil layer underneath (5).
- Through perforated pipes, stormwater in the drainage layer flows to the outlet structure where the outflow was monitored (6).

3. MODELLING THE INFILTRATION PROCESS IN THE SOIL COLUMN FILTER MEDIA

The soil column is considered as a system where water balance can be applied. This means water entering and leaving the system is subject to the water balance concept. In this way, cross interaction between columns and its surrounding columns were considered negligible. Therefore, any possible seepage flow from groundwater and infiltration into the sidewall is negligible. This is acceptable since the soil surrounding the system is silty clay with low infiltration rate. Adopting the water balance approach, the soil column was considered as a storage. The storage volume was replicated to increase or decrease depending on the volume of stormwater entering and leaving the storage. This action was replicated using a standard storage equation in the form of (1).

$$\Delta S = S_{t+\Delta t} - S_t = I.\Delta t - O.\Delta t \qquad (1)$$

Where ΔS = change in storage volume (m^3)
Δt = time interval (sec)
S_t = storage volume (m3) at the beginning of the time interval Δt
$S_{t+\Delta t}$ = storage volume (m^3) at the end of the time interval Δt
I = inflow discharge rate (m^3/sec)
O = outflow discharge rate (m^3/sec)

The input to the system was infiltration while the output components of the system are percolation to the drainage layer underneath and evapotranspiration. Infiltration is considered to be influenced by factors such as soil moisture content, porosity, soil hydraulic conductivity and soil surface condition including vegetation cover. A range of equation formats are available to replicate the infiltration process such as equations proposed by [17][18][19]. All these equation formats were reviewed and Philip and Green-Ampt models were preferred for this study. This is due to the capability of Philip and Green-Ampt models to incorporate soil (media) characteristics in the equation rather than the pure mathematical format adopted in Horton's infiltration model. However, since the Green-Ampt model requires a lesser number of variables compared to the Philip model, the Green-Ampt model was chosen for the conceptual model developed.

The principle of Green-Ampt model is based on continuity and momentum [16]. The conceptual format in which the Green-Ampt equation was applied in this study is presented in Figure 3. Considering the zone 1 soil column as a vertical soil column (see Figure 3 (a)), the control volume was defined as the volume of the soil column from the surface to depth L (see Figure 3 (b)). As the wetting front progresses, the moisture content θ will increase from the initial value θ_i to η (porosity). When θ equals η, the soil is fully saturated. When L equals the thickness of the filter media (m), the whole filter media is considered fully saturated. In this condition, the wetting front fully passes the whole filter media and reaches the drainage layer. Accordingly, infiltration is replaced by percolation. The cumulative water depth infiltrating into the soil is expressed by (2) [16].

$$F(t) = L(\eta - \theta_i) \qquad (2)$$

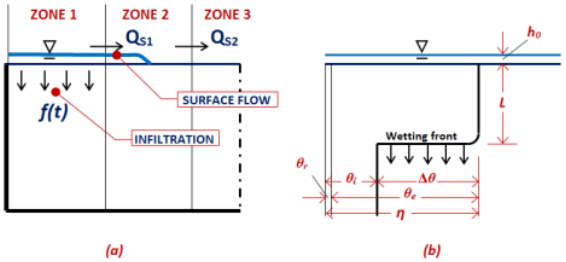

Fig. 3. Vertical soil column and Green-Ampt infiltration model variables

(Figure 3 *(b)* adapted from [16]

The developed model divides the infiltration process into two phases. Phase 1 starts from the beginning of the infiltration process until it reaches the drainage layer. Phase 2 is the phase when the infiltrated stormwater contributes to the storage volume in the drainage layer. In this instance, the drainage layer was considered as the second storage. The stormwater entering and leaving this second storage was also replicated using the water balance approach with a standard storage equation in the form of (1). Detail modelling of phase 1 and phase 2 are explained further as follows:

