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Utilizing Concept of Vegetation Freeboard Equivalence in River Restoration

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ABSTRACT

The concept of vegetation freeboard equivalence (VFE) is presented from the comparison between the rise in stage with/without vegetation and the freeboard height under design discharge conditions. In South Korea, the freeboard height of large, medium and small rivers is defined as a function of river discharge. Two models are used for this analysis of flood stage with and without vegetation: the 1-D model HEC-RAS and the 2-D model RMA-2. Both models are applied to three river study sites of the Geum River in South Korea as representative sites for a large, a medium and a small river. The analysis shows that without vegetation, both models provide comparable results and the calculated results are in very good agreement with the design configuration. The vegetation effects on the medium river are less significant, and the freeboard is adequate to contain the rise in stage from the added floodplain vegetation in large rivers. The concept of vegetation freeboard equivalence is therefore useful for the analysis of flood river stages after the restoration of channels with increased floodplain vegetation.

Keywords: *Vegetation Freeboard Equivalence (VFE); River Restoration; Stream Rehabilitation; Levee Design; Flood Control*

1. INTRODUCTION

South Korean rivers exhibited near natural conditions before 1960. Since then, the rapid growth through demographic expansion, urbanization and industrialization triggered significant changes with levee construction for flood control and disaster prevention. Several small rivers have been subjected to major transformations, deviations and closures to leave space for roads, parking lots and urban development. The more recent emphasis on river restoration underlines the need to reanalyze flood stages on vegetated floodplains. The concept of public river garden has been developed with an increasing concern to protect the river environment. As a result, some low flow channels have enabled public access and activities on river flood plains with significant upgrades in stream ecology, riparian vegetation and river environment [16]. River management in recent years has also been changed to imitate natural river conditions with stream ecology concepts including increased vegetation to maintain aquatic habitat and channel restoration [22]. The addition of vegetation in conveyance channels is expected to raise the water level at a given flood discharge. The evaluation of the effects of vegetation on the hydraulic stability of levees and on irrigation maintenance countermeasures needed to be conducted by hydraulic engineers to determine the effects of adding vegetation on river stages at a given discharge [17]. The increased flood stage from floodplain vegetation therefore needs to be carefully evaluated in river restoration projects.

Some of the early investigations of the effects of vegetation on resistance to flow include Chow [7] and Barnes [2]. The effects of vegetation strips, artificial roughness elements and the biomechanical properties of vegetative channel linings could be studied further with the pioneer contributions of Kouwen and Li [14]. Darby [8] also examined the effect of riparian vegetation of flow resistance and flood potential. Wu *et al.* [29] also studied flow resistance of grass-lined channel banks and the variation in roughness coefficients for vegetation.

In South Korea, studies include the hydraulic resistance in vegetated in open channel flows by Woo *et al.* [28], the prediction of stage in a stream with vegetation on the floodplain by Choi and Shin [6], the changes in the downstream hydraulic geometry of the Hwang River below Hapcheon Dam by Shin and Julien [21].

This paper aims at the quantification of flood stages with and without floodplain vegetation. The new concept of vegetation freeboard equivalence (*VFE*) is introduced and developed in this paper as shown in Fig. 1. The concept hinges on finding the rise in water surface elevation due to the increase in vegetation density, and to compare this quantity with the freeboard height of the designed levees. Three case studies

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representing large, medium and small rivers in South Korea have been selected to illustrate the applicability of the proposed new concept. This article also compares simulation results from both 1-D and 2-D models like HEC-RAS and RMA-2. The applications lead to an evaluation of the proposed new *VFE* criterion for the analysis of restoration of leveed river systems.

2. THEORETICAL BACKGROUND

2.1 Vegetation Freeboard Equivalence

The concept of vegetation freeboard equivalence (*VFE*) is a measure of the rise in water surface elevation due to the vegetation increase in comparison to the freeboard height. Per the definition sketch in Fig. 1, the relationship can be defined as

$$VFE = \frac{H_{veg} - H_{des}}{H_{FB}} \tag{1}$$

Accordingly, the water level with vegetation would simply overtop the levee when $VFE > 100\%$.

