Effect Of Vegetation Density On The Hydrodynamic Of SubmergedVegetatedFlow

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Abstract

Vegetation density affects the hydrodynamic of flowfield,increasingthehydraulicroughnessscale;acceleratetheconversionofmeankineticenergyinto turbulent kinetic energy at the scale of the plantstemsandbranches.Thisstudypresentsthelaboratory experiment on the effect of increase invegetationdensityusingPIVtechniques.Thevegetation densities was varied while the channelbed-slopeandsubmergencedepthwerekeptconstant.Theresultsshowedaremarkablereduction in flow rate, resulting in high turbulentshear stresses at the top of vegetation layer. It isevidentthatvegetationdensityisasignificantvegetation parameter on the induction of hydraulicroughness.

Keywords: *Hydraulic roughness, submergedvegetation,vegetationdensity*

1. Introduction

Freshwaterandsaltwaterwetlandsareimportantmediumbetweenaquaticand terrestrialsystems,mediatingexchangesofsediment (Phillips, 1989), metals (Orson et al.,1992),nutrients(Nixon,1980)andothercontaminants(DixonandFlorian,1993).Aquaticplantscontroltheseexchangesbothdirectlythroughuptakeand biologicaltransformationandindirectlybychangingthehydrodynamicconditions.Theyare,therefore,fundamentalcomponentsofanaturalwaterenvironment,andthecurrentenvironmentalrivermanagementpreferstopreservenaturalwetland and floodplain vegetation, although a lotof aquatic plants have been removed to preventwater disaster in actual rivers. Currently, aquaticplantsenvironmentshavereachedadifferent status.

Vegetation is no longer regarded merelyas an obstruction to the movement of water, butrather as a means of providing stabilization forbanks and channels (Lopez and Garcia, 2001),habitatandfoodforanimalsandpleasing landscapes for recreational use (M.Zhang et al.,2012).Therefore,thepreservationisofgreatrelevancetoecologyofnaturalandartificialsystems. Hence, the hydro-mechanic interactionbetween the flow and vegetation elements needsto bestudied.

Uniformflowinanopenchannelorriver is characterized by depthwise logarithmicshear velocity and turbulence. The presence ofvegetation interrupts the shear and increases theturbulenceinthevegetationregion.Alargescale of coherent vortex is generated near thecanopyedge,whichdominatethemomentumand scalartransportthroughandoverthecanopy.Therefore,estimationoftheflowresistanceofvegetationflowsisofgreatimportancetoriverengineers.

Thepresenceofvegetationalongtheopen channel called for vegetation term. It hasbeenestablishedbyvariousresearchthatthepresence of vegetation in a channel induced flowresistance in the channel. Based on the researchconducted by (Carollo et al, 2005 and Baptist etal, 2007), the flow resistance depends on shearReynolds number, the relative submergence anddegreeofvegetationinflection(afunctionofflexibilityandstemdensity).Theexperimental

Busari et al, (2013a) evaluates the bestprobability distribution model for the predictionofrainfall-runoffforTagwaibasin,andsuggestedappropriate modelfortheestimationofannualrunofffromthebasin.Theoverflow

contribution of Okamoto and Nezu, (2010) onrelationship between the vegetation motion andflowresistancepropertyinavegetatedopenchannel flow showed influence of flexibility ofvegetationontheturbulencestructureandinflection point. Nikora et al, (2008) studied theimpact of vegetation on hydraulic resistance andsuggested simple quantitative relation to predictthese effects based on vegetation parameter. Theresearch has provided relative improvement intheunderstandingof vegetationresistance.

The vegetated open-channel flows havereceivedmuchattentioninthepastdecades.However, in such vegetated open-channel flows,both the vegetation parameters and turbulencecharacteristicsmayaffectthehydrodynamicbehaviourofflows.Therefore,inthepresentstudy,theeffectofvegetationdensityandassociatedturbulencecharacteristicswerestudied in laboratory flume using PIV technique.Thefocusofthisstudyisspecifically,tounderstand the impact of vegetation density onthehydrodynamicofflowfieldsasitisbecominga significantissueinvegetatedwaterways. The practical significance has beenobservedalongtheriverchannelatthedownstreamofTagwaidamleadingchannelwideningand flooding.

fromTagwai (weir) is the chief source erosion tothe downstream channel along which Chanchagabridge is located.This has been the subject oflocal scouron the bridge piers.