Phase 1

When the stormwater inflow from the catchment enters zone 1 or the exceeded surface flow enters the next zone, the stormwater begins to infiltrate into the soil column of the zone at a certain infiltration rate. The actual infiltration rate is equal to the inflow rate, if the inflow rate is less than the infiltration rate capacity of the soil column. However, if the inflow rate is greater than the infiltration rate capacity, the actual infiltration rate is equal to the infiltration rate capacity. The infiltration rate capacity was calculated using (3) [16]).

$$f(t) = k_s \cdot \left(\frac{\psi \Delta\theta}{F(t)} + 1 \right) \qquad (3)$$

Where: $f(t)$ = The infiltration rate capacity (m/h)
$F(t)$ = Cumulative infiltration (m)
k_s = Hydraulic conductivity or saturated soil permeability coefficient (m/h)
ψ = Wetting front soil suction head (m)
$\Delta\theta$ = The difference between the initial water content and saturated water content or porosity (η)

The equation for infiltration rate capacity (3) can be reformulated for cumulative infiltration capacity equation in the form of (4)[16]. Equation format shown in (4) requires iterative solutions to obtain cumulative infiltration capacity $F(t)$.

$$F(t) = k_s \cdot t + \psi\Delta\theta \cdot ln\left(1 + \frac{F(t)}{\psi\Delta\theta}\right) \qquad (4)$$

Where: t = Time elapsed (h)

Phase 2

Phase 2 begins when the wetting front reaches the drainage layer and the stormwater in the filter media starts draining to the drainage layer. It is indicated by the cumulative infiltration capacity calculated using (4) equals the cumulative infiltration obtained using (2). This is known as percolation, which is the movement of water downward in a media which is prompted by gravitational forces. The percolation of stormwater from the filter media to the drainage layer was also divided into two conditions. The first condition is when the filter media is still unsaturated while the second condition is when the filter media is fully saturated. The percolation rate in the second condition was replicated using saturated coefficient of permeability k_s. Therefore, the volume of water which percolates during the modelling time interval Δt can be written as (5).

$$Vw_{\Delta t} = k_s \cdot \Delta t \times A \qquad (5)$$

Where: $Vw_{\Delta t}$ = Volume of water percolating from filter media column (m^3)
Δt = Time interval (h)
A = Cross sectional area of the filter media column (m^2)

When the filter media is not fully saturated, the saturated soil permeability coefficient, k_s in (5) is replaced by k_w, as presented in (6).

$$Vw_{\Delta t} = k_w \cdot \Delta t \times A \qquad (6)$$

Where: k_w = Unsaturated soil permeability coefficient (m/h)

To obtain an accurate unsaturated soil permeability coefficient k_w, a field or laboratory experiment is required. However, [20] has proposed an approximate method to obtain values for k_w, which is presented in (7).

$$k_w = k_s \times {S_e}^{\delta} \qquad (7)$$

Where: S_e = Effective saturation of soil
δ = An empirical constant, expressed by $\delta = (2 + 3\lambda) / \lambda$, where λ is the pore size distribution index

Reference [21] suggested pore size distribution index (λ) as equal to infinity for uniform sand, resulting 3.0 for empirical constant (δ). For natural sand deposits, reference [22] suggested $\lambda = 4.0$, resulting in a δ value of 3.5, while for soil and porous rock, reference [23] proposed 2.0 for λ, resulting in a δ value of 4.0. The developed bioretention basin used $\lambda = 10$ which gives $\delta = 3.5$. This value was obtained from the calibration.

The effective saturation S_e is the ratio of the available moisture content $\theta - \theta_r$ to the maximum possible available moisture content $\eta - \theta_r$. It is written in the form of (8)[16].

$$S_e = \frac{\theta - \theta_r}{\eta - \theta_r} \qquad (8)$$

Where: S_e = Effective saturation of soil
θ = Moisture content
θ_r = The residual moisture content of soil after it has thoroughly drained
η = Porosity

The maximum possible available moisture content is called the effective porosity, reflected by $\eta - \theta_r = \theta_e$. The effective saturation, S_e was monitored during the modelling period to evaluate whether the filter media is in unsaturated or saturated condition. Once the value of S_e reaches 100%, the filter media is considered to be saturated.