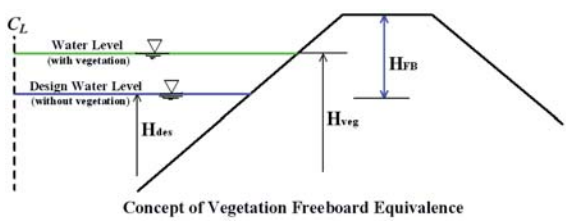


Fig. 1. Concept of Vegetation Freeboard Equivalence (*VFE*).

By analogy, a Vegetation Safety Factor SF_V can be defined as $SF_V=1-VFE$, or

$$SF_V = 1 - VFE = 1 - \frac{H_{veg} - H_{des}}{H_{FB}} \tag{2}$$

where H_{des} is the design flood stage (m) determined as the reference stage corresponding to the design discharge from the flood frequency analysis, H_{veg} is the calculated flood stage with vegetation (m) calculated using the numerical models, H_{FB} is the levee freeboard height (m) determined by the River Design Criterion shown as Table 1 [15]. Consequently, the vegetation effect would overtop the levee when $VFE > 1$ or $SF_V < 0$. The recommended criteria on the need to raise the levees in the perspective of increased vegetation are proposed in Table 2. The criteria are based on the analysis of the water levels from the 1-D and 2-D computer models with vegetation presented in this study.

Table 1. Levee Freeboard Height for Design Flood Discharge in South Korea

Design flood discharge Q_D (m^3/s)	Bank freeboard H_{FB} (m)	Design flood discharge Q_D (m^3/s)	Bank freeboard H_{FB}(m)
$Q_D \geq 200$	$H_{FB} \geq 0.6$	$2{,}000 \leq Q_D < 5{,}000$	$H_{FB} \geq 1.2$
$200 \leq Q_D < 500$	$H_{FB} \geq 0.8$	$5{,}000 \leq Q_D < 10{,}000$	$H_{FB} \geq 1.5$
$500 \leq Q_D < 2{,}000$	$H_{FB} \geq 1.0$	$Q_D > 10{,}000$	$H_{FB} \geq 2.0$

Table 2. Recommended Criteria for the Effect of Vegetation on Levees

SF_V (%)	Vegetation effect on water levels	Recommended action
$SF_V > 100$	Low	Maintenance
$50 < SF_V \leq 100$	Moderate	Low priority to raise the levees •
$0 < SF_V \leq 50$	High	High priority to raise the levees ●
$SF_V \leq 0$	Excessive - Water overflows the levees at the design discharge ●●●	

2.2 Flow Resistance

Frictional resistance to flow in open-channels without vegetation is associated with shear stress along the boundary. The bed shear stress τ_0 is applied at the interface between water flow and the wetted perimeter P. It is defined as $\tau_0=\gamma RS_f$, where γ is the specific weight of water, R is the hydraulic radius, and S_f is the friction slope, respectively. The evaluation of frictional resistance is based on the assumed proportionality between boundary shear stress and square of average velocity for a single coefficient of resistance. The shear stress is also proportional to the square of the shear velocity u_* defined from $\tau_0=\rho u_*^2$, which defines the shear velocity u_* from $u_*=(gRS_f)^{1/2}$.

There are three basic approaches to evaluate channel roughness without vegetation: (1) the Darcy–Weisbach friction factor f [$V=(8/f)^{1/2}(gRS_f)^{1/2}$]; (2) the Manning resistance coefficient n [$V=(1/n)(R^{2/3}S_f^{1/2})$]; and (3) the Chézy conveyance coefficient C [$V=C(RS_f)^{1/2}$], where V is the cross-section averaged velocity and R is the hydraulic radius and S_f is the friction slope. Both f and n describe resistance to flow, while C describes flow conveyance. It is also interesting to note that only f is dimensionless, while $C=L^{1/2}/T$ and $n=T/L^{1/3}$. Manning n values were calculated for various flow discharges in representative study reaches. In this study, values of Darcy-Weisbach f and Chézy C were then computed from Manning n using $f=8g(n/R^{1/6})^2$ and $C=R^{1/6}/n$, respectively [11].

