5. Analysis of results

5.1 Introduction

The friction factors of the various components in any river body are what constitutes the composite roughness (i.e. total resistance due to different components or elements) of the river and hence the composite resistance to flow of water. Therefore it is important to know the friction factors themselves and how they accumulate when combined together in different arrangements, shapes and sizes.

This knowledge will assist engineers in dealing with the behaviour of water in terms of depth of flow, velocity of flow, prediction of discharge, water flow modelling and the behaviour of water in a channel etc.

The following steps were used to analyse the data obtained experimentally

1. Analysis to verify if the total form roughness for the smooth bed is the same for the rough bed for all the different elements involved in the experiments (obstructions, vegetation strands and irregularities) using both Darcy-Weisbach friction factors and Manning’s roughness coefficient.
2. Analysis of data to verify if the total resistance coefficient is the sum of the individual form roughness and the bed roughness) using both Darcy-Weisbach friction factors and Manning’s roughness coefficient.
3. Analysis to see if the form roughness for one element remains the same when other elements are combined with the one element in the flume or permutated or all three elements present at the same time in the flume
4. Analysis to find a relationship between the total roughness in a channel and the different elements in the channel.
5. Analysis to predict the Manning’s roughness coefficient or Darcy-Weisbach friction factor for any of the elements or a combination of these elements in the flume given one hydraulic parameter of the flow (i.e. given either discharge or flow depth).
6. Retesting of the relationship that exists between the total roughness in a channel and the different elements in the channel established in 3 above with the predicted resistance coefficients.

5.2 Useful guide to tables

The difference between table 5.2 and table 5.7 is that the former is for Darcy-Weisbach friction factor and the latter is for Manning's roughness coefficient. Also table 5.3 and 5.6 are the same except that the former is for Darcy-Weisbach friction factor and the latter is for Manning's roughness coefficient. And lastly table 5.5 and table 5.6 are the same with table 5.10 and 5.11 respectively as aforementioned.

Also in section 5.3 and other sections of this chapter the same repetitions as stated above can be observed

5.3 Darcy-Weisbach friction factor and Manning's roughness coefficient.

Analyses were carried out to compare the Darcy-weisbach friction factors and Manning's roughness coefficient for both smooth and rough bed flume respectively below.

5.3.1. Using Darcy-Weisbach friction factor

Table 5.1 and 5.2 show the calculations done in order to arrive at table 5.3. The procedures for obtaining the following in tables 5.1 and 5.2 are explained below.

f_{obst},f_{veg},f_{irr},$f_{obst\,\&\,veg}$,$f_{obst\,\&\,irr}$,$f_{veg\,\&\,irr}$, and $f_{obst,irr\,\&\,veg}$ (total resistance due to these elements) were obtained by using equation 2.14 having measured the discharges and the corresponding depths in the flume. f_{bed} was also obtained using equation 2.14 having measured the discharges and the corresponding depths in the flume when it was without any of the above mentioned elements.

$f_{obst(form)}$,$f_{veg(form)}$,$f_{irr(form)}$,$f_{obst\,\&\,veg(form)}$,$f_{obst\,\&\,irr(form)}$,$f_{veg\,\&\,irr(form)}$ and $f_{obst,veg\&\,irr(form)}$ were obtained by subtracting f_{obst},f_{veg},f_{irr},$f_{obst\,\&\,veg}$,$f_{obst\,\&\,irr}$,$f_{veg\,\&\,irr}$, and $f_{obst,irr\,\&\,veg}$ from f_{bed}

Procedure1 through 3 also means the following columns 1, 2, 3, 4, 5,6,7,8 and 9 were obtained by using the experimentally obtained discharges and depths to calculate the Darcy-Weisbach friction factors. Columns 10, was obtained by subtracting column 9 from column 2, also column 11 was obtained by subtracting column 9 from column 3 similarly column 12 to column 16 were obtained by subtracting column 9 from column 4 to column 8 respectively.

5.3.2 Using Manning's roughness coefficient

Also using Manning's roughness coefficient the errors are not up to 30% except for the combination of irregularities and vegetation which is about 57.02% which was highlighted in bold in table 5.6

Similarly tables 5.4 and 5.5 show the calculations done in order to arrive at table 5.6.

5.3.3 Different Darcy-Weisbach friction factors for rough bed and smooth bed flume

It is important to see if the rough bed flume contributes to the form roughness's of the elements or not. To check this, the following computations were carried out. The form roughness's computed in tables 5.1 and 5.2 for both the rough and smooth channels above have been brought together and compared in table 5.3.

Also these differences between the rough and smooth bed flume in table 5.3 would have developed when the side wall corrections were done and also from observation.

Table 5.3 show the values of friction factors for the permutations of obstruction, irregularities and vegetation in both the smooth and rough bed flume for the different discharges and depths. The average absolute % errors in tables 5.3 were computed by subtracting $f_{obst(form)},$ for the smooth bed flume from $f_{obst(form)},$ for the rough bed flume and dividing by the $f_{obst(form)},$ for the rough bed flume multiplied by 100. This procedure applies to all the % errors. This error margins are not so large hence we can neglect them apart from that of 51.84 noted in bold which is the average absolute form roughness for the combination of irregularities and vegetation.

5.3.4 Different Manning roughness coefficients for rough bed and smooth bed flume

$n_{obst}, n_{veg}, n_{irr}, n_{obst\,\&\,veg}, n_{obst\,\&\,irr}, n_{veg\,\&\,irr},$ and $n_{obst,irr\,\&\,veg}$ (Total resistance due to these elements) were obtained by using equation 2.15 having measured the discharges and the corresponding depths in the flume. n_{bed} was also obtained using equation 2.15 having measured the discharges and the corresponding depths in the flume when it was without any of the above mentioned elements.

$n_{obst(form)}$,$n_{veg(form)}$,$n_{irr(form)}$,$n_{obst\ \&\ veg(form)}$,$n_{obst\ \&\ irr(form)}$,$n_{veg\ \&\ irr(form)}$

and $n_{obst,veg\&\ irr(form)}$ were obtained by subtracting

n_{obst},n_{veg},n_{irr},$n_{obst\ \&\ veg}$,$n_{obst\ \&\ irr}$,$n_{veg\ \&\ irr}$, and $n_{obst,irr\ \&\ veg}$ from n_{bed}

This clearly shows that when Darcy-Weisbach friction factor is used the total average absolute errors is 17.5% and when Manning's roughness coefficient is used the total average absolute error is 28.7%.

Hence **analysis number one** stated in section 5.1 has been concluded which is that the resistance coefficients for both the rough and smooth bed flume are the same and does not change.

Below are tables 5.1-5.6 showing the results of analysis number two for both Darcy-Weisbach friction factor and Manning's roughness coefficient.

Table 5.1 Summary of total Darcy-Weisbach friction factors and friction factors due to form roughness (f_{form}) for the individual elements (obstructions, vegetation & irregularities) and also their permutations in the **rough** bed flume

Column 1 Q (m³/hr)	Column 2 f_{obst}	Column3 f_{veg}	Column 4 f_{irr}	Column 5 $f_{obst\,\&\,veg}$	Column 6 $f_{irr\,\&\,veg}$	Column 7 $f_{obst,\&\,irr}$	Column 8 $f_{obst,irr\,\&\,veg}$	Col.9 f_{bed}	Column 10 $f(obst)_{form}$	Column 11 $f(veg)_{form}$	Column 12 $f(irr)_{form}$
40	0.213	0.181	0.152	0.268	0.232	0.270	0.436	0.143	**0.070**	**0.038**	**0.009**
50	0.204	0.165	0.141	0.270	0.216	0.277	0.478	0.129	**0.074**	**0.035**	**0.011**
60	0.196	0.157	0.144	0.306	0.210	0.289	0.515	0.127	**0.069**	**0.030**	**0.017**
70	0.213	0.150	0.138	0.302	0.208	0.304	0.553	0.120	**0.093**	**0.030**	**0.018**
80	0.216	0.145	0.141	0.340	0.209	0.321	0.594	0.122	**0.094**	**0.023**	**0.019**

Continuation of table 5.1

Column 13 $f(obst, veg)_{form}$	Column 14 $f(irr, veg)_{form}$	Column 15 $f(obst\,\&\,irr)_{form}$	Column 16 $f(obstr, irr\,\&\,veg)_{form}$
0.125	**0.089**	**0.127**	**0.293**
0.140	**0.086**	**0.147**	**0.348**
0.179	**0.083**	**0.162**	**0.384**
0.182	**0.088**	**0.184**	**0.433**
0.218	**0.087**	**0.199**	**0.472**

Table 5.2. Summary of total Darcy-Weisbach friction factors friction factors and friction factors due to form roughness (f_{form}) for the individual elements (obstructions, vegetation & irregularities) and also their permutations in the **smooth** bed flume

Col.1 Q (m^3/hr)	Col.2 f_{obst}	Col.3 f_{veg}	Col.4 f_{irr}	Col.5 $f_{obst\,\&\,veg}$	Col.6 $f_{irr\,\&\,veg}$	Col.7 $f_{obst,\&\,irr}$	Col.8 $f_{obst,irr\,\&\,veg}$	Col.9 f_{bed}	Col.10 $f(obst)_{form}$	Col.11 $f(veg)_{form}$	Col.12 $f(irr)_{form}$
40	0.106	0.080	0.071	0.142	0.082	0.212	0.265	0.058	**0.048**	**0.022**	**0.013**
50	0.100	0.072	0.06	0.188	0.084	0.191	0.346	0.045	**0.055**	**0.027**	**0.015**
60	0.103	0.068	0.058	0.217	0.084	0.179	0.420	0.04	**0.063**	**0.028**	**0.018**
70	0.105	0.065	0.053	0.253	0.085	0.177	0.489	0.036	**0.069**	**0.029**	**0.017**
80	0.102	0.064	0.052	0.296	0.087	0.183	0.545	0.035	**0.067**	**0.029**	**0.017**

Continuation of table 5.2

Col.13 $f(obst,veg)_{form}$	Col.14 $f(irr,veg)_{form}$	Col.15 $f(obst\,\&\,irr)_{form}$	Col.16 $f(obstr,irr\,\&\,veg)_{form}$
0.084	**0.024**	**0.154**	**0.207**
0.143	**0.039**	**0.146**	**0.301**
0.177	**0.044**	**0.139**	**0.380**
0.217	**0.049**	**0.141**	**0.453**
0.261	**0.052**	**0.148**	**0.510**

Table 5.3. Summary showing the difference in form roughness between smooth bed flume and rough bed flume when obstructions, irregularities and vegetation are permutated in the flume using Darcy Weisbach friction factor.

