Hydraulic assessment of grassed swale as bioengineered channel: Proceedings of the 3rd International Conference...

Chapter · August 2016

DOI: 10.1201/b21942-54

4 authors:

Mujahid Muhammad Muhammad

Universiti Teknologi PETRONAS

28 PUBLICATIONS **7** CITATIONS

SEE PROFILE

Khamaruzaman Wan Yusof

Universiti Teknologi PETRONAS

96 PUBLICATIONS **284** CITATIONS

SEE PROFILE

Muhammad Raza Ul Mustafa

Universiti Teknologi PETRONAS

60 PUBLICATIONS **110** CITATIONS

SEE PROFILE

Aminuddin Ab Ghani

Universiti Sains Malaysia

180 PUBLICATIONS **1,353** CITATIONS

SEE PROFILE

Engineering Challenges for Sustainable Future – Zawawi (Ed.)
© 2016 Taylor & Francis Group, London, ISBN 978-1-138-02978-1

Hydraulic assessment of grassed swale as bioengineered channel

M.M. Muhammad, K.W. Yusof & M.R. Mustafa
Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Perak, Malaysia

A.Ab. Ghani
River Engineering and Urban Drainage Research Centre, Universiti Sains Malaysia, Pinang, Malaysia

ABSTRACT: This paper evaluates the suitability of a grassed swale for channel stabilization against erosion, as an alternative to concrete drainage systems. To achieve this objective, hourly flow measurements due to different rainfall events were made along 10 m length of the grassed swale. The data collected were cross sections, grass geometry, flow depth and velocity. Rating curves, velocity distributions, stage and velocity – Manning's resistance relationships were developed, respectively, with correlation coefficients, R^2, mostly above 70%. Also, the centerline velocity of grassed swale was determined to range from 0.05 to 0.76 m/s. The shear stresses fall between 3.47 to 6.59 N/m^2 both on bed and bank of the swale. Comparing the velocity and shear stresses values with standard charts, it was found that all values are within the allowable limit. Thus, the relationships developed would be suitable for designing an erosion resistant grassed swale based on Malaysia climate conditions and alike.

1 INTRODUCTION

A grassed swale may be defined as a shallow and bioengineered open channel with trapezoidal, parabolic or non-uniform shape. Swales are usually vegetated with flood and erosion resistant plants. The design of grassed swales promotes the conveyance of storm water at a steady and regulated rate. It also acts as a filter medium in removing pollutants and improving water quality, where it can detain storm water for several hours or days (SuDS, 2015, DID, 2012). Also, from the economic point of view, vegetated drainage systems are less expensive compared to concrete drainage systems which in several circumstances are being gradual eroded or failed by water actions.

Swales generally have two different types of flows that can be distinguished as surface and subsurface flows. The surface flow occurs due to flow – vegetation interactions with mostly grass being planted along the wetted perimeter of the swale channel. While for the case of sub-surface flow, flow occurs underneath the grass swale through geo-synthetic polypropylene modules in form of mesh, which are normally filled with river sands. It is important to note that the surface flow can only take place when the subsurface modules are saturated through infiltration of run-off, after several rainfall events.

The hydraulic characteristics of grass swales can be analyzed using the flow resistance such as Darcy-Weisbach friction (f), Chezy's resistance (C) and Manning's roughness (n) factors which have been used in a wide range of hydraulic and hydrologic analyses. However, the most common used equation in determining flow resistance in the hydraulic industry is Manning's equation (Kirby et al., 2005). The roughness components in open channels (swales) are conceptually divided into three parts via: form roughness, soil grain roughness and vegetative roughness (Temple, 1999). In most vegetated open channels, vegetative roughness characterized by vegetation density, vegetation height and type of vegetation dominates the flow resistance of the channel.

Investigation of flow characteristics in grass swale have been conducted by numerous researchers. However, the researchers failed to evaluate the swales as an erosion resistant in addition to the hydraulic analysis. Also, the authors recommended that further assessment of grassed swales with different vegetation types, vegetation density, and geometrical cross sectional channel is required for developing a more reliable model in predicting vegetative resistance (Ahmad et al., 2011).

Recently, Department of Irrigation and Drainage (DID) Malaysia has developed a manual termed Urban Storm Water Management Manual (DID, 2012) that will help in designing drainage systems. However, the guidelines in MSMA did not reflect the exact climatic conditions of Malaysia, the manual used foreign standards which are different from the climate of Malaysia. Based on this fact, further studies are required in order to verify the guidelines in MSMA with respect to Malaysia climatic conditions.