2.3 Vegetation Roughness Coefficients

The determination of vegetation roughness coefficients has been somewhat of an art resulting from a vast experience dealing with theoretical advances in turbulence, experimental laboratory studies and empirical field measurements on rivers and streams since the compilation by Chow [7]. Roughness values for flood plains can be quite different from the values for the main channels; therefore, roughness values for flood plains should be determined independently from channel values. As in the computation of channel roughness, a base roughness is assigned to the flood plain, and adjustments for various roughness factors are made to determine the total Manning n value for the flood plain. Although much research has been done on Manning's roughness coefficient, relatively less has been done concerning the roughness values for densely vegetated flood plains. The n value is determined from the values of the factors that affect the roughness of channels and flood plains. In densely vegetated flood plains, the major roughness is caused by trees, grasses, and shrubs [10]. For a wooded flood plain, the vegetation-density method can be used as an alternative to the previous method for determining n values for flood plains. In a wooded flood plain, where the tree

diameters can be measured, the vegetation density of the flood plain can be determined.

In South Korea, the values for Manning n for flood plains can be determined by measuring the vegetation density of the flood plain [15]. Specific procedures can be used to determine the values for roughness coefficients in channels and flood plains. Manning n values for channels are determined by evaluating the effects of certain roughness factors in the channels. Two methods are available to determine the roughness coefficients of flood plains. One method, similar to that for channel roughness, involves the evaluation of the effects of certain roughness factors in the flood plain. The other method involves the evaluation of the vegetation density of the flood plain to determine the Manning n value. This second method is particularly suited to handle roughness for densely wooded flood plains.

2.4 MOCT Method

In South Korea, the analysis of flow in vegetated channels follows the method of the Ministry of Construction and Transportation and KICT [13]. The MOCT method was applied in this study. The approach is based on with vegetation in number of flow cross section and with vegetation only one side flood plain. The average flow velocity is calculated from $V=(8/f)^{1/2}(gRS_f)^{1/2}$ given the roughness coefficients due to channel friction with vegetation given as $f=\lambda+4c\omega R$ in this study, where λ= friction factor in bed or slope side, c= friction constant due to vegetation (1.0-1.5), ω= vegetation type in area per volume (m^{-1}) for grasses = 0.1-1.5, shrubs = 1.5-3.0, trees (detailed below) where d= tree diameter, a_x, a_y= distance between trees in x, y direction, respectively. The average flow velocity in vegetated channels is thus calculated from

$$V=\sqrt{\frac{8gRS_f}{\lambda+4c\omega R}} \tag{3}$$

Manning n in this study is then calculated by the MOCT method with the Chézy friction factor from Eq. (3) including the roughness from the River Vegetation Patterns (RVP) as shown in Fig. 2. The parameters in this flow chart are: A_f = cross-section area of flood plain, b_f= effect width due to vegetation calculated vortex flow width $b_N=3.2(a_y d)^{1/2}$ as a function of diameter d and distance between tree a_y, b_m= averaged width of cross-section without vegetation, P_f = wetted perimeter of flood plain (m), R_f= hydraulic radius of flood plain ($=A_f/P_f$), R_m= assumed hydraulic radius in order to calculate the initial friction factor λ_m, V_f = flood plain velocity with vegetation, V_m= main channel velocity not considering a separated flood plain, λ_f= friction factor due to vortex flow with a separated flood plain. Also, λ_m= friction factor determined by trial and error until approximately equal to λ_f from the assumed initial R_m, λ_{MT} and V_{MT}= friction factor and averaged velocity for total cross-section area with vegetation, respectively. The roughness coefficient is the n converted into a Manning n to simulate by the HEC-RAS and RMA-2 models.

2.5 Numerical Models

The calculation of flood levels with and without vegetation is carried out with the 1-D numerical model HEC-RAS [26] and with the 2-D model RMA-2 [5], respectively. These two models were selected because they are representative of frequently used 1-D and 2-D models. HEC-RAS is used as a standard method in the United States, and elsewhere. The RMA-2 model has been selected here for comparison with 1-D modeling results.