Q (m^3/hr)	$f(obst)_{form}$ rough	$f(obst)_{form}$ smooth	% error	$f(veg)_{form}$ rough	$f(veg)_{form}$ smooth	% error
40	0.070	0.048	31.430	0.038	0.022	42.110
50	0.074	0.055	25.680	0.035	0.027	22.860
60	0.069	0.063	8.696	0.030	0.028	6.667
70	0.093	0.069	25.810	0.030	0.029	3.333
80	0.094	0.067	28.720	0.023	0.029	26.090
		average	24.070			20.212

Continuation of table 5.3

Q (m^3/hr)	$f(irr)_{form}$ rough	$f(irr)_{form}$ smooth	% error	$f(obst \,\&\, veg)_{form}$ rough	$f(obst \,\&\, veg)_{form}$ smooth	% error
40	0.009	0.013	-4.44	0.130	0.080	38.460
50	0.011	0.015	36.36	0.140	0.140	0.000
60	0.017	0.018	5.880	0.180	0.180	0.000
70	0.018	0.017	5.556	0.180	0.220	22.22
80	0.019	0.017	10.53	0.220	0.260	18.180
			Average 20.550			Ave 15.770

Continuation of table 5.3

Q (m^3/hr)	$f(irr \,\&\, veg)_{form}$ rough	$f(irr \,\&\, veg)_{form}$ smooth	% error	$f(obst \,\&\, irr)_{form}$ rough	$f(obst \,\&\, irr)_{form}$ smooth	% error
40	0.089	0.024	73.030	0.127	0.154	21.26
50	0.086	0.039	54.650	0.147	0.146	0.680
60	0.083	0.044	46.990	0.162	0.139	14.20
70	0.088	0.049	44.320	0.184	0.141	23.37
80	0.087	0.052	40.230	0.199	0.148	25.63
		Average	**51.840**		Average	17.020

Continuation of table 5.3

Q (m^3/hr)	$f(obst, veg \,\&\, irr)_{form}$ rough	$f(obst, veg \,\&\, irr)_{form}$ smooth	% error
40	0.290	0.210	27.590
50	0.350	0.300	14.290
60	0.384	0.380	1.127
70	0.430	0.450	4.651
80	0.470	0.510	8.5110
			Average 11.520

Table 5.4 Summaries of total Manning's roughness coefficient and Manning's roughness coefficient due to form roughness (n_{form}) for the individual elements (obstructions, vegetation & irregularities) and also their permutations in the **rough bed flume**

Col.1 Q (m^3/hr)	Col.2 n_{obst}	Col.3 n_{veg}	Col.4 n_{irr}	Col.5 $n_{obst\ \&\ veg}$	Col.6 $n_{irr\ \&\ veg}$	Col.7 $n_{obst,\&\ irr}$	Col.8 $n_{obst,irr\ \&\ veg}$	Col.9 n_{bed}	Col.10 $n(obst)_{form}$	Col.11 $n(veg)_{form}$	Col.12 $n(irr)_{form}$
40	0.0350	0.0315	0.0290	0.0390	0.0364	0.0400	0.0520	0.0276	**0.0074**	**0.0039**	**0.0014**
50	0.0340	0.0307	0.0280	0.0400	0.0359	0.0410	0.0560	0.0268	**0.0072**	**0.0039**	**0.0012**
60	0.0340	0.0305	0.0290	0.0440	0.0360	0.0430	0.0590	0.0270	**0.0070**	**0.0035**	**0.0020**
70	0.0370	0.0302	0.0290	0.0450	0.0365	0.0450	0.0630	0.0266	**0.0104**	**0.0036**	**0.0024**
80	0.0380	0.0301	0.0300	0.0480	0.0371	0.0470	0.0660	0.0273	**0.0107**	**0.0028**	**0.0027**

Continuation of table 5.4

Col.13 Q (m^3/hr)	Col.14 $n(obst, veg)_{form}$	Col.15 $n(irr, veg)_{form}$	Col.16 $n(obst\ \&\ irr)_{form}$	Col.17 $n(obstr, irr\ \&\ veg)_{form}$
40	**0.0114**	**0.0088**	**0.0124**	**0.0244**
50	**0.0132**	**0.0091**	**0.0142**	**0.0292**
60	**0.0170**	**0.0090**	**0.0160**	**0.3840**
70	**0.0184**	**0.0099**	**0.0184**	**0.0364**
80	**0.0207**	**0.0098**	**0.0197**	**0.0387**

Table 5.5 Summary of total Manning's roughness coefficient and Manning's roughness coefficient due to form roughness (n_{form}) for the individual elements (obstructions, vegetation & irregularities) and also their permutations in the **smooth bed flume**

Col.1 Q (m^3/hr)	Col.2 n_{obst}	Col.3 n_{veg}	Col.4 n_{irr}	Col.5 $n_{obst\ \&\ veg}$	Col.6 $n_{irr\ \&\ veg}$	Col.7 $n_{obst,\&\ irr}$	Col.8 $n_{obst,irr\ \&\ veg}$	Col.9 n_{bed}	Col.10 $n(obst)_{form}$	Col.11 $n(veg)_{form}$	Col.12 $n(irr)_{form}$
40	0.0231	0.0198	0.0185	0.0270	0.0199	0.0337	0.0380	0.0165	**0.0066**	**0.0033**	**0.0020**
50	0.0228	0.0191	0.0172	0.0320	0.0206	0.0325	0.0450	0.0148	**0.0080**	**0.0043**	**0.0024**
60	0.0237	0.0188	0.0172	0.0350	0.0211	0.0320	0.0510	0.0140	**0.0097**	**0.0048**	**0.0032**
70	0.0242	0.0187	0.0166	0.0390	0.0216	0.0322	0.0560	0.0135	**0.0107**	**0.0052**	**0.0031**
80	0.0241	0.0187	0.0166	0.0430	0.0221	0.0332	0.0600	0.0135	**0.0106**	**0.0052**	**0.0031**

Continuation of table 5.5

Col.13 Q (m^3/hr)	Col.14 $n(obst, veg)_{form}$	Col.15 $n(irr, veg)_{form}$	Col.16 $n(obst\ \&\ irr)_{form}$	Col.17 $n(obstr, irr\ \&\ veg)_{form}$
40	**0.0105**	**0.0034**	**0.0172**	**0.0215**
50	**0.0172**	**0.0058**	**0.0177**	**0.0302**
60	**0.0210**	**0.0071**	**0.0180**	**0.0370**
70	**0.0255**	**0.0081**	**0.0187**	**0.0425**
80	**0.0295**	**0.0086**	**0.0197**	**0.0465**

Table 5.6 Summary showing the difference in Manning's form roughness coefficient between smooth bed flume and rough bed flume when obstructions, irregularities and vegetation are permutated in the flume.

Q (m^3/hr)	$n(obst)_{form}$ rough	$n(obst)_{form}$ smooth	% error	$n(veg)_{form}$ rough	$n(veg)_{form}$ smooth	% error
40	0.0074	0.0066	10.8110	0.0039	0.0033	25.000
50	0.0072	0.0080	11.111	0.0039	0.0043	0.000
60	0.0070	0.0097	38.571	0.0035	0.0048	25.000
70	0.0104	0.0107	2.8850	0.0036	0.0052	25.000
80	0.0107	0.0106	0.9350	0.0028	0.0052	66.667
		average	12.863			Ave 28.333

Continuation of table 5.6

Q (m^3/hr)	$n(irr)_{form}$ rough	$n(irr)_{form}$ smooth	% error	$n(obst\ \&\ veg)_{form}$ rough	$n(obst\ \&\ veg)_{form}$ smooth	% error
40	0.0011	0.0020	81.818	0.0114	0.0105	7.895
50	0.0014	0.0024	71.429	0.0132	0.0172	30.303
60	0.0017	0.0032	88.235	0.0170	0.0210	23.529
70	0.0023	0.0031	34.783	0.0184	0.0255	38.587
80	0.0034	0.0031	8.823	0.0207	0.0295	42.512
			Ave. 57.018			Ave 28.565

Continuation of table 5.6

Q (m^3/hr)	$n(irr\ \&\ veg)_{form}$ rough	$n(irr\ \&\ veg)_{form}$ smooth	% error	$n(obst\ \&\ irr)_{form}$ rough	$n(obst\ \&\ irr)_{form}$ smooth	% error
40	0.0088	0.0034	61.364	0.0124	0.0172	38.709
50	0.0091	0.0058	36.264	0.0142	0.0177	24.648
60	0.0090	0.0071	21.111	0.0160	0.0180	12.500
70	0.0099	0.0081	18.182	0.0184	0.0187	1.6304
80	0.0098	0.0086	12.245	0.0197	0.0197	0.0000
		Average	29.833		Average	15.498

Continuation of table 5.6

Q (m^3/hr)	$n(obst, veg \,\&\, irr)_{form}$ rough	$n(obst, veg \,\&\, irr)_{form}$ smooth	% error
40	0.0244	0.0215	11.885
50	0.0292	0.0302	3.4250
60	0.3840	0.0370	90.365
70	0.0364	0.0425	16.758
80	0.0387	0.0465	20.155
		Average	28.518

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5.4 Analysis to verify the total resistance coefficient for Darcy-Weisbach friction factors and Manning's roughness coefficient.

The form roughness obtained by subtracting the bed roughness from the total roughness due to the permutations of elements were also added to see if they would be same for the "observed" form roughness (I.e. roughness coefficient computed directly from measured discharges and depths minus the bed roughness) coefficients of the respective permutations using Darcy-weisbach friction factor as seen in table 5.7 and table 5.8 and using Manning's roughness coefficient as seen in tables 5.9 and table 5.10.

The average absolute errors are quite large for both rough and smooth bed flumes using both Darcy-Weibach friction factors and Manning's roughness coefficient. This shows that direct adding of the friction resistances due to the form roughness (elements alone) does not equal the total form roughness of the different permutations of those elements. Therefore the total resistance is not the algebraic sum of the individual form roughness's and the bed roughness.