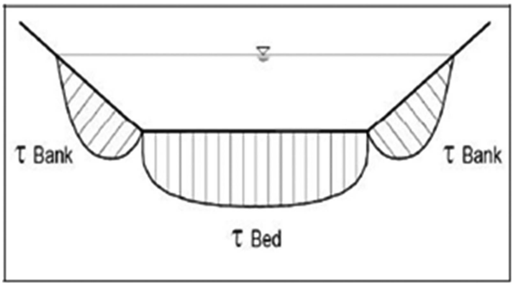

Figure 1. Distribution of shear stress on streambed and banks.

Therefore, the present study has attempted in solving the above issues through field experiments in a grassed swale. Through this, the effectiveness of grass swale for channel stability was examined. And comparisons were made from our findings with the standard charts provided in MSMA, in order to assess the suitability of adapting the guidelines in MSMA within the environment of Malaysia.

2 METHODOLOGY

2.1 *Modelling the vegetated flows through the swale*

The usual method for estimating energy losses in hydraulic modeling is through the use of popular equation by Manning.

$$Q = \frac{1}{n} A R^{2/3} S_0^{1/2} \tag{1}$$

Where: A = cross-sectional area of flow (m2), R = Hydraulic radius in (m), S = Bed slope of the channel, and n = Manning's coefficient.

2.2 *Evaluation of channel stability in the swale*

The resistance to erosion may vary on the nature of the biomaterial and the location of the channel. Lane's diagram given in Figure 1, shows theoretical distribution of shear stress on trapezoidal channel section. This means biomaterials of greater shear resistance are required lower on the bank, while a lighter-duty treatment may be sufficient near the top of the bank.

Shear stress is an essential parameter in channel rehabilitation, because all materials, whether manufactured or natural, must be able to withstand the expected shear stress at the design discharge (Saldi-Caromile, 2004). Thus, for maximum shear stress on the bed the following expression is used:

$$\tau_{bed} = \gamma RS = \gamma (A/P) S \tag{3}$$

$$\tau_{bed} = 9806\, RS \tag{4}$$

where, τ_{bed} = maximum bed shear stress (N/m^2), γ = the specific weight of water = 9806 N/m^3,

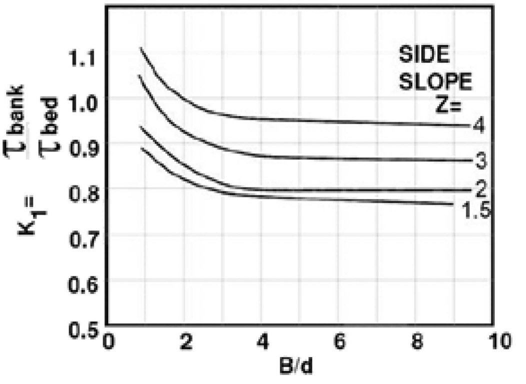

Figure 2. Coefficient K_1 vs. side slope z, and width/depth B/d Ratio.

R = hydraulic radius in m, A = flow cross-sectional area (m^2), P = wetted perimeter (m) and S = energy slope = 0.002.

Also, multiplying the maximum bed shear stress, τ_{bed}, by a coefficient or factor, K_1, given in Figure 2. The value of K_1, varies based on channel side slope (z) and the ratio of bottom width (B) to depth (d). This approach is used for a relatively straight channel reach. For maximum shear stress on the bank, τ_{bank}, equation (5) can be applied:

$$\tau_{bank} = K_1 \tau_{bed} \tag{5}$$

It should be noted that K_1 is estimated by knowing the aspect ratio = B/d, that is, the ratio of width (B) to the flow depth (d), and the side slope z of the channel. For this project z = 1:2.

Table 1 presents velocity range for various channel boundaries conditions which has been provided in MSMA 2nd Edition. And to account for the limiting values of the shear stresses as well as erosion limits based on flow duration, Figs. 3 and 4 may be used as a guide to assess the suitability of channels in erosion control. These were also provided by the guidelines of MSMA 2nd Edition.

2.3 *Study area*

Figure 5 shows the locations of swales at USM Engineering Campus, Nibong Tebal, Pineng, Malaysia. There are 3 types of swale system in USM namely, swale Type A, swale Type B, and swale Type C, based on their sizes and capacities. The swale Type A consists of a single sub-surface module, swale Type B (which was considered in the present study) has two numbers of single sub-surface modules and swale Type C contains 3 numbers of single modules respectively (Zakaria et al., 2003).