4. WATER LOSSES DUE TO PERCOLATION

Since the type of soil underneath the bioretention basin is silty clay with a very low percolation rate, a constant percolation rate of 1.8 x 10^{-6} m/h as suggested by [24] was applied in the model throughout the bioretention basin area. However, during model calibration, this percolation rate was adjusted to obtain better results.

5. DIRECT PRECIPITATION

Direct precipitation is rainfall which directly falls on the bioretention basin surface and the area surrounding the bioretention basin without entering through the inlet measurement device. The amount of direct precipitation for a certain duration is considered as the rainfall depth for that duration multiplied by the bioretention basin surface area. In the case where the rainfall falls on the surroundings of the bioretention basin area and the runoff produced does not flow through the inlet measurement device, but seeps through the bioretention basin, runoff was estimated by applying a runoff coefficient. The initial runoff coefficient of 0.7 was considered appropriate to compensate for the loss of water due to interception and infiltration. However, this value was adjusted during model calibration.

6. MODELLING THE FLOW THROUG PERFORATED PIPES TO OUTLET

Flow through the perforated pipes was modelled as flow in a circular open channel. Initially, this flow was assumed as laminar and later confirmed after calibration. The flow at the end of the perforated pipe near the outlet was also assumed as uniform and steady. This assumption was based on the fact that the longitudinal slope of the perforated pipe is very small (0.005).

Flow through a circular open channel is explained by a range of researchers such as by [25][26][27][28] and [29]. Based on the suggestions provided in literature, Manning's equation, in the form of (9), was used to simulate flow through the perforated pipes in the model developed.

$$Q = \frac{k}{n} \times A \times R^{2/3} \times S^{1/2} \qquad (9)$$

Where: Q = Discharge (m^3/sec)
k = Conversion factor ($m^{1/3}$/sec)
n = Manning's coefficient
A = Wetted cross sectional area of the circular pipe (m^2)
R = Hydraulic radius of the wetted cross sectional area (m)
S = Slope of the hydraulic grade line (equal to the longitudinal slope for uniform flow)

The internal surface of the perforated pipe was considered as rough due to the presence of perforations. Therefore, the Manning's roughness coefficient in the range of 0.012 to 0.017 was initially used [29]. The actual Manning's coefficient was obtained from the calibration.

7. CALIBRATION OF THE MODEL

Finalised model parameters were obtained by model calibration. Calibration was undertaken to obtain model parameters ensuring that the model was performing as close as possible to the stormwater bioretention basin system. It was primarily a trial and error changing of parameters until outputs reach best visual fit to the measured outcomes [30][31]. The method is widely used and commonly recommended for complex models [32][33][34].

In order to obtain a good comparison during the calibration process, a noise suppression technique was required to reduce the data noise due to the sensitivity of the pressure sensor reading the fluctuating water depth in the V-notch weir boxes. In this study, the average method was used for noise suppression, by averaging several data points before and after each data point as a corrected data point. The typical hydrographs before and after reducing noise using the averaging method are shown in Figure 4.

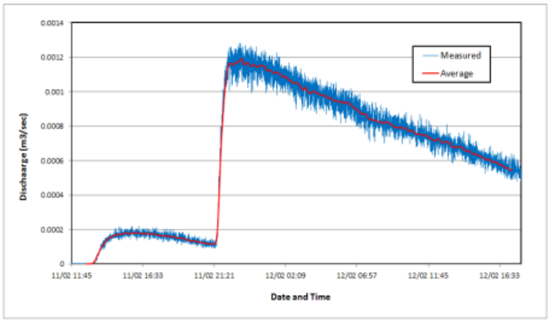

Fig. 4. Hydrograph before and after noise suppression

The model calibration was done using data from twelve storm events during April 2008 to March 2011 period [35], and the calibration results were found to be satisfactory [36]. To assess the accuracy of the calibrated model, the study adopted a well-known statistical analysis method developed based on the regression analysis technique [37][38]). In this method, coefficient of determination (R^2) which can be used to measure the 'goodness-of-fit' of the estimated model is calculated based on regression residual by taking time as the independent variable (x) and measured and model values as dependent variables. The residual ($\hat{u}_i$) associated with each paired data values (measured and model) is the vertical distance between the measured value (y_i) and model value ($\hat{y}_i$) which can be written as $\hat{u}_i = y_i - \hat{y}_i$ (see Figure 5) [38].