The added columns in tables 5.7 and table 5.8 for Darcy-weisbach friction factor and 5.9 and table 5.10 for Manning's roughness coefficient were obtained by directly adding the resistances due to form roughness of the elements (obstructions, vegetation and irregularities) as seen in column 2, 3 & 4 of tables 5.1 and 5.2 for both rough and smooth channels respectively for Darcy-Weisbach friction factors and tables 5.4 and 5.5 for Manning's roughness coefficient.

Now the essence of doing this exercise of directly adding the Darcy-Weisbach friction factors or the Manning's resistances due to form roughness is to see if it gives us the total form roughness when the different elements are actually permutated or all three elements are present in the flume. If this were right then the next step would have been to add the bed resistances and then compute the total Darcy-Weisbach resistances or Manning's resistance coefficients as the case may be.

The % errors for both table 5.7, 5.8, 5.9 and 5.10 were obtained by subtracting the columns with the "added" titles from the columns with the "observed" titles and then dividing the result by the columns with the observed titles and finally multiplying by 100.

As stated earlier the errors are large therefore the direct adding of this roughness's does not give the representative total roughness thus a relationship for computing the effects of combining different elements in the flume hence, remains to be determined.

Below are table 5.7-5.10 showing the results of analysis **number two** stated in section 5.1

5.4.1Using Darcy-Weisbach friction factors

Table 5.7 Summary showing the computed Darcy-Weisbach f values against the Darcy-Weisbach observed f values (using observed discharge and depth) for the **rough bed flume**

Column 1 Q (m^3/hr)	Column 2 Added $f_{obst\ and\ veg\ (form)}$	Column 3 Observed $f_{obst\ and\ veg\ (form)}$	Column 4 % error	Column 5 Added $f_{veg\ and\ irr\ (form)}$	Column 6 Observed $f_{veg\ and\ irr\ (form)}$	Column 7 % error	Column 8 Added $f_{obst\ and\ irr\ (form)}$	Column 9 Observed $f_{obst\ and\ irr\ (form)}$	Column 10 % error	Column 11 Added $f_{obst,veg\ and\ irr\ (form)}$	Column 12 Observed $f_{obst,veg\ and\ irr\ (form)}$	Column 13 % error
40	0.108	0.125	13.54	0.047	0.089	47.07	0.079	0.127	37.72	0.117	0.293	60.00
50	0.110	0.141	21.76	0.047	0.087	45.76	0.086	0.148	41.75	0.121	0.349	65.17
60	0.099	0.179	44.86	0.047	0.083	43.67	0.086	0.162	47.10	0.115	0.384	69.94
70	0.123	0.182	32.42	0.048	0.088	45.45	0.111	0.184	39.67	0.141	0.433	67.44
80	0.116	0.218	46.57	0.041	0.087	52.36	0.112	0.199	43.47	0.135	0.472	71.39
		Averages	31.83			46.86			41.94			66.79

Table 5.8 Summary showing the computed Darcy-Weisbach f values against the Darcy-Weisbach observed f values (using observed discharge and depth) for the **smooth bed flume**

Column 1 Q (m^3/hr)	Column 2 Added $f_{obst\ and\ veg\ (form)}$	Column 3 Observed $f_{obst\ and\ veg\ (form)}$	Column 4 % error	Column 5 Added $f_{veg\ and\ irr\ (form)}$	Column 6 Observed $f_{veg\ and\ irr\ (form)}$	Column 7 % error	Column 8 Added $f_{obst\ and\ irr\ (form)}$	Column 9 Observed $f_{obst\ and\ irr\ (form)}$	Column 10 % error	Column 11 Added $f_{obst,veg\ and\ irr\ (form)}$	Column 12 Observed $f_{obst,veg\ and\ irr\ (form)}$	Column 13 % error
40	0.070	0.084	16.67	0.035	0.024	-5.83	0.061	0.154	60.39	0.083	0.207	59.90
50	0.082	0.143	42.66	0.042	0.039	7.69	0.070	0.146	52.05	0.097	0.301	67.77
60	0.091	0.177	48.33	0.046	0.044	4.55	0.081	0.139	41.40	0.109	0.380	71.19
70	0.098	0.217	54.84	0.046	0.049	6.12	0.086	0.141	39.01	0.115	0.453	74.61
80	0.096	0.261	63.22	0.046	0.052	11.54	0.084	0.148	43.24	0.113	0.510	77.84
		AVerages	45.14			15.15			47.22			70.27

5.4.2 Using Manning,s roughness coefficient

Table 5.9 Summary showing the computed Manning's n values against the observed Manning's n values (using observed discharge and depth) for the **rough bed flume**

Column 1 Q (m^3/hr)	Column 2 Added $n_{obst\ and\ veg}$ $(form)$	Column 3 Observed $n_{obst\ and\ veg}$ $(form)$	Column 4 % error	Column 5 Added $n_{veg\ and\ irr}$ $(form)$	Column 6 Observed $n_{veg\ and\ irr}$ $(form)$	Column 7 % error	Column 8 Added $n_{obst\ and\ irr}$ $(form)$	Column 9 Observed $n_{obst\ and\ irr}$ $(form)$	Column 10 % error	Column 11 Added $n_{obst,veg\ and\ irr}$ $(form)$	Column 12 Observed $n_{obst,veg\ and\ irr}$ $(form)$	Column 13 % error
40	0.0113	0.0114	0.8772	0.0053	0.0088	39.773	0.0088	0.0124	29.032	0.0127	0.0244	47.951
50	0.0111	0.0132	15.909	0.0051	0.0091	43.956	0.0084	0.0142	40.845	0.0123	0.0292	57.877
60	0.0105	0.0170	38.235	0.0055	0.0090	38.889	0.0090	0.0160	43.750	0.0125	0.3840	96.745
70	0.0140	0.0184	23.913	0.0060	0.0099	39.394	0.0128	0.0184	30.435	0.0164	0.0364	54.945
80	0.0135	0.0207	34.783	0.0055	0.0098	43.878	0.0134	0.0197	31.979	0.0162	0.0387	58.139
		Averages	26.800			41.178			35.208			63.131

Table 5.10 Summary showing the computed Manning's n values against the observedManning's n values (using observed discharge and depth) for the **smooth bed flume**

Column 1 Q (m^3/hr)	Column 2 Added $n_{obst\ and\ veg}$ $(form)$	Column 3 Observed $n_{obst\ and\ veg}$ $(form)$	Column 4 % error	Column 5 Added $n_{veg\ and\ irr}$ $(form)$	Column 6 Observed $n_{veg\ and\ irr}$ $(form)$	Column 7 % error	Column 8 Added $n_{obst\ and\ irr}$ $(form)$	Column 9 Observed $n_{obst\ and\ irr}$ $(form)$	Column 10 % error	Column 11 Added $n_{obst,veg\ and\ irr}$ $(form)$	Column 12 Observed $n_{obst,veg\ and\ irr}$ $(form)$	Column 13 % error
40	0.0099	0.0105	6.0000	0.0052	0.0034	54.118	0.0086	0.0172	50.174	0.0118	0.0215	44.930
50	0.0123	0.0172	28.721	0.0067	0.0058	14.655	0.0104	0.0177	41.299	0.0147	0.0302	51.490
60	0.0145	0.0210	31.190	0.0079	0.0071	11.408	0.0129	0.0180	28.556	0.0176	0.0370	52.405
70	0.0159	0.0255	37.765	0.0083	0.0081	2.4691	0.0138	0.0187	26.043	0.0190	0.0425	55.294
80	0.0158	0.0295	46.339	0.0083	0.0086	3.2558	0.0137	0.0197	30.508	0.0189	0.0465	59.312
		average	18.630			15.879			35.316			52.686

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5.5. Analysis to check the form roughnesses of elements for different permutations of elements in the flume

Table 5.11-5.22 below were generated to show the different form roughness for one particular element in the flume when these elements are present alone in the flume and when they are combined in the flume with other elements. The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in these cases (i.e. the form roughness' obstruction values in bold letters are totally different from each other). These values seen in these columns were obtained as indicated on the titles of the columns i.e. for instance the fourth column to the right in table 5.11says $f(obstform)(= bed\ \&\ obst - bed)$ on the title this means that the form roughness due to obstructions in the flume bed was obtained by subtracting the roughness of the bed from the total roughness of the flume when obstructions are introduced in the bed.

Similarly the next column which says $f(obstform)(= obst, veg\ \&\ bed - veg\ \&\ bed)$ on the title means that the form roughness due to obstructions in the flume bed was obtained by subtracting the total roughness of the flume when vegetation are present in the flume from the total roughness of the flume when obstructions and vegetation are present in the flume. And so on for the last two columns of the table. The same procedure was used for (tables 5.11 and 5.14) and also (table 5.12 and 5.15) and lastly (tables 5.13 and 5.16) i.e. as the title reads so were the subtractions carried out.These same procedure carried out using Darcy-Weisbach friction factors was carried out using Manning's roughness coefficient as seen in tables 517-5.22.

With all the differences noted for tables 5.11-5.22 it clearly shows that total resistance is not equal to the sum of bed and form resistance only but involves some other factors (i.e. a non linear relationship exists between roughness characteristics when one element is present in a flume and when two elements are present and so on.)

It is therefore of importance to find out the relationship that exists between different elements in a flume when combined differently. Hence analysis **number three** stated in section 5.1 has been done.

5.5.1 For the rough bed flume using Darcy-Weisbach friction factor

Table 5.11 Summary showing the different form roughness' (f_{form}) for the rough bed with **obstructions** obtained from all the different permutations of the elements in the **rough** bed flume using Darcy-Weisbach friction factor.