Recently,Busarietal,(2013b)examinedth elocalscouronthebridgepierusingonsite-empiricalmodelsapproachandsuggestedthesuitabilityofthemodelsfuturemeasurement.However,duringlowflowvegetationgrowthareun-avoidable,itretardsflowandallowssedimentdeposition.This results in increase in water level and subsequentflooding. This study is based on experimentalstudy and no specific model scale is taken intoconsideration. Hence aspect ratio is not requiredand the results can be generalized for vegetatedchannelflows.

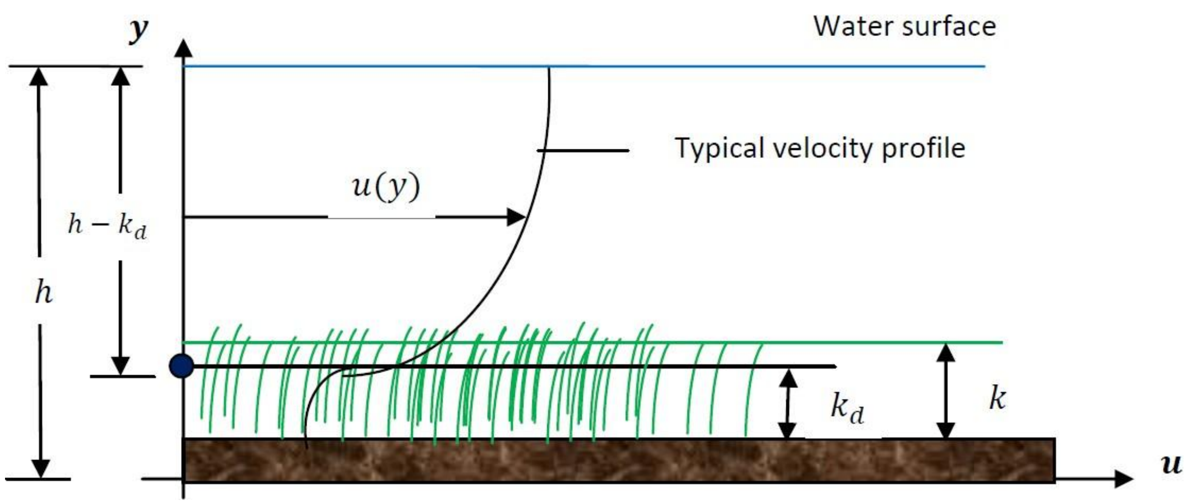


Figure1: Definitionsketch forthe usedvariables

2. Background:Velocityprofileand resistance

Ithasbeenshownthatwhenvegetationis sufficientlysubmerged,theverticaldistributionofvelocityabovethevegetationlayerobeysa logarithmicprofile.Acommonapproachtothedeterminationofflowresistanceisbasedon relatingaroughnessfactor$f$tomeancross-sectionalvelocity$U_m$and shearvelocityu_*as

$$\frac{U_m}{u_*}=\sqrt{\frac{8}{f}} \quad (1)$$

ThevelocityprofileisgivenbyPrandtl'sloglawmodifiedbyNikuradse as:

$$\frac{u}{u_*}=\frac{1}{\kappa}\ln\frac{y}{y_o}+A \quad (2)$$

WhereκisvonKarmanconstant;,isequivalent sand roughness; y,vertical coordinate;and$A$isconstantofintegration.Theintegration ofequation (2) yieldsthe meanvelocity, U_m.Stephan,(2002)modifiedtheloglawandderived anequationforthevelocityprofile above vegetationcanopy

$$\frac{u}{u_*}=\frac{1}{}\ln\frac{y-kd}{k_d}+8.5 \quad (3)$$

Where $=0.4$ and k_d = mean deflected heightof vegetation (see Figure **1**).In this study, therelativesubmergence $/k$iskeptconstantthroughout the experiments while the vegetationdensityremainsvariable.Basedonthesensitivityanalysisontheshearvelocitydetermination, the shear velocity in this study isdefinedas:

$$u_*=\sqrt{(\ -k_d)S_o} \quad (4)$$

Equation(4)hasbeentestedamongotherdifferent definitions of shear stresses as it offersbetterpracticalapplicabilitythantheoriginalformulation$u_*=\sqrt{-(u^l v^l)_{max}}$whichrequired complicated turbulence measurements (Jarvela,2005).Moresignificantly,equation(4)isadoptedinthisstudybecauseitisstraightforwardtoapplywithinanumericalmodeling framework, which is part of our futurefocus relating hydraulic roughness parameter forTagwai basin.