Also, *Axonopus Compressus* commonly known as *Cow grass* was used within the channel bed of the swale Type B. Figure 6 shows the pictorial representation of the grass. The technical details of swale components was well illustrated by Ghani *et al* (Ab. Ghani et al., 2004).

Table 1. Stability of channel linings for given velocity limits (Fischenich, 2001).

Lining	Velocity limits 0 – 0.61 m/s	0.61 – 1.22 m/s	1.22 – 1.83 m/s	1.83 – 2.44 m/s	> 2.44 m/s
Sandy Soils					
Firm Loam					
Mixed Gravel and Cobbles					
Average Turf					
Degradable RECPs Stabilizing Bioengineering					
Good Turf					
Permanent RECPs Armoring Bioengineering CCMs & Gabions					
Riprap					
Concrete					
Key :					
	Appropriate				
	Use Caution				
	Not Appropriate				

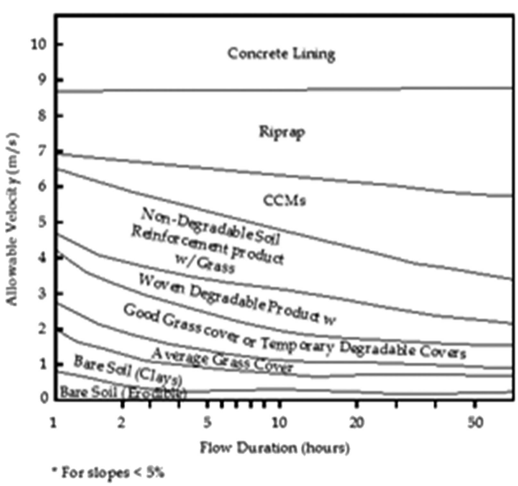

Figure 3. Erosion limits as a function of flow duration (Fishenich and Allen, 2000).

2.4 *Measurement of physical quantities*

Field measurements were obtained by selecting a control section of 10 m length along the channel in swale Type B on a bed slope of 1:500. The data collected were cross section, slope, flow depth, velocity, grass

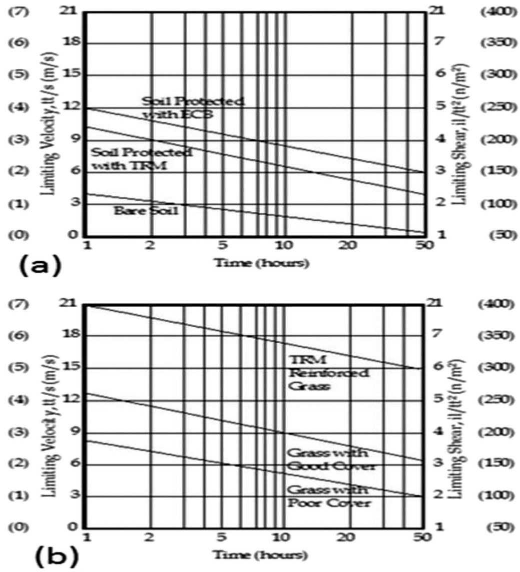

Figure 4. Limiting value for velocity and shear for (a) TRM, ECB and/or Soil; (b) Grass and/or TRM (Sprague, 1999).

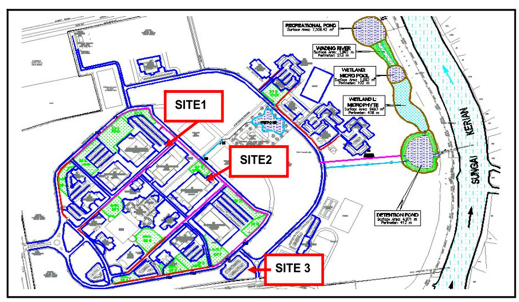

Figure 5. Study area of grassed swale.

Figure 6. Sample of *cow grass*.

height and flow measurements were carried out using current meter at 1 hour intervals due to different rainfall events from September to October 2015 as shown in Fig. 7. In this study the grass height was maintained at 150 mm. This is because a minimum grass heights of 75 mm and maximum of 150 mm should be sustained within grass swale [1]. And the swale was regularly clean, to ensure that it is free of debris and excessive silt [11].