Q(m^3/hr)	$obst$	veg	irr	$f(obst \,\&\, veg)$	$f(irr \,\&\, veg)$	$f(obst \,\&\, irr)$	$f(obst, irr \,\&\, veg)$	$f(bed)$	$f(obstform)$ $(= bed \,\&\, obst - bed)$	$f(obstform)$ $(= obst, veg \,\&\, bed - veg \,\&\, bed)$	$f(obstform)$ $(= obst, irr \,\&\, bed - irr \,\&\, bed)$	$f(obstform)$ $(= obtr, veg, irr \,\&\, bed - veg, irr \,\&\, bed)$
40	0.2130	0.1810	0.1520	0.2680	0.2320	0.2700	0.4360	0.1429	**0.0701**	**0.0870**	**0.1180**	**0.2040**
50	0.2040	0.1650	0.1410	0.2700	0.2160	0.2770	0.4780	0.1295	**0.0745**	**0.1050**	**0.1360**	**0.2620**
60	0.1960	0.1570	0.1440	0.3060	0.2100	0.2890	0.5150	0.1272	**0.0688**	**0.1490**	**0.1450**	**0.3050**
70	0.2130	0.1500	0.1380	0.3020	0.2080	0.3040	0.5530	0.1200	**0.0930**	**0.1520**	**0.1660**	**0.3450**
80	0.2160	0.1450	0.1410	0.3400	0.2090	0.3210	0.5940	0.1224	**0.0936**	**0.1950**	**0.1800**	**0.3850**

Table 5.12 Summary showing the different form roughness'(f_{form}) for the rough bed with **vegetation** obtained from all the different permutations of the elements in the **rough** bed flume Darcy-Weisbach friction factor

Q(m³/hr)	$obst$	veg	irr	$f(obst \,\&\, veg)$	$f(irr \,\&\, veg)$	$f(obst \,\&\, irr)$	$f(obst, irr \,\&\, veg)$	$f(bed)$	$f(vegform)$ $(= bed \,\&\, veg - bed)$	$f(vegform)$ $(= obst, veg \,\&\, bed - obst \,\&\, bed)$	$f(vegform)$ $(= veg, irr \,\&\, bed - irr \,\&\, bed)$	$f(vegform)$ $(= obtr, veg, irr \,\&\, bed - obst, irr \,\&\, bed)$
40	0.2130	0.1810	0.1520	0.2680	0.2320	0.2700	0.4360	0.1429	**0.0381**	**0.0550**	**0.0800**	**0.1660**
50	0.2040	0.1650	0.1410	0.2700	0.2160	0.2770	0.4780	0.1295	**0.0355**	**0.0660**	**0.0750**	**0.2010**
60	0.1960	0.1570	0.1440	0.3060	0.2100	0.2890	0.5150	0.1272	**0.0298**	**0.1101**	**0.0660**	**0.2260**
70	0.2130	0.1500	0.1380	0.3020	0.2080	0.3040	0.5530	0.1200	**0.0300**	**0.0890**	**0.0700**	**0.2490**
80	0.2160	0.1450	0.1410	0.3400	0.2090	0.3210	0.5940	0.1224	**0.0226**	**0.1240**	**0.0680**	**0.2730**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case. The same procedure was used for tables 5.13-5.16.

Table 5.13 Summary showing the different form roughness (f_{form}) for the rough bed with **irregularities** obtained from all the different permutations of the elements in the **rough** bed flume Darcy-Weisbach friction factor

Q(m^3/hr)	$obst$	veg	irr	$f(obst\ \&\ veg)$	$f(irr\ \&\ veg)$	$f(obst\ \&\ irr)$	$f(obst, irr\ \&\ veg)$	$f(bed)$	$f(irrform)$ $(= bed\ \&\ irr - bed)$	$f(irrform)$ $(= irr, veg\ \&\ bed - veg\ \&\ bed)$	$f(irrform)$ $(= obst, irr\ \&\ bed - obst\ \&\ bed)$	$f(irrform)$ $(= obtr, veg, irr\ \&\ bed - obst, veg\ \&\ bed)$
40	0.2130	0.1810	0.1520	0.2680	0.2320	0.2700	0.4360	0.1429	**0.0091**	**0.0510**	**0.1180**	**0.1680**
50	0.2040	0.1650	0.1410	0.2700	0.2160	0.2770	0.4780	0.1295	**0.0115**	**0.0510**	**0.1360**	**0.0730**
60	0.1960	0.1570	0.1440	0.3060	0.2100	0.2890	0.5150	0.1272	**0.0168**	**0.0530**	**0.1450**	**0.0931**
70	0.2130	0.1500	0.1380	0.3020	0.2080	0.3040	0.5530	0.1200	**0.0180**	**0.0580**	**0.1660**	**0.0910**
80	0.2160	0.1450	0.1410	0.3400	0.2090	0.3210	0.5940	0.1224	**0.0186**	**0.0640**	**0.1800**	**0.1050**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case. The same procedure was used for tables 5.14-5.17

5.5.2. For the smooth flume using Darcy-Weibach friction factor

Table 5.14 Summary showing the different form roughness (f_{form}) for the rough bed with **obstructions** obtained from all the different permutations of the elements in the **smooth** bed flume Darcy-Weisbach friction factor

Q(m^3/hr)	$obst$	veg	irr	$f(obst \,\&\, veg)$	$f(irr \,\&\, veg)$	$f(obst \,\&\, irr)$	$f(obst, irr \,\&\, veg)$	$f(bed)$	$f(obstform)$ $(= bed \,\&\, obst - bed)$	$f(obstform)$ $(= obst, veg \,\&\, bed - veg \,\&\, bed)$	$f(obstform)$ $(= obst, irr \,\&\, bed - irr \,\&\, bed)$	$f(obstform)$ $(= obtr, veg, irr \,\&\, bed - veg, irr \,\&\, bed)$
40	0.1060	0.0800	0.0710	0.1420	0.0820	0.2120	0.2650	0.0580	**0.0480**	**0.0620**	**0.1410**	**0.1830**
50	0.1000	0.0720	0.0600	0.1880	0.0840	0.1910	0.3460	0.0450	**0.0550**	**0.1160**	**0.1310**	**0.2620**
60	0.1035	0.0680	0.0580	0.2170	0.0840	0.1790	0.4200	0.0400	**0.0635**	**0.1490**	**0.1210**	**0.3360**
70	0.1050	0.0650	0.0530	0.2530	0.0850	0.1770	0.4890	0.0360	**0.0690**	**0.1880**	**0.1240**	**0.4040**
80	0.1020	0.0640	0.0520	0.2960	0.0870	0.1830	0.5450	0.0350	**0.0670**	**0.2320**	**0.1310**	**0.4580**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

Table 5.15 Summary showing the different form roughness (f_{form}) for the rough bed with **vegetation** obtained from all the different permutations of the elements in the **smooth** bed flume Darcy-Weisbach friction factor

Q(m^3/hr)	$obst$	veg	irr	$f(obst \& veg)$	$f(irr \& veg)$	$f(obst \& irr)$	$f(obst, irr \& veg)$	$f(bed)$	$f(vegform)$ $(= bed \& veg - bed)$	$f(vegform)$ $(= obst, veg \& bed - obst \& bed)$	$f(vegform)$ $(= veg, irr \& bed - irr \& bed)$	$f(vegform)$ $(= obtr, veg, irr \& bed - obst, irr \& bed)$
40	0.1060	0.0800	0.0710	0.1420	0.0820	0.2120	0.2650	0.0580	**0.022**	**0.036**	**0.011**	**0.053**
50	0.1000	0.0720	0.0600	0.1880	0.0840	0.1910	0.3460	0.0450	**0.027**	**0.088**	**0.024**	**0.155**
60	0.1035	0.0680	0.0580	0.2170	0.0840	0.1790	0.4200	0.0400	**0.028**	**0.1135**	**0.026**	**0.241**
70	0.1050	0.0650	0.0530	0.2530	0.0850	0.1770	0.4890	0.0360	**0.029**	**0.148**	**0.032**	**0.312**
80	0.1020	0.0640	0.0520	0.2960	0.0870	0.1830	0.5450	0.0350	**0.029**	**0.194**	**0.035**	**0.362**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

Table 5.16 Summary showing the different form roughness (f_{form}) for the rough bed with **irregularities** obtained from all the different permutations of the elements in the **smooth** bed flume Darcy-Weisbach friction factor

Q(m^3/hr)	$obst$	veg	irr	$f(obst\ \&\ veg)$	$f(irr\ \&\ veg)$	$f(obst\ \&\ irr)$	$f(obst,\ irr\ \&\ veg)$	$f(bed)$	$f(irrform)$ $(= bed\ \&\ irr - bed)$	$f(irrform)$ $(= irr,\ veg\ \&\ bed - veg\ \&\ bed)$	$f(irrform)$ $(= obst, irr\ \&\ bed - obst\ \&\ bed)$	$f(irrform)$ $(= obtr, veg, irr\ \&\ bed - obst, veg\ \&\ bed)$
40	0.1060	0.0800	0.0710	0.1420	0.0820	0.2120	0.2650	0.0580	**0.0130**	**0.0020**	**0.1410**	**0.1230**
50	0.1000	0.0720	0.0600	0.1880	0.0840	0.1910	0.3460	0.0450	**0.0150**	**0.0120**	**0.1310**	**0.0910**
60	0.1035	0.0680	0.0580	0.2170	0.0840	0.1790	0.4200	0.0400	**0.0180**	**0.0160**	**0.1210**	**0.0755**
70	0.1050	0.0650	0.0530	0.2530	0.0850	0.1770	0.4890	0.0360	**0.0170**	**0.0200**	**0.1240**	**0.0720**
80	0.1020	0.0640	0.0520	0.2960	0.0870	0.1830	0.5450	0.0350	**0.0170**	**0.0230**	**0.1310**	**0.0810**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

5.5.3 For the rough bed flume using Manning's roughness coefficient

Doing the same analysis with Manning's roughness coefficient gives the following

Table 5.17 Summary showing the different form roughness (n_{form}) for the rough bed with **obstructions** obtained from all the different permutations of the elements in the **rough** bed flume using Manning's roughness coefficient.

Q (m^3/hr)	$obst$	veg	irr	$n(obst \,\&\, veg)$	$n(irr \,\&\, veg)$	$n(obst \,\&\, irr)$	$n(obst, irr \,\&\, veg)$	$n(bed)$	$n(obstform)$ $(= bed \,\&\, obst - bed)$	$n(obstform)$ $(= obst, veg \,\&\, bed - veg \,\&\, bed)$	$n(obstform)$ $(= obst, irr \,\&\, bed - irr \,\&\, bed)$	$n(obstform)$ $(= obtr, veg, irr \,\&\, bed - veg, irr \,\&\, bed)$
40	0.0350	0.0315	0.0290	0.0390	0.0364	0.0400	0.0520	0.0276	**0.0074**	**0.0075**	**0.0110**	**0.0156**
50	0.0340	0.0307	0.0280	0.0400	0.0359	0.0410	0.0560	0.0268	**0.0072**	**0.0093**	**0.0130**	**0.0201**
60	0.0340	0.0305	0.0290	0.0440	0.0360	0.0430	0.0590	0.0270	**0.0070**	**0.0135**	**0.0140**	**0.0230**
70	0.0370	0.0302	0.0290	0.0450	0.0365	0.0450	0.0630	0.0266	**0.0104**	**0.0148**	**0.0160**	**0.0265**
80	0.0380	0.0301	0.0300	0.0480	0.0371	0.0470	0.0660	0.0273	**0.0107**	**0.0179**	**0.0170**	**0.0289**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

Table 5.18 Summary showing the different form roughness (n_{form}) for the rough bed with **vegetation** obtained from all the different permutations of the elements in the **rough** bed flume using Manning's roughness coefficient.