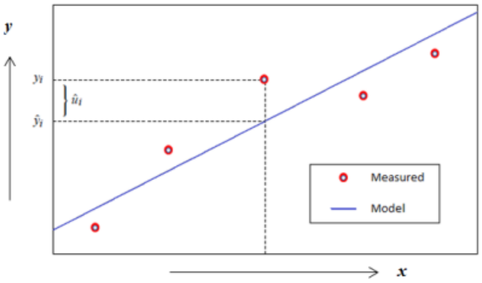

Fig. 5. Regression residual (Adapted from [38])

The R^2 value is calculated using (10) [37].

$$R^2 = 1 - \frac{SSR}{SST} = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \qquad (10)$$

Where: R^2 = Coefficient of determination

SSR = The sum of the squared residuals and can be expressed as $SSR = \sum(y_i - \hat{y}_i)^2 = \sum \hat{u}_i^{\,2}$

SST = Total sum of squares and can be expressed as $\sum(y_i - \bar{y})^2$.

y_i = Measured value of dependent variable

$\hat{y}$ = Model value of dependent variable

$\bar{y}$ = Mean value of dependent variable

The sum of squared residuals (SSR) represents the residuals/errors of the model to the measured data while the total sum of squares (SST) represents the variation of the dependent variable around its mean. Therefore, $\frac{SSR}{SST}$ can be defined as the proportion of the residual to the variation in the dependent variables. R^2 can be written as 1 minus the proportion of the residual to the variation in the dependent variable and must be bounded by 0 and 1 ($0 \leq R^2 \leq 1$). The higher the R^2 value, the better the model or the closer the value of R^2 to 1, the closer the model to the data points [38].

An example of a typical analytical result showing the goodness-of-fit of the developed wetland conceptual model hydrograph for the measured data is presented in Figure 6.

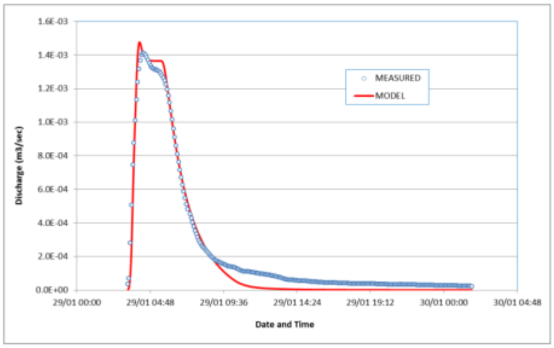

Fig. 6. Bioretention basin measured and modelled discharge hydrograph

The coefficient of determination (R^2) calculated for twelve monitored rainfall events are shown in Table 1.

Table 1. The goodness-of-fit, coefficient of determination R^2

No.	Rainfall event	R^2
1	29-01-2008	0.89
2	03-02-2008	0.91
3	17-03-2008	0.92
4	18-04-2008	0.91
5	29-05-2008	0.92
6	22-01-2009	0.94
7	29-01-2010	**0.98**
8	18-04-2010	0.91
9	23-06-2010	0.92
10	19-07-2010	**0.88**
11	02-03-2011	0.93
12	29-03-2011	0.94
	Average	**0.92**

Note: Minimum $R^2 = 0.88$, maximum $R^2 = 0.98$ and average $R^2 = 0.92$ (printed in bold)

Table 1 shows that the R^2 ranges from 0.88 to 98 with an average of 0.92. This range was considered satisfactory. This suggests that the approaches adopted in the model development are appropriate.