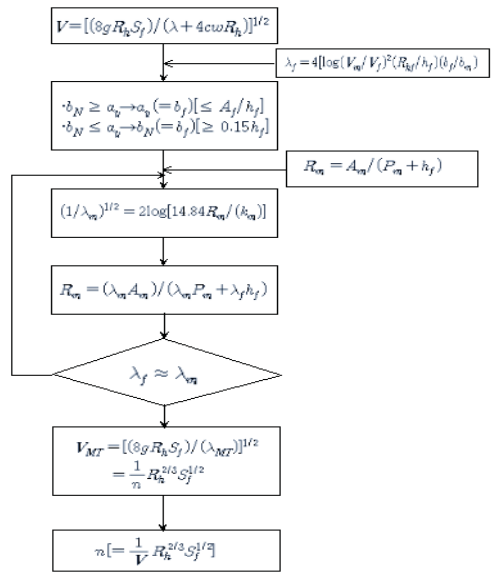


Fig. 2. Flow Chart for Calculation of Vegetation Density in the RVP

2.5.1 One-dimensional model HEC-RAS: HEC-RAS is a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers [26]. The system is capable of modeling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, a dendritic system, or a single river reach. The model results are routinely applied in floodplain management and flood insurance studies in order to evaluate the effects of floodway encroachments. At each cross-section, HEC-RAS uses several input parameters to describe shape, elevation, and relative location along the stream. River stations (cross-section) number, lateral and elevation coordinates for each (dry, unflooded) terrain point are also required as well as left and right bank station locations. Reach lengths between the left floodway, stream centerline, and right floodway of adjacent cross-sections represent the main three reach segments of a cross section. For steady and gradually varied flow, the primary procedure for computing water surface profiles between cross-sections is called the direct step method (HEC-RAS also supports the momentum, WSPRO bridge, and Yarnell methods). The basic computational procedure is based on the iterative solution of the energy equation.

Many field investigations on the validation of HEC-RAS have been presented in the recent literature: Brunner [3] on hydraulic reference manual for river analysis system; Ackerman *et al.* [1] about new floodplain delineation capabilities in HEC-RAS; Stevenson [23] on 1-D HEC-RAS model and sensitivity analysis for St. Clair River from 1971–

2007; Mashriqui and Aschwanden [18] on toward modeling of river-estuary-ocean interactions to enhance operational river forecasting in the NOAA National Weather Service; Timbadiya *et al*. [25] about calibration of HEC-RAS model on prediction of flood for lower Tapi River, India, respectively.

2.5.2 Two-dimensional model RMA-2: The Surface Water Modeling System (SMS) is a comprehensive computational software package for 1D, 2D, and 3D hydrodynamic modeling[5]. The numerical models supported in SMS-2D compute a variety of information applicable to surface water modeling. Primary applications of the models include calculation of water surface elevations and flow velocities for shallow water flow problems, for both steady-state or dynamic conditions. New enhancements and developments continue at the Environmental Modeling Research Laboratory (EMRL) at Brigham Young University in cooperation with the U.S. Army Corps of Engineers Waterways Experiment Station (USACE-WES), and the US Federal Highway Administration (FHWA). Analysis results from any of the models in SMS can be output or displayed graphically using a variety of plots, including vector plots, contour plots, color-shaded contour plots, and time-history plots. Contour plots and color-shaded contour plots of water surface elevation, velocity, discharge, contaminant concentration, and bed scour and deposition can easily be generated for any of the computed time-steps. It has also been frequently applied to engineering designs projects for bank protection and grade-control structures which must extended below the potential channel bed scour and withstand the design flood.

Applications of the 2D-model RMA-2 have been presented such as Gee *et al*. [9] on 2-D floodplain modeling; Swindon *et al.* [24] about ungauged watershed modeling-utilization of hydraulic models for validation; Wagner and Mueller [27] on calibration and validation of a 2-D hydrodynamic model of the Ohio River; Bruxer and Thompson [4] about St. Clair River hydrodynamic modeling using RMA-2, respectively.

Both models have been also used in South Korea. For instance, Park *et al.* [20] have used both models for applications on the Lower Nakdong River in a recent report for K-Water on the Improvement of Maintenance Enhancement Methods for the Nakdong River Estuary Barrage. The selected models are therefore appropriate for the analysis of river restoration problems.

3. STUDY SITES FOR RIVER RESTORATION

Rivers in South Korea are classified as large, medium, or small depending on the design flood discharge Q_D in m^3/s and the drainage area A_r in km^2 as shown in Table 3 [17] ,[19].

Table 3. South Korean River Classification

River type	Design flood discharge Q_D (m^3/s)	Drainage area (km^2)	Remarks
Large	$Q_D > 10{,}000$	$A_r > 1{,}000$	· Q_D = Design flood discharge · A_r = Drainage area
Medium	$5{,}000 < Q_D \leq 10{,}000$	$10 < A_r \leq 1{,}000$	
Small	$Q_D \leq 5{,}000$	$1 < A_r \leq 10$	

3.1 Description of the Three Field Study Sites

Three reference river reaches (one large, one medium and one small) of the Geum River were selected for this study. The location map of the study sites is shown in Fig. 3 and a brief summary of the main river characteristics is presented in Table 4.