Q (m³/hr)	$obst$	veg	irr	$n(obst\ \&\ veg)$	$n(irr\ \&\ veg)$	$n(obst\ \&\ irr)$	$n(obst, irr\ \&\ veg)$	$n(bed)$	$n(vegform)$ $(= bed\ \&\ veg - bed)$	$n(vegform)$ $(= obst, veg\ \&\ bed - obst\ \&\ bed)$	$n(vegform)$ $(= veg, irr\ \&\ bed - irr\ \&\ bed)$	$n(vegform)$ $(= obtr, veg, irr\ \&\ bed - obst, irr\ \&\ bed)$
40	0.0350	0.0315	0.0290	0.0390	0.0364	0.0400	0.0520	0.0276	**0.0039**	**0.0040**	**0.0074**	**0.0120**
50	0.0340	0.0307	0.0280	0.0400	0.0359	0.0410	0.0560	0.0268	**0.0039**	**0.0060**	**0.0079**	**0.0150**
60	0.0340	0.0305	0.0290	0.0440	0.0360	0.0430	0.0590	0.0270	**0.0035**	**0.0100**	**0.0070**	**0.0160**
70	0.0370	0.0302	0.0290	0.0450	0.0365	0.0450	0.0630	0.0266	**0.0036**	**0.0080**	**0.0075**	**0.0180**
80	0.0380	0.0301	0.0300	0.0480	0.0371	0.0470	0.0660	0.0273	**0.0028**	**0.0100**	**0.0071**	**0.0190**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

Table 5.19 Summary showing the different form roughness (n_{form}) for the rough bed with **irregularities** obtained from all the different permutations of the elements in the **rough** bed flume using Manning's roughness coefficient.

Q (m³/hr)	$obst$	veg	irr	$n(obst\ \&\ veg)$	$n(irr\ \&\ veg)$	$n(obst\ \&\ irr)$	$n(obst, irr\ \&\ veg)$	$n(bed)$	$n(irrform)$ $(= bed\ \&\ irr - bed)$	$n(irrform)$ $(= irr, veg\ \&\ bed - veg\ \&\ bed)$	$n(irrform)$ $(= obst, irr\ \&\ bed - obst\ \&\ bed)$	$n(irrform)$ $(= obtr, veg, irr\ \&\ bed - obst, veg\ \&\ bed)$
40	0.0350	0.0315	0.0290	0.0390	0.0364	0.0400	0.0520	0.0276	**0.0014**	**0.0049**	**0.005**	**0.013**
50	0.0340	0.0307	0.0280	0.0400	0.0359	0.0410	0.0560	0.0268	**0.0012**	**0.0052**	**0.007**	**0.016**
60	0.0340	0.0305	0.0290	0.0440	0.0360	0.0430	0.0590	0.0270	**0.002**	**0.0055**	**0.009**	**0.015**
70	0.0370	0.0302	0.0290	0.0450	0.0365	0.0450	0.0630	0.0266	**0.0024**	**0.0063**	**0.008**	**0.018**
80	0.0380	0.0301	0.0300	0.0480	0.0371	0.0470	0.0660	0.0273	**0.0027**	**0.007**	**0.009**	**0.018**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

5.5.4 For the smooth channel

Table 5.20 Summary showing the different form roughness (n_{form}) for the rough bed with **obstructions** obtained from all the different permutations of the elements in the **smooth** bed flume using Manning's roughness coefficient.

Q (m³/hr)	$obst$	veg	irr	$n(obst\ \&\ veg)$	$n(irr\ \&\ veg)$	$n(obst\ \&\ irr)$	$n(obst, irr\ \&\ veg)$	$n(bed)$	$n(obstform)$ $(= bed\ \&\ obst - bed)$	$n(obstform)$ $(= obst, veg\ \&\ bed - veg\ \&\ bed)$	$n(obstform)$ $(= obst, irr\ \&\ bed - irr\ \&\ bed)$	$n(obstform)$ $(= obtr, veg, irr\ \&\ bed - veg, irr\ \&\ bed)$
40	0.0231	0.0198	0.0185	0.0270	0.0199	0.0337	0.0380	0.0165	**0.0066**	**0.007**	**0.015**	**0.018**
50	0.0228	0.0191	0.0172	0.0320	0.0206	0.0325	0.0450	0.0148	**0.0080**	**0.013**	**0.015**	**0.024**
60	0.0237	0.0188	0.0172	0.0350	0.0211	0.0320	0.0510	0.0140	**0.0097**	**0.016**	**0.015**	**0.030**
70	0.0242	0.0187	0.0166	0.0390	0.0216	0.0322	0.0560	0.0135	**0.0107**	**0.020**	**0.016**	**0.034**
80	0.0241	0.0187	0.0166	0.0430	0.0221	0.0332	0.0600	0.0135	**0.0106**	**0.024**	**0.017**	**0.038**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

Table 5.21 Summary showing the different form roughness (n_{form}) for the rough bed with **vegetation** obtained from all the different permutations of the elements in the **smooth** bed flume using Manning's roughness coefficient.

Q (m^3/hr)	$obst$	veg	irr	$n(obst\ \&\ veg)$	$n(irr\ \&\ veg)$	$n(obst\ \&\ irr)$	$n(obst, irr\ \&\ veg)$	$n(bed)$	$n(vegform)$ $(= bed\ \&\ veg - bed)$	$n(vegform)$ $(= obst, veg\ \&\ bed - obst\ \&\ bed)$	$n(vegform)$ $(= veg, irr\ \&\ bed - irr\ \&\ bed)$	$n(vegform)$ $(= obtr, veg, irr\ \&\ bed - obst, irr\ \&\ bed)$
40	0.0231	0.0198	0.0185	0.0270	0.0199	0.0337	0.0380	0.0165	**0.0033**	**0.0039**	**0.0014**	**0.0043**
50	0.0228	0.0191	0.0172	0.0320	0.0206	0.0325	0.0450	0.0148	**0.0043**	**0.0092**	**0.0034**	**0.0125**
60	0.0237	0.0188	0.0172	0.0350	0.0211	0.0320	0.0510	0.0140	**0.0048**	**0.0113**	**0.0039**	**0.0190**
70	0.0242	0.0187	0.0166	0.0390	0.0216	0.0322	0.0560	0.0135	**0.0052**	**0.0148**	**0.0050**	**0.0238**
80	0.0241	0.0187	0.0166	0.0430	0.0221	0.0332	0.0600	0.0135	**0.0052**	**0.0189**	**0.0055**	**0.0268**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

Table 5.22 Summary showing the different form roughness (n_{form}) for the rough bed with **irregularities** obtained from all the different permutations of the elements in the **smooth** bed flume using Manning's roughness coefficient.

Q (m³/hr)	$obst$	veg	irr	$n(obst\ \&\ veg)$	$n(irr\ \&\ veg)$	$n(obst\ \&\ irr)$	$n(obst, irr\ \&\ veg)$	$n(bed)$	$n(irrform)$ $(= bed\ \&\ irr - bed)$	$n(irrform)$ $(= irr, veg\ \&\ bed - veg\ \&\ bed)$	$n(irrform)$ $(= obst, irr\ \&\ bed - obst\ \&\ bed)$	$n(irrform)$ $(= obtr, veg, irr\ \&\ bed - obst, veg\ \&\ bed)$
40	0.0231	0.0198	0.0185	0.0270	0.0199	0.0337	0.0380	0.0165	**0.0020**	**0.0001**	**0.0106**	**0.0110**
50	0.0228	0.0191	0.0172	0.0320	0.0206	0.0325	0.0450	0.0148	**0.0024**	**0.0015**	**0.0097**	**0.0130**
60	0.0237	0.0188	0.0172	0.0350	0.0211	0.0320	0.0510	0.0140	**0.0032**	**0.0024**	**0.0083**	**0.0160**
70	0.0242	0.0187	0.0166	0.0390	0.0216	0.0322	0.0560	0.0135	**0.0031**	**0.0029**	**0.0080**	**0.0170**
80	0.0241	0.0187	0.0166	0.0430	0.0221	0.0332	0.0600	0.0135	**0.0031**	**0.0034**	**0.0091**	**0.0170**

The differences observed between each of the last four columns to the right are quite significant and cannot be ignored. This shows that total resistance is not the sum of the bed and form resistance only in this case.

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5.6 Testing of the existing formulas that account for the total resistance in channel

5.6.1 SCS method

The SCS method which has been explained in chapter says that the total resistance is the algebraic sum of the individual resistances and the bed resistance and a modification factor m where the channel meanders. In this experiment there is no meander in the channel. The procedure for carrying out the test is as follows

"$n_{\substack{obst\ and \\ veg \\ (form)}}$ Added" seen in table 5.24 was obtained by adding the $n(obst)_{form}$ and the $n(veg)_{form}$ in table 5.23 which is just a brought forward of the part in bold of table 5.4 but has been rounded off to 3 decimal places.

for the rough bed flume together i.e. following equation 2.10 of chapter 2. Also the "$n_{\substack{obst\ and \\ veg \\ (form)}}$ Added" seen in table 5.26 was obtained by adding the $n(obst)_{form}$ and the $n(veg)_{form}$ in table 5.25 for the smooth bed flume together i.e. following equation 2.10 of chapter 2 note Table 5.25 is just a brought forward of the part in bold of table 5.5.

The average absolute %errors were obtained by subtracting the columns with the added titles from the columns with the observed titles and then dividing the result by the columns with the observed titles and finally multiplying by 100.