Wilson,etal.(2003),TamandLi,(2005),OkamotoandNezu,(2010)havedefined vegetationdensity a asthetotalfrontalarea Apervegetation volume V asshowninequation(5).

$$a=\frac{A}{V}=\frac{n*w}{S}=n\frac{w}{S} \quad (5)$$

$$=a \quad (6)$$

Where n is the number of vegetation elementsallocated in the area $S=60cm\times 60cm$ on thechannel and the frontal area of one vegetationelement is $w=100mm\times 6mm$ in this study.For this study $=a$ is used as the vegetationdensity because it is a dimensionless factor andtherefore,canbecomparedwithterrestrialcanopyflow(forexample,Raupachet,al.1996).

3. Experimentalsetup

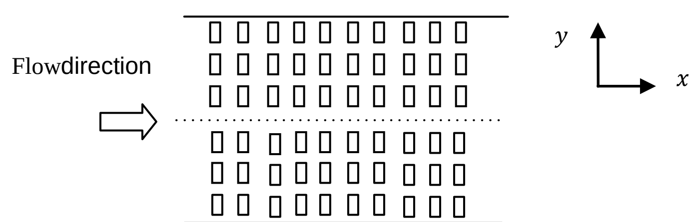
3.1 Hydraulicconditionsandvegetation model

Theexperimentswereconductedina 12.5 m long and 60 cm wide tilting flume. ThesidesweremadeofopticalglassforParticleImage Velocimetry (PIV) measurements. The setupconsistsofvaryingvegetationdensity$=a$ onturbulencestructureforconstantsubmergencedepth, i.e., $/k$ = 3.0 .Table1showsthehydraulicconditionsinwhich$U_m$is themeanbulkvelocity,$F_r\equiv U_m/\sqrt{g}$ and $R_e=U_m/\nu$ are Froude number and Reynoldsnumber respectively.

Table1: Hydraulicconditions

λ	U_m (m/s)	h(m)	u_*(m/s)	S_o (-)	K_d (m)	F_r	Re
0.170	0.458	0.225	0.075	0.0036	0.072	0.305	103050
0.420	0.327	0.225	0.073	0.0036	0.078	0.218	73575
0.830	0.257	0.225	0.071	0.0036	0.084	0.171	57825
1.250	0.226	0.225	0.070	0.0036	0.086	0.151	50850
1.670	0.207	0.225	0.069	0.0036	0.09	0.138	46575
2.080	0.194	0.225	0.069	0.0036	0.09	0.129	43650

Theelementsofvegetationmodelwerecomposed of strip plates with flexural rigidity of4.75Nm^2.Thesizeofonevegetationelementwas$k$ =100mmheight,d=6mmwidthand t = 1mm thickness. The elements were attachedvertically on the channel bed using the miniaturelego blocks as shown in Figure **2**. A transitionzone of 1 m length was set from the channelentrance.Then,thevegetationzonewassett hrough9mlengthinthestream-wisedirection andthefullchannelwidthof B=60 cm inspan-wisedirection.$L_v$and$B_v$arethestreamwiseand spanwise spacing betweentheneighbouring vegetation elements, respectively.Theydecreasewithincreasein.Theme asurement was set 6.5 m downstream of theleading edge of the vegetation, i.e., x = 0. Thepreliminaryrunsfoundthattheflowatthemeasur ementzone$x$ = 6.5 $m$wasfullydevelopedand uniformtwo-dimensionalone.