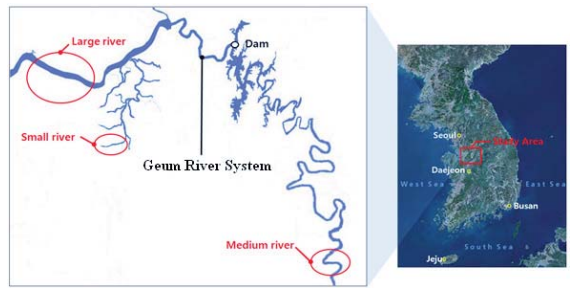


Fig. 3. Study Site in Geum River System

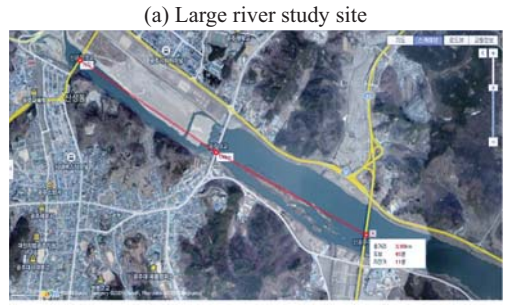
Table 4. Summary of Hydraulic Geometry of the Three Field Study Sites

River type	Station	Reach length (m)	Normal level		Flood level	
			Width (m)	Depth (m)	Width (m)	Depth (m)
Large	Chungnam Gongju	3,000	250	3	420	15
Medium	Chungbuk Youngdong	1,000	80	1	210	7
Small	Chungnam Gongju	200	6	0.3	22	2.2

3.2 Large River Study Site

Fig. 4 illustrates the field study conditions for the large river site near Chungnam Gongju on the Geum River basin. A photo of the site (Fig. 4a) is complemented with an aerial photo (Fig. 4b) of the field study site.

(a) Large river study site



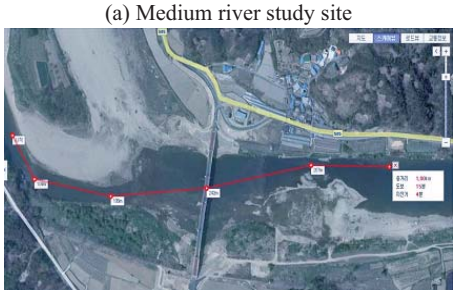
(b) Aerial photo

Fig. 4. Field Conditions of the Large River Study Site on the Geum River

3.3 Medium River Study Site

Fig. 5 illustrates the field study conditions for the medium river study site near Chungbuk Youngdong on the Geum River basin. A photo of the site (Fig. 5a) is complemented with an aerial photo (Fig. 5b) of the field study site.

(a) Medium river study site



(b) Aerial photo

Fig. 5. Field Conditions of the Medium River Study Site on the Geum River

3.4 Small River Study Site

Fig. 6 illustrates the field study conditions for the small river study site near Yongsu stream of the Geum River basin. A photo of the site (Fig. 6a) is complemented with an aerial photo (Fig. 6b) of the field study site.

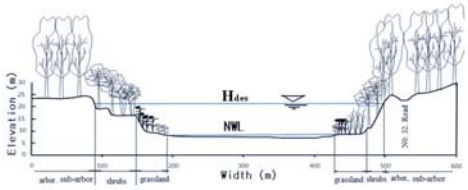
(a) Small river study site

(b) Aerial photo

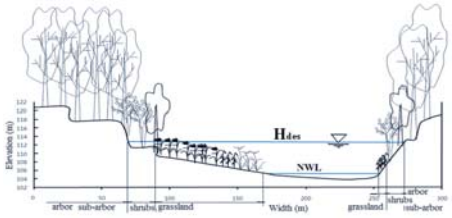
Fig. 6. Field Conditions of the Small River Study Site on the Geum River

3.5 River Vegetation Patterns for River Restoration

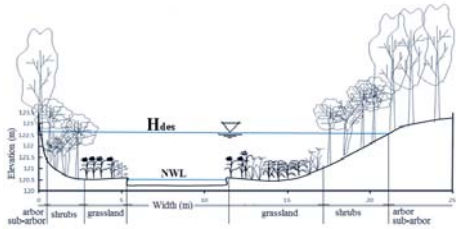
A study of River Vegetation Patterns (RVP) for the restoration of the three sites is shown in Fig. 7 [19]. Different vegetation patterns are being considered for the three different sites. On the large river in Fig. 7(a) the RVP is composed trees, shrubs and grasses, including *Salix gracilityla Miq*., *Salix integra Thunb.*, and tree species of *Salix koreensis*, *Salix grandulosa*, *Salix nipponica*.