In essence tables 5.24 and 5.26 are done to show how well the SCS method works with the experimental data. While tables (5.23 and 5.27), (5.25 and 5.29) are brought forward from tables 5.4 and 5.5 respectively and were used to compute for tables (5.24 and 5.28), (5.26 and 5.30) respectively for both SCS method and HR Wallingford's method.The average absolute errors of table 5.24 and table 5.26 for the rough and smooth bed flume respectively are not so large except for their last columns highlighted in bold on the right which is the flume with all three elements combined together. Therefore one can say that for Darcy-Weisbach friction factors for combinations of 2 different elements in the rough bed flume; the SCS method can be used to obtain the total resistance in the flume to a reasonable degree of accuracy.

The SCS method is quite useful for computing the total Manning’s roughness coefficient values for the different permutations of the elements in the flume especially for the permutations of two elements, however for the combination of the three elements it can be said that the SCS method is not so accurate as the absolute errors of 30.4% and 37.1% in both the rough and smooth flume respectively indicate.

5.6.2. For the rough bed flume

Table 5.23 Summary showing the total Manning's n values computed from the measured discharges and depths for the **rough** bed flume as seen in the tables of the appendix

Column1 Q(m^3/hr)	Column 2 n (bed)	Column3 $n(obst)_{form}$	Column4 $n(veg)_{form}$	Column5 $n(irr)_{form}$	Column6 $n(obst, veg)_{form}$	Column7 $n(irr, veg)_{form}$	Column8 $n(obst\ \&\ irr)_{form}$	Column9 $n(obstr, irr\ \&\ veg)_{form}$
40	0.0276	0.0074	0.0039	0.0014	0.0288	0.0279	0.0286	0.0289
50	0.0268	0.0072	0.0039	0.0012	0.0280	0.0271	0.0278	0.0280
60	0.0270	0.0070	0.0035	0.0020	0.0281	0.0273	0.0280	0.0282
70	0.0266	0.0104	0.0036	0.0024	0.0288	0.0269	0.0287	0.0289
80	0.0273	0.0107	0.0028	0.0027	0.0295	0.0276	0.0294	0.0296

Table 5.24 Comparison of Manning's n values predicted by SCS method and experimental values for rough bed case

Q(m³/hr)	Added $n_{obst\ and\ veg}$ $(form)$	Observed $n_{obst\ and\ veg}$ $(form)$	% error	Added $n_{veg\ and\ irr}$ $(form)$	Observed $n_{veg\ and\ irr}$ $(form)$	% error	Added $n_{obst\ and\ irr}$ $(form)$	Observed $n_{obst\ and\ irr}$ $(form)$	% error	Added $n_{obst,veg\ and\ irr}$ $(form)$	Observed $n_{obst,veg\ and\ irr}$ $(form)$	% error
40	0.039	0.039	1.026	0.033	0.036	10.440	0.036	0.040	11.000	0.040	0.052	23.846
50	0.038	0.040	5.500	0.032	0.036	11.421	0.035	0.041	15.122	0.039	0.056	30.714
60	0.038	0.044	13.636	0.033	0.036	8.333	0.036	0.043	16.279	0.040	0.059	32.203
70	0.041	0.045	9.778	0.033	0.037	10.685	0.039	0.045	14.222	0.043	0.063	32.381
80	0.041	0.048	13.958	0.033	0.037	10.243	0.041	0.047	12.128	0.044	0.066	32.879
		averages	8.780			10.224			13.750			**30.405**

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5.6.3 For the smooth bed flume

Table 5.25 Summary showing the total Manning's n values computed from the measured discharges and depths for the smooth bed flume as seen in the tables of the appendix

Column 1 Q(m^3/hr)	Column2 $n(obst)_{form}$	Column3 $n(veg)_{form}$	Column4 $n(irr)_{form}$	Column5 $n(obst, veg)_{form}$	Column6 $n(irr, veg)_{form}$	Column7 $n(obst\ \&\ irr)_{form}$	Column8 $n(obstr, irr\ \&\ veg)_{form}$	Column 9 n (bed)
40	0.0066	0.0033	0.0020	0.0105	0.0034	0.0172	0.0215	0.0165
50	0.0080	0.0043	0.0024	0.0172	0.0058	0.0177	0.0302	0.0148
60	0.0097	0.0048	0.0032	0.0210	0.0071	0.0180	0.0370	0.0140
70	0.0107	0.0052	0.0031	0.0255	0.0081	0.0187	0.0425	0.0135
80	0.0106	0.0052	0.0031	0.0295	0.0086	0.0197	0.0465	0.0135

Table 5.26 Comparison of Manning's n values predicted by SCS method and experimental values for smooth bed case

$Q(m^3/hr)$	Added $n_{obst\ and\ veg}$ $(form)$	Observed $n_{obst\ and\ veg}$ $(form)$	% error	Added $n_{veg\ and\ irr}$ $(form)$	Observed $n_{veg\ and\ irr}$ $(form)$	% error	Added $n_{obst\ and\ irr}$ $(form)$	Observed $n_{obst\ and\ irr}$ $(form)$	% error	Added $n_{obst,veg\ and\ irr}$ $(form)$	Observed $n_{obst,veg\ and\ irr}$ $(form)$	% error
40	0.026	0.027	2.2220	0.022	0.020	9.548	0.025	0.034	25.519	0.028	0.038	25.263
50	0.027	0.032	15.313	0.022	0.021	4.369	0.025	0.033	22.462	0.030	0.045	34.444
60	0.029	0.035	18.571	0.022	0.021	4.265	0.027	0.032	15.938	0.032	0.051	37.843
70	0.029	0.039	24.615	0.022	0.022	0.926	0.027	0.032	15.217	0.033	0.056	41.964
80	0.029	0.043	31.860	0.022	0.022	1.357	0.027	0.033	18.072	0.032	0.060	46.000
		averages	18.516			4.093			19.442			**37.103**

5.7 HR Wallingford method.

Using the HR Wallingford's method which is stated in equation 2.9 of chapter 2 taking the n_{sur} to be the bed roughness and adding a third component where three elements are used or combined the following was found.

Columns 2,3,4,5,6,7,8 and 9 of tables 5.27 and 5.29 are just a brought forward of columns 9-17 of tables 5.4 and 5.5 for the rough and smooth bed flume respectively as stated earlier.

Procedure for tables 5.28 and 5.30

"$n_{\substack{obst\ and \\ veg \\ (form)}}$ Added", "$n_{\substack{veg\ and \\ irr}}$ Added", "$n_{\substack{obst\ and \\ irr}}$ Added" and "$n_{\substack{obst,veg \\ and\ irr}}$ Added" were obtained by equation 2.9 of chapter 2.

"$n_{\substack{obst\ and \\ veg \\ (form)}}$ Observed", "$n_{\substack{veg\ and \\ irr}}$ Observed", "$n_{\substack{obst\ and \\ irr}}$ Observed" and "$n_{\substack{obst,veg \\ and\ irr}}$ Observed" were obtained from the measured discharge and depth in the flume using equation 2.15

The average absolute % errors were obtained by subtracting the columns with the added titles from the columns with the observed titles and then dividing the result by the columns with the observed titles and finally multiplying by 100.

In table 5.28 the average absolute errors observed shows that the data for the rough bed flume does not agree with HR Wallingford's method. This means that the HR Wallingford's method cannot be used to obtain the total resistance in a flume with composites (different elements).

As was the case in table 5.28, Manning's roughness coefficient values for the smooth flume bed seen in table in table 5.30 showed large errors also indicating that the data does not agree with HR Wallingford's method. This means that the HR Wallingford's method cannot be used to compute the total resistance in a flume with composites (different elements).

The HR Wallingford method has been tested as seen above and the errors which were obtain are too large to be ignored it therefore means that the HR Wallingford method is not suited for the current set up in computing total resistance.

5.7.1 For the rough bed flume

Table 5.27 Summary of computed form resistances for the permutations of the three elements (obstructions, vegetation and irregularities for the rough bed flume using Manning's roughness coefficient

Column1 $Q(m^3/hr)$	Column 2 n (bed)	Column3 $n(obst)_{form}$	Column4 $n(veg)_{form}$	Column5 $n(irr)_{form}$	Column6 $n(obst, veg)_{form}$	Column7 $n(irr, veg)_{form}$	Column8 $n(obst \,\&\, irr)_{form}$	Column9 $n(obstr, irr \,\&\, veg)_{form}$
40	0.0276	0.0074	0.0039	0.0014	0.0288	0.0279	0.0286	0.0289
50	0.0268	0.0072	0.0039	0.0012	0.0280	0.0271	0.0278	0.0280
60	0.0270	0.0070	0.0035	0.0020	0.0281	0.0273	0.0280	0.0282
70	0.0266	0.0104	0.0036	0.0024	0.0288	0.0269	0.0287	0.0289
80	0.0273	0.0107	0.0028	0.0027	0.0295	0.0276	0.0294	0.0296

Table 5.28 Summary showing the testing of the HR Wallingford's method for both predicted Manning's n values and the % error due to their differences for the rough bed flume.