Vegetationpattern

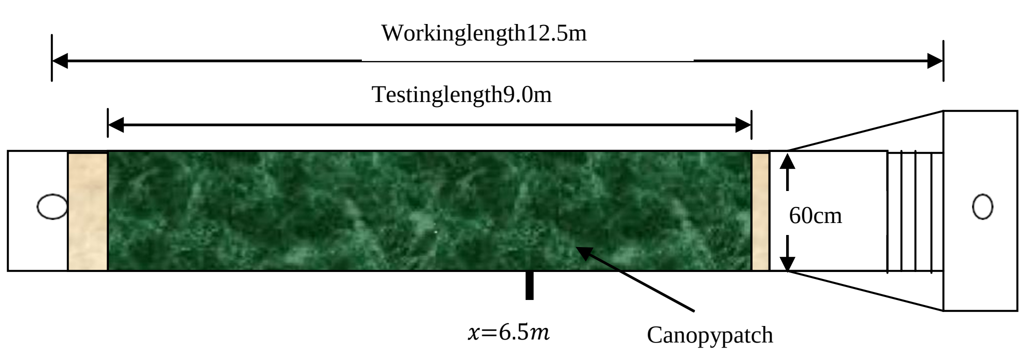
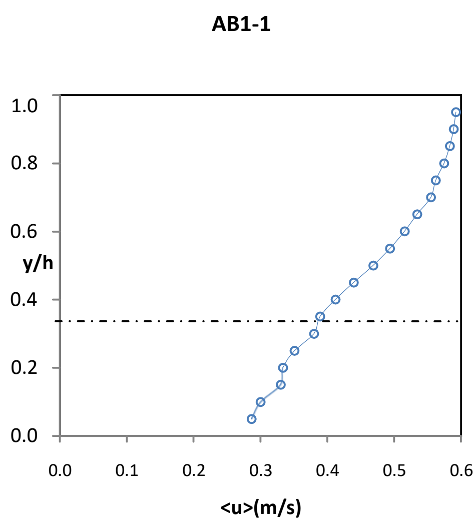
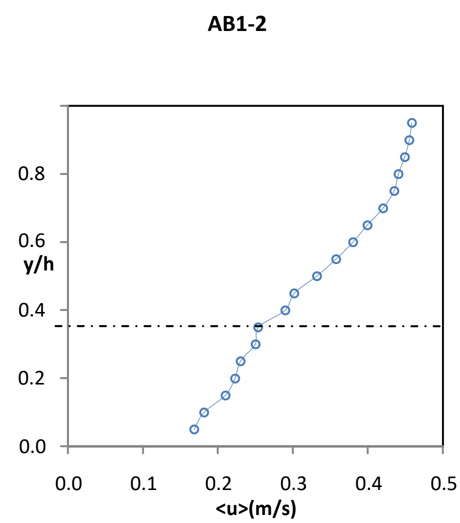


Figure2: Schematicexperimentalsetup

3.2 ProceduresofPIVmeasurements

Alaserlightsheet(LLS)wasprojected into the water vertically from thefreesurface.The2mmthickLLSwasgenerat edby2WArgon-ionlaserusingacylindrical lens and fiber-optical cable. TheilluminationpositionofLLSwaslocatedat $x = 6.5$ .Theilluminatedflowpicturesweretakenbyahi ghspeedCCDcamera ($1\times 1K$pixels)withtheframe rateandsamplingtimewereset200Hzand60s,re spectively.Thediameterandspecificdensityoft racerparticles(Nylon12)were 0.1 and 1.02, respectively. The instantaneousvelocityvectors$(\tilde{u},\tilde{v})$ in the vertical plane of$(20\times 20cm)$and the resolution was 0.2