(a) Large river



(b) Medium river



(c) Small river

Fig. 7. RVP for the Restoration of the Three Study Sites

Vegetation for the medium river shown in Fig. 7(b) includes grasses and shrubs including primarily *Salix integra Thunb., Rosa multiflora*, and some sub-arbor and arbor species of *Salix koreensis, Acer ginnale Maxim.*, respectively. In the case of the small river, Fig. 7(c) shows the RVP grassland and shrubs including primarily *Salix gracilityla Miq., Rosa multiflora*, and tree species like *Salix koreensis, Acer ginnale Maxim., Morus bombycis Koidz*. The vegetation density from these RVP has also been investigated. Table 5 summarizes typical characteristics of the number and size of shrubs and trees for the three river types.

Table 5. Vegetation Density per Number and Size of Shrubs and Trees for the Three River Types

River type		Vegetation density per 100m²	
		Shrubs	Trees
Large	Tree number(-)	2.4	0.88
	Mean dia.(m)	0.080	0.138
Medium	Tree number(-)	2.6	1.1
	Mean dia.(m)	0.080	0.199
Small	Tree number(-)	2.0	1.4
	Mean dia.(m)	0.067	0.147

4. MODEL APPLICATIONS AND SIMULATION RESULTS

The application of the concept of Vegetation Freeboard Equivalence has been carried out by comparing 1-D HEC-RAS and 2-D RMA-2 simulation for the large, medium and small rivers.

4.1 HEC-RAS Simulation Results

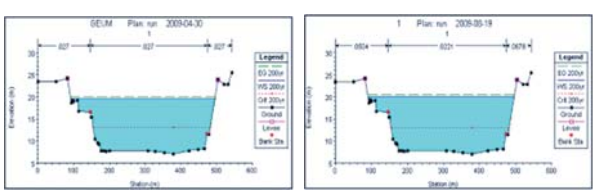
The hydraulic characteristics for each station and cross section were used for the HEC-RAS simulation of the large, medium and small rivers respectively. A summary of the mean conditions for the HEC-RAS simulations without vegetation is shown in Table 6. The hydraulic conditions to calculate for flood stage in large, medium and small rivers using HEC-RAS are also summarized in Table 7 and the results with vegetation are also shown in Fig. 8.

Table 6. HEC-RAS Simulation Conditions without Vegetation for the Three River Types

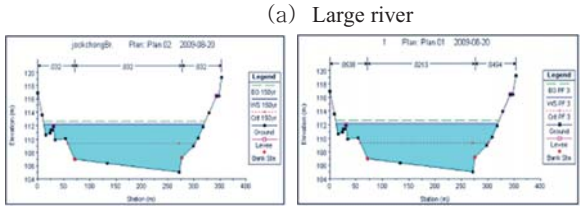
Boundary conditions	Large river	Medium river	Small river
Design flood discharge Q_D (m^3/s)	11,800 (200yr)	3,960 (150yr)	195 (100yr)
Design flood stage H_{des} (EL.m)	19.18	112.10	122.82
Bed slope S_f `(m/m)	1/5,000	1/1,191	1/245
Manning n coefficient	0.027	0.032	0.032

Table 7. Comparison of Hydraulic Conditions with and without Vegetation during Floods Using HEC-RAS