$Q(m^3/hr)$	Added $n_{obst\ and\ veg}$	Observed $n_{obst\ and\ veg}$	% error	Added $n_{veg\ and\ irr}$	Observed $n_{veg\ and\ irr}$	% error	Added $n_{obst\ and\ irr}$	Observed $n_{obst\ and\ irr}$	% error	Added $n_{obst,veg\ and\ irr}$	Observed $n_{obst,veg\ and\ irr}$	% error
40	0.0288	0.0390	26.051	0.0279	0.0364	23.326	0.0286	0.0400	28.477	0.0289	0.0520	44.473
50	0.0280	0.0400	29.942	0.0271	0.0359	24.488	0.0278	0.0410	32.254	0.0280	0.0560	49.912
60	0.0281	0.0440	36.111	0.0273	0.0360	24.168	0.0280	0.0430	34.967	0.0282	0.0590	52.234
70	0.0288	0.0450	36.029	0.0269	0.0365	26.165	0.0287	0.0450	36.309	0.0289	0.0630	54.147
80	0.0295	0.0480	38.635	0.0276	0.0371	25.672	0.0294	0.0470	37.349	0.0296	0.0660	55.183
		Averages	33.354			24.764			33.871			51.190

5.7.2 For the smooth bed flume

Table 5.29 Summary of computed form resistances for the permutations of the three elements (obstructions, vegetation and irregularities) using HR Wallingford's method for the smooth bed flume using Manning's roughness coefficient

Column1 Q(m^3/hr)	Column 2 n (bed)	Column3 $n(obst)_{form}$	Column4 $n(veg)_{form}$	Column5 $n(irr)_{form}$	Column6 $n(obst, veg)_{form}$	Column7 $n(irr, veg)_{form}$	Column8 $n(obst\ \&\ irr)_{form}$	Column9 $n(obstr, irr\ \&\ veg)_{form}$
	0.0165	0.0066	0.0033	0.0020	0.0105	0.0034	0.0172	0.0215
	0.0148	0.0080	0.0043	0.0024	0.0172	0.0058	0.0177	0.0302
	0.0140	0.0097	0.0048	0.0032	0.0210	0.0071	0.0180	0.0370
	0.0135	0.0107	0.0052	0.0031	0.0255	0.0081	0.0187	0.0425
	0.0135	0.0106	0.0052	0.0031	0.0295	0.0086	0.0197	0.0465

Table 5.30 Summary showing the testing of the HR Wallingford's method for both predicted Manning's n values and the % error due to their differences for the smooth bed flume

Q(m^3/hr)	Added $n_{obst\ and\ veg}$	Observed $n_{obst\ and\ veg}$	% error	Added $n_{veg\ and\ irr}$	Observed $n_{veg\ and\ irr}$	% error	Added $n_{obst\ and\ irr}$	Observed $n_{obst\ and\ irr}$	% error	Added $n_{obst,veg\ and\ irr}$	Observed $n_{obst,veg\ and\ irr}$	% error
40	0.0185	0.0270	31.485	0.0170	0.0199	14.511	0.0181	0.0337	46.178	0.0185	0.0380	51.179
50	0.0169	0.0320	47.144	0.0153	0.0206	25.475	0.0165	0.0325	49.225	0.0169	0.0450	62.318
60	0.0160	0.0350	54.174	0.0146	0.0211	30.954	0.0158	0.0320	50.687	0.0162	0.0510	68.308
70	0.0174	0.0390	55.338	0.0142	0.0216	34.368	0.0172	0.0322	46.553	0.0176	0.0560	68.604
80	0.0174	0.0430	59.414	0.0140	0.0221	36.429	0.0174	0.0332	47.482	0.0177	0.0600	70.567
		averages	49.511			28.347			48.025			64.195

5.8 Empirical formulas

Therefore empirical formulas have been derived which are similar to equation 2.9 proposed by HR Wallingford. These formulas were suggested since equation 2.15 shows that $f \propto n^2$ hence the squares of the Manning's n values have been used.
Where f and n are Darcy-Weisbach friction factors and Manning's roughness coefficient respectively.

The following empirical formulas were tried to see if lesser errors will be achieved. Here the bed roughness has been accounted for twice where permutations of two elements are done and thrice, were the three elements have been combined as can be observed in equations 5.1-5.4

$$n_{irr,obst\,\&\,bed} = ((n\ irr\ \&\ bed)^2 + (n\ obst\ \&\ bed)^2)^{0.5} \qquad 5.1$$

$$n_{irr\,\&\,Veg} = ((n\ irr\ \&\ bed)^2 + (n\ veg\ \&\ bed)^2)^{0.5}. \qquad 5.2$$

$$n_{Veg\,\&\,obst} = ((n\ veg\ \&\ bed)^2 + (n\ obst\ \&\ bed)^2)^{0.5}. \qquad 5.3$$

$$n_{irr\,,obst\,\&\,Veg} = ((n\ irr\ \&\ bed)^2 + (n\ obst\ \&\ bed)^2 + (n\ veg\ \&\ bed^2))^{0.5}. \qquad 5.4$$

Where n_{irr} = Manning's n for the irregularities, n_{obst} = Manning's n for the obstructions,

n_{veg} = Manning's n for vegetation n_{bed} = Manning's n for the smooth channel with no elements.

Below are tables showing the results of the tested formulas

Procedure for tables 5.31 and 5.32

"$n_{\substack{obst\ and\\ veg\\ (form)}}$ Emp.for", "$n_{\substack{veg\ and\\ irr}}$ Emp.for", "$n_{\substack{obst\ and\\ irr}}$ Emp.for" and "$n_{\substack{obst,veg\\ and\ irr}}$ Emp.for" were obtained by equations 5.1-5.4 above. The titles in table 5.31 and 5.32 where it says "Emp.for" means that the values in those columns have be computed using the empirical formulas

"$n_{obst\ and\ veg\ (form)}$ Observed", "$n_{veg\ and\ irr}$ Observed", "$n_{obst\ and\ irr}$ Observed" and "$n_{obst,veg\ and\ irr}$ Observed" were obtained from the measured discharge and depth in the flume using equation 2.15

The average absolute % errors were obtained by subtracting the columns with the added titles from the columns with the observed titles and then dividing the result by the columns with the observed titles and finally multiplying by 100.

The values used for computing the total Manning's roughness coefficients in table 5.31 and 5.32 can be found in column 2, 3 and 4 of tables 5.4 and 5.5 respectively for the rough and smooth bed flume

So far table 5.31 gives the lowest average absolute errors of computed total resistances this therefore shows that the empirical formula was able to compute the total resistances for the different permutations of the different elements. This empirical formula which account for the bed roughness twice and thrice as the case may be has been able to compute the total resistances and the reason for this is that when composites are present in body of water they actually exert an additional resistance approximately equal to the bed resistance. We can then overlook the average absolute errors in table 5.32 which is for the smooth flume since we showed in the beginning that the smooth bed flume gives the same resistance as the rough bed flume when the values of the rough bed flume are corrected with the side-wall correction formula of Vanoni and Brooks (1957).

Now having tested and verified the empirical formulas one can now say that ways of combining the effects of the different permutations of the elements in the flume have been achieved. The next step is to try to predict ways of computing the resistance coefficients when given either flow depth or discharge only at any given time when any of the three elements are individually present in the flume. Therefore analysis **number four** has been concluded.

5.8.1 For the rough bed flume

Table 5.31 Summary showing the testing of the empirical method for both predicted Manning's n values and the experimentally computed (observed) Manning's n values for the rough bed flume.

Q(m^3/hr)	Emp.for $n_{obst\ and\ veg}$	Observed $n_{obst\ and\ veg}$	% error	Emp.for $n_{veg\ and\ irr}$	Observed $n_{veg\ and\ irr}$	% error	Emp.for $n_{obst\ and\ irr}$	Observed $n_{obst\ and\ irr}$	% error	Emp.for $n_{obst,veg\ and\ irr}$	Observed $n_{obst,veg\ and\ irr}$	% error
40	0.0471	0.0390	20.738	0.0428	0.0364	17.628	0.0455	0.0400	13.633	0.0553	0.0520	6.3489
50	0.0458	0.0400	14.523	0.0416	0.0359	15.741	0.0440	0.0410	7.4279	0.0537	0.0560	4.1271
60	0.0457	0.0440	3.8079	0.0421	0.0360	16.906	0.0447	0.0430	3.9251	0.0541	0.0590	8.2982
70	0.0478	0.0450	6.1339	0.0419	0.0365	14.710	0.0470	0.0450	4.4681	0.0559	0.0630	11.309
80	0.0485	0.0480	0.9935	0.0425	0.0371	14.547	0.0484	0.0470	3.0104	0.0570	0.0660	13.623
		averages	9.2392			15.907			6.4929			8.7413

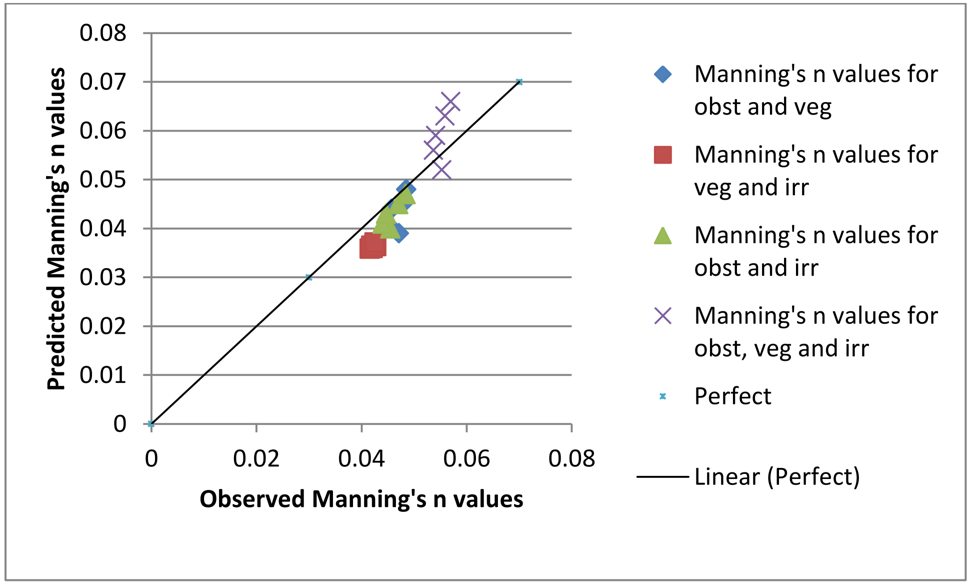

Figure 5.1.Graph showing the correlation between computed Manning's n values using the empirical formulas against the Manning's n values computed from the actual measured discharges and depths for the rough bed flume.

5.8.2 For the smooth bed flume

Table 5.32 Summary showing the testing of the empirical method for both predicted Manning's n values and the experimentally computed (observed) Manning's n values for the smooth bed flume.