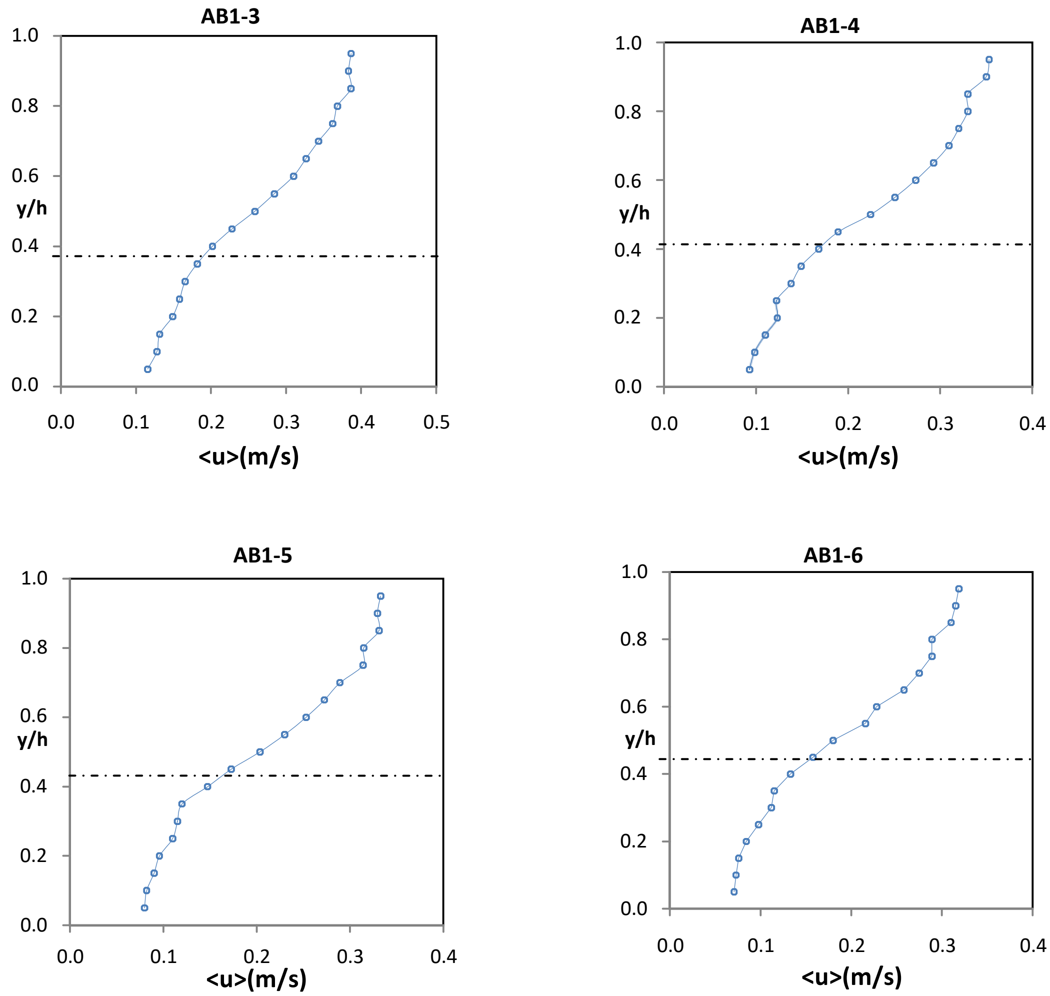


Figure3: Meanvelocityprofileandnormalizedflowdepth.Thedashedlinedenotesthe meandeflectedplant height(seeTable1for seriesdescription).

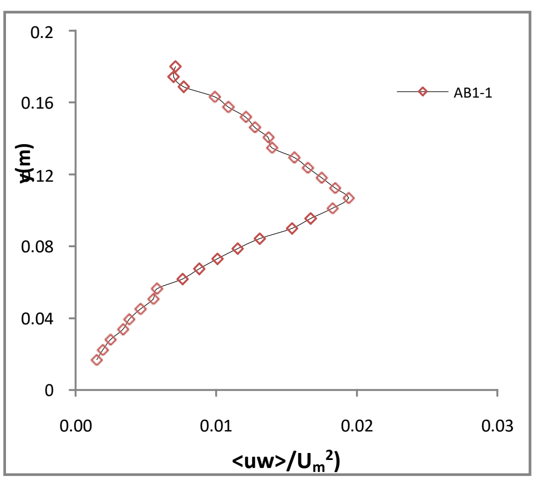
mm/pixelweremeasuredusingavailablestandardPIVsoftware.Moredetailedinformation about PIV is available in Nezu et al,(2007),Okamoto and Nezu, (2010).

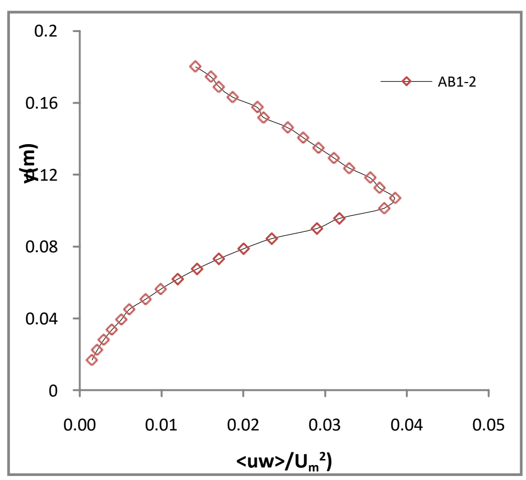
4. Resultsanddiscussion

Figure**3**,showedvelocitydistributionprofile, water depth was normalized by depth *y*,abovethechannelbed.Theflowreduceswith increaseinvegetationdensityunderconstantsubmergencedepth.Overall,theobservedvelocityprofilesabovethedottedlinewerecomparable to typical profiles above vegetation.Thus, the flow above the vegetation reasonablyfollowedthelogarithmiclaw.Strongershearlayer near the top of the canopy is produced andasignificantinflectionpointappearsneartheveg etationtop($=k$),whichisingoodagreement withOkamotoandNezu,(2010).