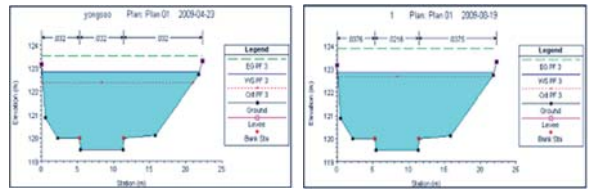
Hydraulic conditions		Without vegetation			With vegetation		
		Left	Main	Right	Left	Main	Right
Roug. Coef.f	L	0.027	0.027	0.027	0.050	0.027	0.068
	M	0.032	0.032	0.032	0.0538	0.032	0.0494
	S	0.032	0.032	0.032	0.038	0.032	0.037
Area (m^2)	L	117.97	3791.27	111.68	144.85	3948.31	122.44
	M	136.80	1,289.84	130.58	131.50	1,271.55	126.74
	S	11.81	17.22	19.25	12.51	18.01	20.61
Mean velocity (m/s)	L	0.97	3.03	1.67	0.46	2.96	0.53
	M	1.39	2.75	1.68	0.58	2.98	0.78
	S	3.64	4.78	3.63	2.61	4.99	2.64
Disch. (m^3/s)	L	114	11,488	186	67	11,687	65
	M	190	3,547	219	76	3,789	99
	S	43	82	69	33	90	54



(a) Large river



(b) Medium river



(c) Small river

(1) Without vegetation (2) With vegetation

Fig. 8. Comparison of Flood Stages Calculated with RVP Using HEC-RAS

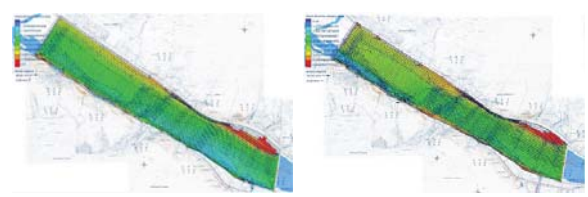
4.2 RMA-2 Simulation Results

The main characteristics of the RMA-2 mesh network and element scale for the two-dimensional simulation of flood stages during floods with vegetation are listed in Table 8. The calculated velocity profiles with and without vegetation and the water surface elevation profiles are shown in Fig. 9 for the three river types, respectively.

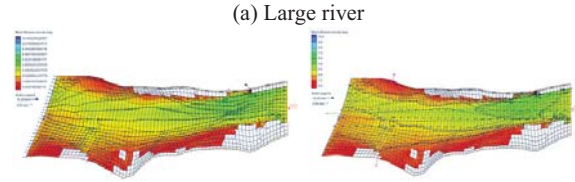
Table 8. Mesh Size Characteristics and Boundary Conditions for the RMA-2 Simulations

Rv	Node No.	Elem. Scale (m)	Elements			Boundary conditions		
			Rec.	Tri.	Total	T. D. Coef. (Ns/m²)	Dis. (m^3/s)	W.L. (EL.m)
L	12,041	20×20	3,622	412	4,034	1,500	11,800	19.18
M	3,966	20×20	1,158	155	1,313	1,000	3,960	112.10
S	1,858	3×3	575	1	576	1,000	195	122.82

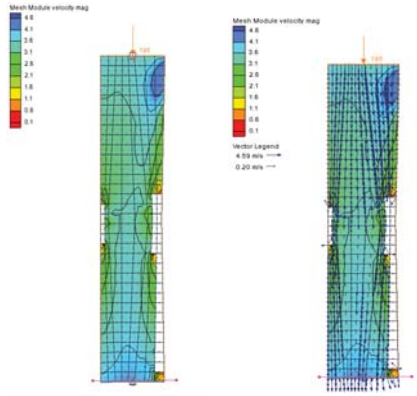
From RMA-2, the mean flow velocity with and without vegetation are shown to increase by 2~15% in the main channel with a corresponding decrease by 8~27% on the overbank flows. The main results are summarized in Table 9 for the large, medium, and small river. It is important to notice that vegetation primarily decreases the flow velocity on the floodplain an increases velocity in the main channels. The effects are more pronounced in large rivers than in small rivers.



(a) Large river



(b) Medium river



(c) Small river

(1) Without vegetation (2) With vegetation

Fig. 9. Profiles of Velocity Calculated by RMA-2

Table 9. Comparisons of Mean Velocity Calculated by RMA-2 in RVP

River type	Main channel			Left and right channel		
	WO veg.	W veg.	Var.	WO Veg.	W Veg.	Var.
Large	2.78 m/s	3.21 m/s	+15%	2.67 m/s	1.95 m/s	-27%
Med.	3.04 m/s	3.21 m/s	+8%	1.46 m/s	1.01 m/s	-25%
Small	3.23 m/s	3.29 m/s	+2%	3.27 m/s	3.01 m/s	-8%

4.3 VFE Analysis

Table 10 shows the applicability of the Vegetation Freeboard Equivalence concept to three types of rivers studied in this article. In the case with vegetation, the freeboard height is adequate for the large river. However, the levees would need to be raised for the medium and the small rivers. The results without vegetation are quite similar between the two models HEC-RAS and RMA-2. However in presence of vegetation, the differences between the two models become more pronounced, and this is particularly true for the medium and small rivers.