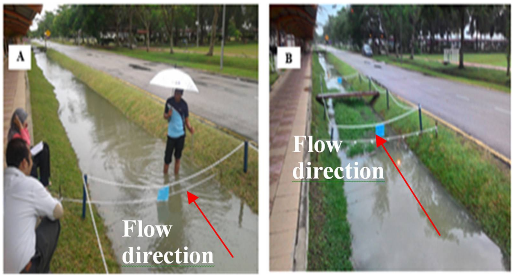

Figure 7. Flow scenarios when the grass is Submerged (A) and Unsubmerged (B).

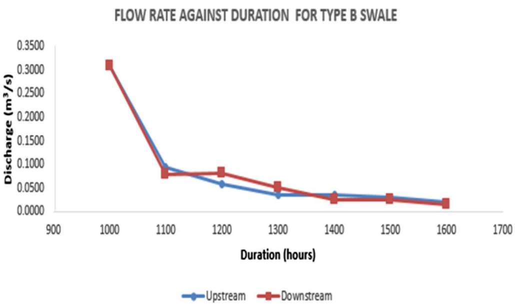

Figure 8. Discharge variation in upstream and downstream on 9/9/15.

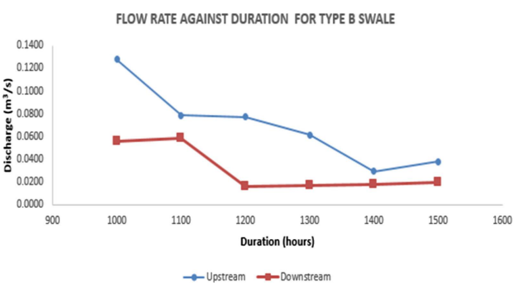

Figure 9. Discharge variation in upstream and downstream on 17/9/15.

3 RESULTS AND DISCUSSION

3.1 *Flow parameters relationship*

From Figs. 8 and 9 the discharge was plotted against time for different rainfall events. Generally, the discharge decreases over time, with the upstream discharge being higher than the downstream discharge. This has agreed with the statement by several researchers that vegetation reduces the magnitude of flow and obstructing water to reach the downstream smoothly (Guscio et al., 1965, Muhammad et al., 2015).

Figure 10 shows the rating curve of grass swale Type B. The curves indicate that strong relationship exist between discharge, Q and flow area, A, as the correlation coefficients, R^2, are all above 70%. This

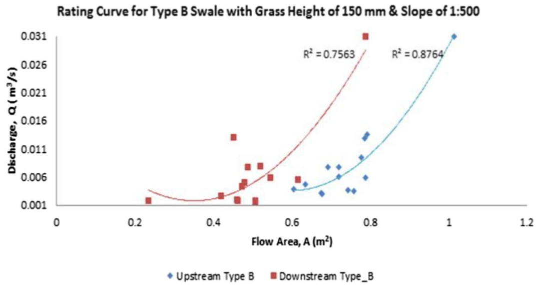

Figure 10. Rating curves for Type B swale.

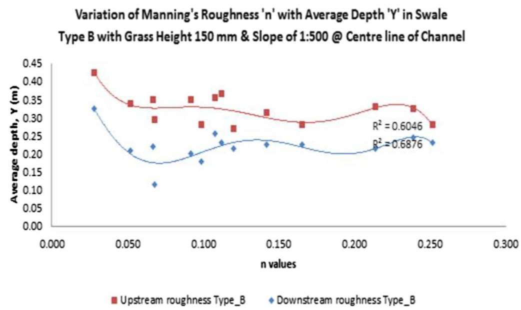

Figure 11. n–y relationship.

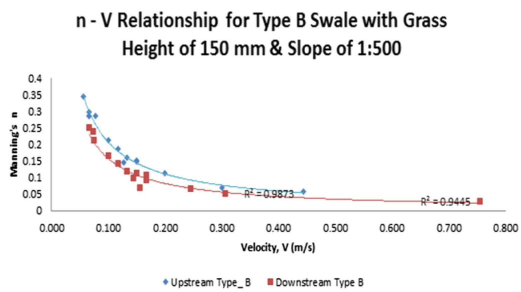

Figure 12. n–V relationship.

means the upstream accommodates larger flow area compared to the downstream.