Thedeflectedheightofvegetation(dotted lines,Figure**3**)showedthatdeflectiondecreases withincreaseinvegetationdensityduetoadditional increase in drag from the vegetation.Consequently, the hydraulic roughness increasesasvelocityisreduced.Doublingvegetationdensitycouldresultin25%attenuationofdischarge as shown in the velocity profile; thiscouldincreasethelevelofuncertaintyintheforecast of lead time. From Table 1, the Froudenumberswerelessthanunity,indicatingsubcriticalflowthroughouttheexperiments.However, the Reynolds numbers were found tobe within the range of (40,000 – 105,000). Thissignifies the level of turbulence in the flume as acharacterizationofflowregime.

Figure**4**,showstheverticaldistributionofReynolds stress$-\overline{uw}$normalized by the bulk meanvelocity$U_m$for different vegetation densitymodels. The ratio of $-\overline{uw}/U_m^2$ isa measure of momentum exchange efficiency. Thestrongshearlayernearthevegetationedgegenerate large scale coherent vortex and largermomentumistransportedtowardswithinthevegetation.Thisincreaseasthevegetationdensity increases, resulting in higher turbulentshears. The maximum turbulence intensity wasfound at the interface of the vegetation layer.Infigure **5**, the measured velocity was correlatedwith the predicted velocity using equation(3),theresultsshowedagoodagreement.Furthermore,Figure**6**,showedtheroughnessincrease withincreaseinvegetationdensity.This implies that vegetation density increase thehydraulic resistance. Consequently, the frictionfactorincreasesas $k_d$becomeslarger,thereby,increasingthe water level.