Table 10. Evaluation of the Levels with Vegetation Density for the Three Sites Studied

Ri	Dis. (m)	H_{des} (m)	Num. model	Water level (m)		SF_V (%)		Recom.	
				WO veg.	W veg.	WO veg.	W veg.	WO veg.	W veg.
L	0	19.21	RAS	19.21	19.21	100	100		
			RMA	19.38	19.38	91.5	91.5	•	•
	430	19.23	RAS	19.21	19.28	101	97.5		•
			RMA	19.39	19.40	92.0	91.5	•	•
	940	19.28	RAS	19.26	19.45	101	91.5		•
			RMA	19.41	19.42	93.5	93.0	•	•
	1,450	19.37	RAS	19.35	19.79	101	79		•
			RMA	19.44	19.48	96.5	94.5	•	•
	1,990	19.44	RAS	19.40	19.85	102	79.5		•
			RMA	19.45	19.50	99.5	97	•	•
	2,040	19.57	RAS	19.53	20.01	102	78		•
			RMA	19.43	19.67	107	95		•
	2,440	19.78	RAS	19.73	20.16	102.5	81		•
			RMA	19.60	19.95	111	99.5		•
	2,790	19.83	RAS	19.61	20.22	111	80.5		•
			RMA	19.60	19.95	111.5	94		•
M	0	112.10	RAS	112.10	112.32	100	81.67		•
			RMA	112.10	112.10	100	100		
	180	112.10	RAS	112.07	112.45	102.5	70.83		•
			RMA	112.13	112.22	97.50	90	•	•
	350	112.11	RAS	112.17	112.53	95	65.00	•	•
			RMA	112.20	112.41	92.50	75	•	•
	570	112.37	RAS	112.26	112.66	109.17	75.83		•
			RMA	112.38	112.53	99.17	86.67	•	•
	860	112.51	RAS	112.34	112.87	114.17	70.00		•
			RMA	112.52	112.61	99.17	91.67	•	•
	1020	112.53	RAS	112.59	113.26	95	39.17	•	●
			RMA	112.55	112.74	98.33	82.50	•	•
	1,220	112.67	RAS	112.76	113.52	92.5	29.17	•	●
			RMA	112.72	112.89	95.83	81.67	•	•
S	0	122.82	RAS	122.82	123.10	100	53.33		•
			RMA	122.82	122.82	100	100		
	50	122.82	RAS	123.39	123.21	21.67	35.00	●	●
			RMA	123.08	123.18	56.67	40	•	●
	100	122.82	RAS	123.00	123.63	70	-35.00	•	●●●
			RMA	123.10	123.22	53.33	33.33	•	●

5. CONCLUSIONS

The concept of vegetation freeboard equivalence (*VFE*) is detailed in this article. The rise in flood stage from the added vegetation is compared with the freeboard height under design flood discharge conditions. Three rivers in South Korea have been modeled with and without vegetation using the 1-D model HEC-RAS and the 2-D model RMA-2. The vegetation safety factor is defined from the *VFE* for each of the three reaches of the large, medium and small river selected for the study analysis. The main conclusions of this study are:

1. All models show that floodplain velocity decreases and channel flow velocity increases when adding floodplain vegetation.
2. Without vegetation, both models HEC-RAS and RMA-2 adequately predict the flood stages of the large and medium river. The small river is however more subject to spatial variability in flood stage levels.
3. The effects of vegetation on freeboard height are most important in small river systems. The vegetation effects on the medium river are less significant, and the freeboard is adequate to contain the rise in stage from the added floodplain vegetation in large rivers.

Note that these conclusions may not be universally applicable to all large, medium and small rivers. However, the novel *VFE* approach described in this paper with HEC-RAS and/or RMA-2 may be very useful in river restoration projects.

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