From Fig. 11, the results reveal that Manning's n at upstream was high compared to downstream. This can be explained based on the greater roughness exerted by the grass in obstructing the discharge from the upstream. Thus, Manning's n – values decrease with increase in the flow depth, y. This agrees with the findings of other researchers (Chow, 1959, García Díaz, 2005, Chen et al., 2009), where smaller Manning's n was observed for greater flow depth. However, Manning's n was observed to be constant in both upstream and downstream when the flow depth was very high and the grass was completely submerged.

Similarly, Figs. 12 and 13, show the variations of Manning's n with Velocity, V and Discharge, Q, respectively. It was observed that, n, declines as both, V and Q, increased which is similar to the findings of Ahmad *et al* (Ahmad et al., 2011).

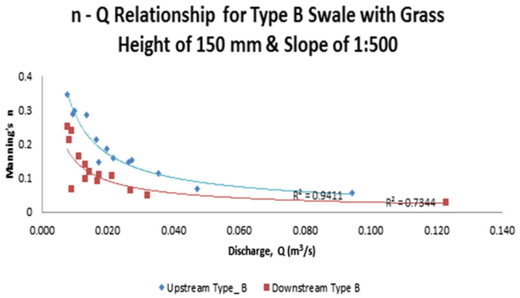

Figure 13. n–Q relationship.

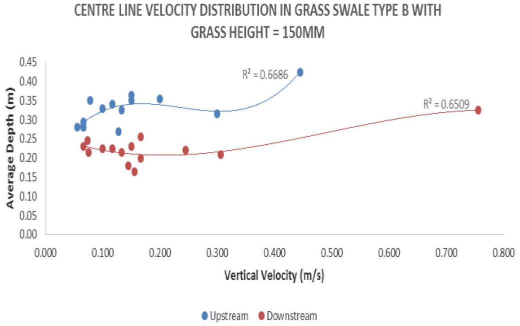

Figure 14. Centre line velocity distribution in swale Type B.

Table 2. Upstream Shear Stresses for 9th and 17th September, 2015.

Depth, y	Area, A	Wetted Perimeter, P	Hydraulic Radius, R	Bed Shear Stress, τ_b	Bank Shear Stress, τ_s
(m)	(m^2)	(m)	(m)	(N/m3)	(N/m3)
Date of observation: 09/09/15					
0.45	1.013	3.136	0.323	6.332	5.066
0.37	0.777	2.797	0.278	5.448	4.304
0.35	0.788	3.063	0.257	5.042	4.009
0.37	0.759	2.708	0.280	5.492	4.339
0.33	0.743	2.606	0.285	5.588	4.415
0.30	0.675	2.610	0.259	5.072	3.982
Average Values				5.496	4.353
Date of observation: 17/09/15					
0.36	0.785	2.967	0.265	5.188	4.124
0.36	0.720	2.633	0.273	5.363	4.291
0.33	0.693	2.798	0.248	4.858	3.862
0.34	0.719	2.825	0.255	4.992	3.969
0.33	0.677	2.671	0.253	4.968	3.949
0.30	0.605	2.488	0.243	4.764	3.788
Average Values				5.022	4.796

Table 3. Downstream Shear Stresses for 9th and 17th September, 2015.

Depth, y (m)	Area, A	Wetted Perimeter, P (m)	Hydraulic Radius, R	Bed Shear Stress, τ_b	Bank Shear Stress, τ_s
(m)	(m^2)	(m)	(m)	(N/m^3)	(N/m^3)
Date of observation: 09/09/15					
0.35	0.788	3.062	0.257	5.044	3.985
0.25	0.488	2.471	0.197	3.870	3.057
0.26	0.520	2.537	0.205	4.020	3.176
0.24	0.480	2.531	0.190	3.719	2.919
0.13	0.234	2.143	0.109	2.141	1.681
0.21	0.420	2.522	0.167	3.266	2.564
Average Values				3.677	3.476
Date of observation: 17/09/15					
0.30	0.615	2.648	0.232	4.556	3.622
0.28	0.546	2.450	0.223	4.371	3.475
0.26	0.507	2.451	0.207	4.056	3.205
0.26	0.507	2.457	0.206	4.048	3.198
0.24	0.461	2.382	0.193	3.795	2.998
0.23	0.460	2.521	0.182	3.579	2.810
Average Values				4.067	3.861

3.2 *Velocity profiles*

Figure 14 shows the trend pattern of the average vertical velocity profiles at the centerline of grass swale Type B considering both upstream and downstream flow conditions. Comparing the velocity ranges of the upstream and downstream of Fig. 14 with values in Table 1 provided in MSMA 2nd edition, it follows that all velocities fall within the allowable standards and hence, the channel will be resistive to erosion.