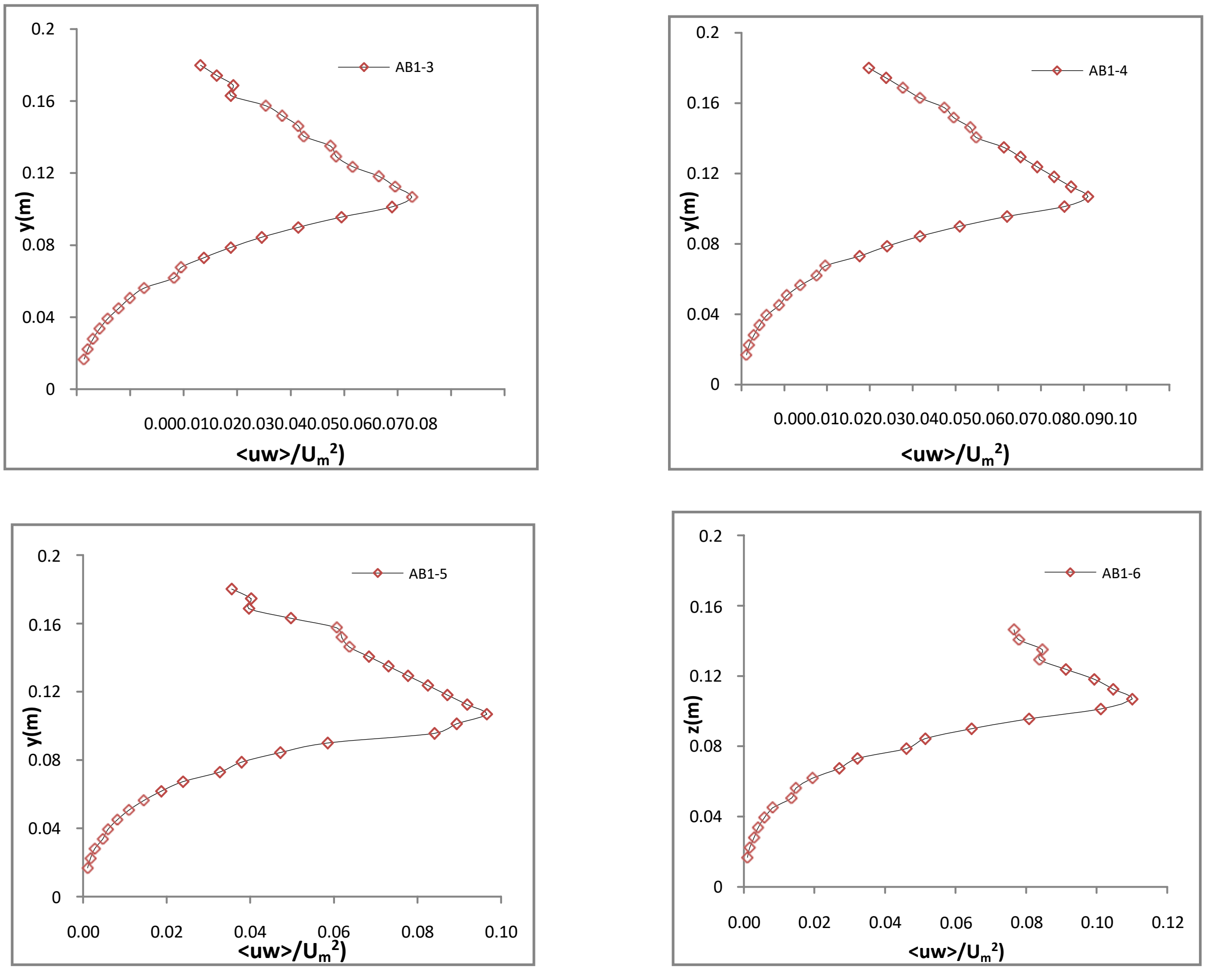


Figure4: VerticaldistributionofReynoldsstresses

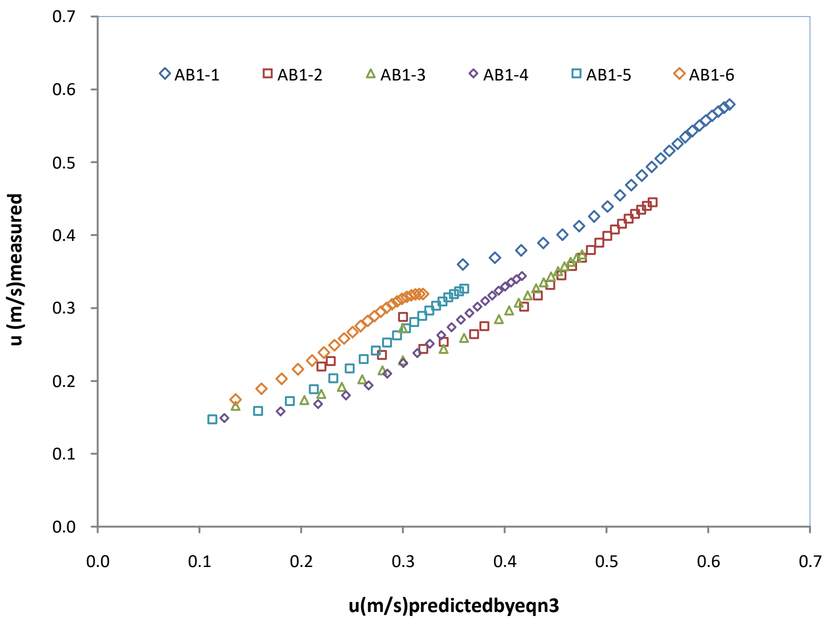


Figure5:Velocitymeasuredandpredictedbyequation(3)

Thefittedmodelforthevariationofvegetationdensit iesandthecorrespondingfrictionfactoris wellrepresentedbyequation(7).