Based on the trial and error procedure, the parameters were adjusted during the calibration and the best fit parameters were obtained for the developed model. The parameters obtained and their final values are given below:

- Hydraulic conductivity of the filter media : 0.025 m/hr
- Wetting front soil suction head, ψ : 0.167 m
- Porosity of the filter media, η : 0.501
- Pore size distribution index, λ : 10
- Percolation rate of soil underneath the basin : 5×10^{-5} m/hr
- Manning's coefficient of the perforated pipe : 0.015
- Runoff coefficient : 0.7

7. CONCLUSION

The treatment processes of stormwater in a bioretention basin are influenced by a range of hydraulic factors. However, these influential factors may vary during an event and the variation can be generated using a detailed modelling approach. Therefore, in this study a hydraulic conceptual model of bioretension basin which is capable to replicate the hydraulic conditions within the wetland was developed. The model was calibrated using trial and error procedure which is the most robust procedures available.

The model was simplified from 3-dimension flow system to a 1-dimensional flow system. However, the approaches adopted to develop the bioretention basin hydraulic conceptual model in this study are satisfactory. The average coefficient of determination of model-measured outflow discharge, R^2 of 0.92 confirms the suitability of the model developed to simulate hydraulic factors.

REFERENCES

[1] Davis, A. P., Shokouhian, M., Sharma, H. and Minami, C., 2006, 'Water Quality improvement through bioretention media: nitrogen and phosphorus removal', Water Environment Research, Vol. 78, pp. 2177-85.

[2] Hatt, B. E., Deletic, A. and Fletcher, T. D., 2007, 'Stormwater reuse: designing biofiltration systems for reliable treatment', Water Science Technology, Vol. 55, No. 4, pp. 201-9.

[3] Henderson, C., Greenway, M. and Phillips, I., 2007, 'Removal of dissolved nitrogen, phosphorus and carbon from stormwater by biofiltration mesocosms', Water Science and Technology, Vol. 55, No. 4, pp. 183-91.

[4] Greenway, M. 2008. 'The role of media, microbes and macrophytes in improving the effectiveness of bioretention systems, have we got it right?'. In SIA Stormwater Conference. Gold Coast.

[5] Hunt, W. F., Jarrett, A. R., Smith, J. T. and Sharkey, L. J., 2006, 'Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina', Journal of Irrigation and Drainage Engineering, Vol. 132, No. 6, pp. 600–8.

[6] Davis, A. P., 2007, 'Field Performance of Bioretention: Water Quality', Environmental Engineering Science, Vol. 24, No. 8, pp. 1048-64.

[7] Davis, A. P., 2008, 'Field performance of bioretention: Hydrology impacts', Journal of Hydrologic Engineering, Vol. 13, No. 2, pp. 90-5.

[8] Dietz, M. E. and Clausen, J. C., 2005, 'A field evaluation of rain garden flow and pollutant treatment', Water, Air and Soil Pollution, Vol. 167, No. 1-4, pp. 123-38.

[9] He, Z., Davis, A. P. and Asce, F., 2011, 'Process Modeling of Storm-Water Flow in a Bioretention Cell', Journal of Irrigation and Drainage Engineering, Vol. 137, No. 3, pp. 121-31.

[10] Heasom, W., Traver, R. G. and Welker, A., 2006, 'Hydrologic modeling of a bioretention best management practice', Journal of the American Water Resources Association, Vol. 42, No. 5, pp. 1329-47.

[11] Hsieh, C. H. and Davis, A. P., 2005, 'Evaluation and optimization of bioretention media for treatment of urban stormwater runoff', Journal of Environmental Engineering, Vol. 131, No. 11, pp. 1521-31.

[12] Hsieh, C. H., Davis, A. P. and Needelman, B. A., 2007b, 'Nitrogen removal from urban stormwater runoff through layered bioretention columns', Water Environment Research, Vol. 79, No. 12, pp. 2404-11.

[13] Hsieh, C.-h., Davis, A. P. and Needelman, B. A., 2007a, 'Bioretention column studies of phosphorus removal from urban stormwater runoff', Water environment research : a research publication of the Water Environment Federation, Vol. 79, No. 2, pp. 177-84.

[14] Moore, J. R., 2008, 'Effect of compaction on removal efficiency of lead, copper, zinc, nitrate, and phosphate in a bioretention system a column study' Thesis.