3.3 *Shear stresses*

Tables 2 and 3 show the variations of average bed and bank shear stresses with the flow depth, y, respectively. As the depth decreases the shear stresses decreases for both cases of rainfall events. Also, comparing the shear stresses calculated in Tables 2 and 3 with charts in Figures 3 and 4 as provided in MSMA 2nd edition, it shows that the shear stress values are within the allowable range and hence the biomaterials are stable against erosion.

4 CONCLUSION

The results obtained from this study shows that the grassed swale is suitable to be used in urban drainage systems to convey water in a non-erosive manner. This is obvious as velocity values were found to be within the allowable standards, and appropriate for designing a stable bio-channel, with minor cautions especially when the velocity is very large. Thus, the curves developed can be used to enhance the estimation of roughness and discharge of grassed channels in guidelines provided by the MSMA.

ACKNOWLEDGMENT

We would like to thank the support from Ministry of Education under HiCOE's niche area Sustainable Urban Stormwater Management, Universiti Sains Malaysia, USM (Grant No. 311.PREDAC.4403901). The first author would also like to acknowledge Universiti Teknologi PETRONAS for the fellowship scheme to undertake the postgraduate study.

REFERENCES

AB. Ghani, A., Zakaria, N. A., Abdullah, R., Yusof, M. F., Mohd Sidek, L., Kassim, A. H. & Ainan, A. 2004. Bio-ecological drainage system (Bioecods): concept, design and construction. *lnternariond Conference on Hydro-Science and Engineering.* Brisbane, Australia.

Ahmad, N. A., AB. Ghani, A. & Zakaria, N. A. 2011. Hydraulic characteristic for flow in swales. *3rd International Conference on Managing Rivers in the 21st Century: Sustainable Solutions for Global Crisis of Flooding, Pollution and Water Scarcity.* Rivers, Penang, Malaysia.

Chen, Y.-C., Kao, S.-P., Lin, J.-Y. & Yang, H.-C. 2009. Retardance coefficient of vegetated channels estimated by the Froude number. *Ecological Engineering*, 35, 1027–1035.

Chow, V. T. 1959. *Open channel hydraulics*, New York, McGraw-Hill.

DID 2012. Urban storm water management manual for Malaysia. Department of Irrigation & Drainage (DID) Malaysia.

Fischenich, C. 2001. Stability thresholds for stream restoration materials. DTIC Document.

Fishenich, C. & Allen, H. 2000. Stream Management, Water Operations Technical Support Program. *US Army Corps of Engineers, Environmental Laboratory. Waterways Experiment Station. Vicksburg, MS.*

García Díaz, R. 2005. Analysis of Manning coefficient for small-depth flows on vegetated beds. *Hydrological Processes*, 19, 3221–3233.

Guscio, F. J., Bartley, T. R. & Beck, A. N. 1965. Water resources problems generated by obnoxious plants. *Journal of the Waterways and Harbors Division*, 91, 47–62.

Kirby, J. T., Durrans, S. R., Pitt, R. & Johnson, P. D. 2005. Hydraulic resistance in grass swales designed for small flow conveyance. *Journal of Hydraulic Engineering*, 131, 65–68.

Muhammad, M. M., Yusuf, K. W., Mustafa, M. R. & AB. Ghani, A. Vegetated Open Channel Flow for Urban Stormwater Management: A Review. 36 th IAHR World Congress, 2015 The Hague, the Netherlands.

Saldi-Caromile, K., Bates, K., Skidmore, P., Barenti, J., and Pineo, D. 2004. Stream habitat restoration guidelines: Final draft. Washington Department of Fish and Wildlife and Ecology and the U.S. Fish and Wildlife Service, Olympia, WA.

Sprague, C. 1999. Green Engineering: Design principles and applications using rolled erosion control products. Part Two. *Civil Engineering News*, 11.

SUDS 2015. Sustainable Drainage Manual: Guidance on Design of Swales. Construction Industry Research and Information Association. *In:* (CIRIA) (ed.) C753 ed.

Temple, D. 1999. Flow resistance of grass-lined channel banks. *Applied engineering in agriculture*.

Zakaria, N. A., AB. Ghani, A., Abdullah, R., Mohd Sidek, L. & Anita, A. 2003. Bio-ecological drainage system (BIOECODS) for water quantity and quality control. *International Journal of River Basin Management*, 1, 237–251.