$$f= 0.669\lambda^{0.6297} \quad (7)$$

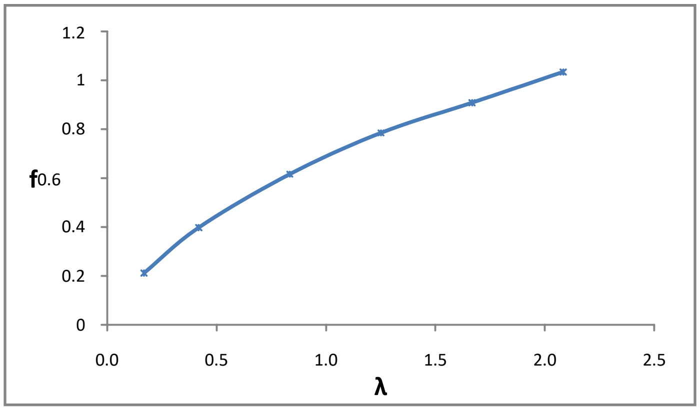


Figure6:Variationofvegetationdensitywithfrictionfactor

5.Conclusions

Theflowstructurewithinandabovesubmerged artificial canopy was comparable toprevious studies involving submerged vegetation.The velocity profile is more of “S” shape and thepeakReynoldsstresseswerefoundcorrespondin gthetopofthevegetation.Theflowvelocityfarabovet hevegetationobeyslogarithmic law when compared with equation(3).Thesimpleshearvelocitydefinitionofu_*in equation (4) based on the mean deflected plantheight yielded good results. The friction factorandReynoldsstresseswerefoundtobeincreasi ng with increase in vegetation density.This is an indicator that vegetation density is arelevantparameterfordescribinghydraulicroughn essinvegetatedflow.Theimpactofvegetationdensit yonthehydraulicroughnesswas revealed. Special attention is required on theeffect of vegetation density in river restorationandfloodriskmanagement.

References

Baptist,M.J,Babovic,V,Keijzer,M,Uttenbogaard, R.E, Mynett, A and Verwey, A(2007). Oninducingequationsforvegetationresistance.Journal of Hydraulic Research, Vol.45, No. 4, pp435 -450.

Busari A. O, Saidu, M and Ajibola, S, (2013a). Evaluation of Best Fit Probability DistributionModels for the Prediction of Rainfall and RunoffVolume(CasestudyTagwaidam,Minna-Nigeria).InternationalJournalofEngineeringandTechnologyUK, Volume 3No. 2, pp 94-98

BusariA.O,GbadeboA.O,JimohI.O,Takeet,O.E andEnifu,J.E,(2013b). Evaluation of performance of empirical modelsfor the prediction of local scour at bridge piers(Case study Chanchaga

Bridge, Minna, Nigeria).International Journal of Engineering Research &Technology(IJERT).Vol.2 Issue 3, pp 1-11.

Carollo,F.G.,Ferro,V.andtermini,D(2005): Flow resistancelawin channels with flexiblesubmergedvegetation.JournalofHydraulic Engineering, Vol.131, No.7.,pp 554-564.

Dixon, K. and Florian, J., (1993). ModellingmobilityandeffectsofcontaminantsinWetlands. Environmental Toxicology Chem., 12,2281-2292.

Jarvela, J (2005). Effect of submerged flexiblevegetationonflowstructureandresistance.Journal of hydrology,307, pp.233-241.

Lopez, F and Garcia, M.H (2001). Mean flowturbulencestructureofopen-channelflowthroughnon-emergentvegetation.JournalofHydraulic Engineering, Vol.127, No.5.,pp 392-402.

M.Zhangetal.,(2012). Depth-averagedmodeling of free surface flows in open channelswithemergedandsubmergedvegetation. Applied Mathematical Modelling.Published byElsevierInc.

Nezu, I., Sanjou, M., Okamoto, T. (2007).PIVmeasurements in vegetated open channelflows,Proc. of 32nd IAHR Congress of Venice, No.466(10pageson CD-ROM).

Nikora, V., Scott, L., Nina, N., Koustuv, D.,Glenn, C. and Michael, R., (2008). Hydraulicresistanceduetoaquaticvegetationinsmallstreams:Fieldstudy.JournalofHydraulicEngineering,Vol.134,No.9.,pp1326-1332.

Nixon, S.,(1980). Between coastal marshes andcoastal waters – A review of twenty years ofspeculationandresearchontheroleofsaltmarshes inestuarineproductivityandwaterchemistry, in Estuarine and Wetland processes,edited by P. Hamilton and K. MacDonald, pp.438-525,Plenum, New York.

Okamoto,T.,and,Nezu,I.,(2010). Flowresistance law in open-channel flows with rigidandflexiblevegetation.RiverFlow2010-dittrich,Koll,Aberle&Geisenhainer(eds)BundesanstaltfurWasserbauISBN97-3-939230-00-7.

Orson, R., Simpson,R. and Good, R., (1992).A mechanism for the accumulation and retentionof heavy metals in tidal freshwater marshes oftheUpperDelawareRiverestuary,EstuarineCoastal Shelf science,34, 171-186.

Phillips, J., (1989). Fluvial sediment storage inWetlands,WaterResourcesBull.,25,867-87