[15] Zhang, L., Seagren, E. A., Davis, A. P. and Karns, J. S., 2011, 'Long-term sustainability of Escherichia coli removal in conventional bioretention media', Journal of Environmental Engineering, Vol. 137, No. 8, pp. 669.

[16] Chow, V. T., Maidment, D. R. and Mays, L. W., 1988, 'Applied hydrology'. Ed. Clark, B. J. and Morriss, J., New York: McGraw-Hill, Inc.

[17] Horton, R. E., 1933, 'The role of infiltration in the hydrologic cycle', Trans. Am. Geophys. Union, Vol. 14, pp. 446-60.

[18] Philip, J. R., 1957, 'The theory of infiltration: 1. The infiltration equaiton and its solution', Soil Sci., Vol. 83, No. 5, pp. 345-57.

[19] Green, W. H. and Ampt, G. A., 1911, 'Studies on soil physics, part I, the flow of air and water through soils', Agric. Sci, Vol. 4, No. 1, pp. 1-24.

[20] Brook, R. H. and Corey, A. T., 1964, 'Hydraulic properties of porous

[21] Irmay, S., 1954, On the Hydraulic Conductiviy of Unsaturated Soils, Trans. AGU, Vol. 35, No.3, pp. 463-467

[22] Averjanov, S. F., 1950, 'About permeability of subsurface soils in case of complete saturation', English Collection, Vol. 7, pp. 19-21.

[23] Corey, A. T., 1977, Mechanics of Heterogeneous Fluids in Porous Media, Water Resources Pubs., Fort Collins, Colorado

[24] Lambe, T. W. and Whitman, R. V., 1969, 'Soil mechanics', New York: John Wiley and Sons, Inc.

[25] Chow, V. T., 1959, 'Open Channel Hydraulics', New York: McGraw-Hill Book Company.

[26] Akan, A. O., 2006, 'Open Channel Hydraulics', First Edition, Oxford: Elsevier Butterworth-Heinemann.

[27] Chanson, H., 2004, 'The Hydraulics of Open Channel Flow: An Introduction', Second Edition, Oxford: Elsevier Butterworth-Heinemann.

[28] Sturm, T. W., 2001, 'Open Channel Hydraulics', New York: McGraw-Hill.

[29] Han, D., 2008, 'Concise Hydraulics': Ventus Publishing.

[30] Gupta, H. V. and Sorooshian, S., 1998, 'Toward improved calibration of hydrologic models: Multiple and noncommensurable measures of information', Water Resources Research, Vol. 34, No. 4, pp. 751-63.

[31] Li, X. and Yeh, A. G.-o., 2002, 'Neural-network-based cellular automata for simulating multiple land use change using GIS', International Journal of Geographical Information Science, Vol. 16, No. 4, pp. 323-43.

[32] Abbott, M. B. and Refsgaard, J. C., 1996, 'Distributed Hydrological

[33] Yu, Z. and Schwartz, F. W., 1998, 'Application of an integrated basin-scale hydrologic model to simulate surface-water and ground-water interactions', Journal of the American Water Resources Association, Vol. 34, No. 2, pp. 409-25.

[34] James, L. D., 1972, 'Hydrologic modeling, parameter estimation, and watershed characteristics', Journal of Hydrology, Vol. 17, No. 4, pp. 283-307.

[35] Mangangka, Isri Ronald, 2013, Role of Hydraulic Factors in Constructed Wetland and Bioretention Basin Treatment Performance, Ph.D. Thesis, Queensland University of Technology, Brisbane, Australia.

[36] Mangangka Isri R., Liu An, Goonetilleke Ashantha, Egodawatta Prasanna (2016), Creating Conceptual Models of Treatment Systems, in Enhancing the Storm Water Treatment Performance of Constructed Wetlands and Bioretention Basins. pp. 15-38., Singapore: Springer Singapore.

[37] Chatterjee, S. and Hadi, A. S. 2006. 'Regression Analysis by Example'. Hoboken: Wiley-Interscience.

[38] Rawlings, J. O., Pantula, S. G., and Dickey, D. A., I., 1998, 'Applied regression analysis: a research tool', New York: Springer.

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