Q(m^3/hr)	Emp.for $n_{obst\ and\ veg}$	Observed $n_{obst\ and\ veg}$	% error	Emp.for $n_{veg\ and\ irr}$	Observed $n_{veg\ and\ irr}$	% error	Emp.for $n_{obst\ and\ irr}$	Observed $n_{obst\ and\ irr}$	% error	Emp.for $n_{obst,veg\ and\ irr}$	Observed $n_{obst,veg\ and\ irr}$	% error
40	0.0304	0.0270	12.611	0.0271	0.0199	35.957	0.0296	0.0337	12.237	0.0356	0.0380	6.3807
50	0.0297	0.0320	7.1331	0.0257	0.0206	24.596	0.0286	0.0325	12.141	0.0343	0.0450	23.709
60	0.0302	0.0350	13.657	0.0254	0.0211	20.460	0.0293	0.0320	8.5621	0.0348	0.0510	31.858
70	0.0306	0.0390	21.628	0.0250	0.0216	15.752	0.0294	0.0322	8.8100	0.0348	0.0560	37.864
80	0.0305	0.0430	29.014	0.0250	0.0221	13.216	0.0293	0.0332	11.873	0.0347	0.0600	42.100
		averages	16.809			21.996			10.725			28.382

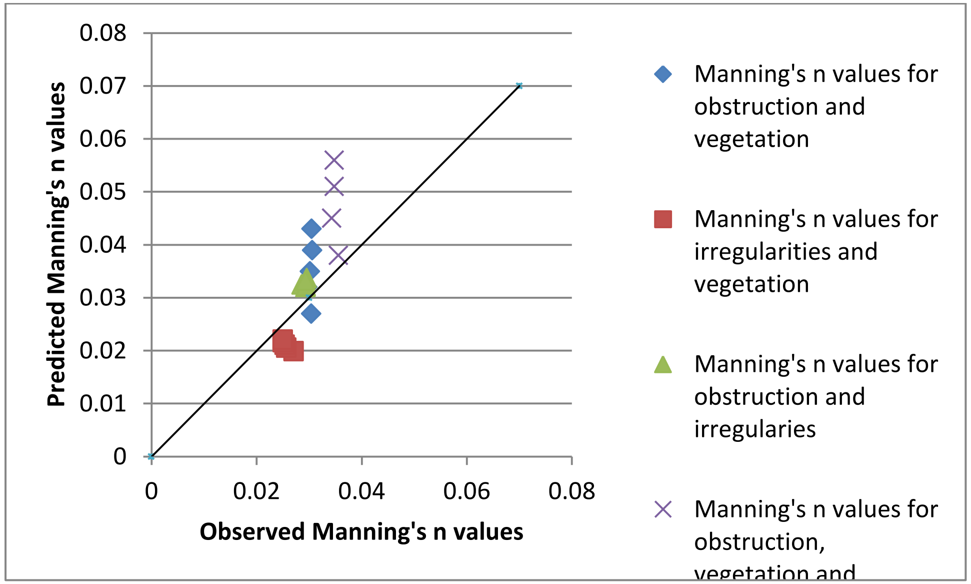

Figure 5.2 Graph showing the correlation between computed Manning's n values using the empirical formulas against the Manning's n values computed from the actual measured discharges and depths for the smooth bed flume.

5.9 Computing Resistance Coefficient by prediction

A lot of the literatures in chapter two have attempted to predict the total resistance in a river bed for different conditions such as when irregularities or vegetation or obstructions exists. Some of this ways have been quite successful. In this section three of these methods have been adopted namely;

1. The semi-empirical drag coefficient where bank irregularities exists in the channel (Meile et al. 2011).
2. The obstruction formulation (James, 2012) for obstacles in the channel and the
3. Vegetation formulation (Hirschowitz and James, 2009) when vegetation exist in the channel.

5.9.1. Bank irregularities calculation (Semi-empirical Drag-Coefficient Model)

Figures 17A and 1A in the appendix show the arrangement of the bank irregularities in both the rough bed flume and the smooth bed flume respectively. These irregularities contribute to the total resistance in the flume. Analysis to predict this additional resistance values have been carried out below.

5.9.2 Rough bed flume

Figure 1A in the appendix shows the arrangement of the bank irregularities. In order to predict the total resistance in a flume with bank irregularities, the formula tested was that of (Meile et al. 2011). The second case scenario as seen in figure 2.4.2b of chapter 2 was observed for the experiment i.e. where $\Delta B/L_b =$ = 0.1515

Therefore using equation 2.39 where C_d = 0.5 (obtained experimentally by best fit)

$(L_b + L_c) = 1.1m$ B = 0.945, $\Delta B = 0.1$ $R_h = effective\ depth$ $L_b = 0.66m$ L_c = 0.44m.

Table 5.33. Summary of calculations for $f_{bed}$for rough bed flume with bank irregularities.

Q(m^3/h)	Q(m^3/s)	Depth (m)	Effective Depth (m)	A_{bf} (m^2)	Area (m^2)	$V(m)$	$R(m)$	f_{bed}
33.5	0.0093	0.0845	0.0685	0.0037	0.0651	0.1358	0.0599	0.1450
45.0	0.0125	0.0988	0.0828	0.0045	0.0786	0.1510	0.0705	0.1285
57.6	0.0160	0.1131	0.0971	0.0053	0.0922	0.1648	0.0806	0.1166
68.3	0.0190	0.1230	0.1070	0.0058	0.1017	0.1772	0.0874	0.1101
82.2	0.0228	0.1364	0.1204	0.0066	0.1144	0.1896	0.0961	0.1030
60.0	0.0167	0.1140	0.0980	0.0053	0.0931	0.1701	0.0812	0.1160
40.0	0.0111	0.0920	0.0760	0.0041	0.0722	0.1462	0.0655	0.1356
50.0	0.0139	0.1030	0.0870	0.0047	0.0827	0.1596	0.0735	0.1246
70.0	0.0194	0.1240	0.1080	0.0059	0.1026	0.1800	0.0880	0.1096
80.0	0.0222	0.1350	0.1190	0.0065	0.1131	0.1867	0.0952	0.1037

Procedure for table 5.33

Discharge was given and depth was determined by trying to obtain uniform flow by adjusting the tail gate. Effective depth was obtained here by subtracting 0.016 from the observed depth. (I.e. 0.19-(0.19*0.16 = 0.016). The computation in parenthesis is due to the 19mm stones used. A_{bf} (m^2) was obtained by multiplying the effective depth by the weighted width of the obstructions 0.0545 (i.e. the total length of flume which is 12.1m divided by the total length of irregularities which is 6.6m to get a factor of 1.83 which is then used to divide the width of the obstructions. Area was obtained by multiplying the effective depth by 0.945 (effective width of channel with obstructions i.e. 1-0.0545 = 0.945) or by subtracting A_{bf} from the effective depth since the width of the flume is 1m. Hydraulic radius R was obtained by dividing the area by (0.945+2(eff. depth)). S_f was obtained experimentally by plotting the depths against the distances seen in table 17A of the appendix similarly all other S_f were computed for any other combination obtained using the corresponding data as are in the appropriate tables of the appendix. Thus has been reported as obtained e**xperimentally** in future . f_{bed} was obtained using equation 2.33.

This average absolute error of 3.4253 seen in table 5.34 is minimal and would be from observation in the laboratory. The average absolute error is obtained by subtracting the observed f from the predicted f or vice-versa since it is absolute error that is used. Then the result from the subtraction is divided by the one from which the other is subtracted and finally multiplied by 100%.

Procedure for tables 5.34.

Discharge was given and depth was determined by trying to obtain uniform flow by adjusting the tail gate. Effective depth was obtained here by subtracting 0.016 from the observed depth. (0.19-(0.19*0.16) = 0.016). This is due to the 19mm stone used. A_{bf} (m^2) was obtained by multiplying the effective depth by the weighted width of the obstructions 0.0545 (i.e. the total length of flume which is 12.1m divided by the total length of irregularities which is 6.6m to get a factor of 1.83 which was then used to divide the width of the obstructions to obtain 0.0545). Area was obtained by multiplying the effective depth by 0.945 (effective width of channel and obstructions i.e. 1-0.0545 = 0.945). f_{Mr} was obtained from equation 2.41. Hydraulic radius R was obtained by dividing the area by (0.945+2(eff. depth)). f_{bed} was obtained using equation 2.33. $f_{total} = f_{bed} + f_{Mr}$. f observed (i.e. Darcy-Weisbach friction factor computed from the measured discharge and depths note were ever observed f or n is stated it means the same procedure as stated in this parenthesis was used to compute them) was obtained from equation 2.14. n was obtained using equation 2.15.

Table 5.34 Summary of calculations for f_{Mr} and f_{total} for rough bed with bank irregularities.

Q(m^3/h)	Q(m^3/s)	Depth (m)	Depth(m)	A_{bf}	Area(m^2)	$R(m)$	f_{Mr}	f_{bed}	f_{total}	observed f	% error	n	f_{form}	n_{form}
33.5	0.0093	0.0845	0.0685	0.0037	0.0667	0.0616	0.0179	0.1450	**0.1629**	0.1540	5.7891	0.0286	0.018	**0.0095**
45.0	0.0125	0.0988	0.0828	0.0045	0.0805	0.0725	0.0211	0.1280	**0.1491**	0.1480	0.7322	0.0281	0.021	**0.0106**
57.6	0.0160	0.1131	0.0971	0.0053	0.0944	0.0829	0.0241	0.1166	**0.1407**	0.1440	2.2871	0.0280	0.024	**0.0116**
68.3	0.0190	0.1230	0.1070	0.0058	0.1041	0.0898	0.0261	0.1101	**0.1362**	0.1400	2.6980	0.0279	0.026	**0.0122**
82.2	0.0228	0.1364	0.1204	0.0066	0.1171	0.0987	0.0287	0.1030	**0.1317**	0.1370	3.8534	0.0279	0.029	**0.0130**
60.0	0.0167	0.1140	0.0980	0.0053	0.0953	0.0835	0.0243	0.1160	**0.1403**	0.1390	0.9313	0.0280	0.024	**0.0116**
40.0	0.0111	0.0920	0.0760	0.0041	0.0739	0.0674	0.0196	0.1356	**0.1552**	0.1450	7.0317	0.0284	0.020	**0.0101**
50.0	0.0139	0.1030	0.0870	0.0047	0.0846	0.0756	0.0220	0.1246	**0.1466**	0.1390	5.4615	0.0281	0.022	**0.0109**
70.0	0.0194	0.1240	0.1080	0.0059	0.1051	0.0904	0.0263	0.1096	**0.1359**	0.1360	0.0643	0.0279	0.026	**0.0123**
80.0	0.0222	0.1350	0.1190	0.0065	0.1131	0.0955	0.0278	0.1037	**0.1315**	0.1390	5.4042	0.0277	0.028	**0.0127**
										average	3.4253			

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5.9.3 Smooth bed flume with irregularities

Using equation 2.41 where C_d =0.5, $(L_b + L_{c)} = 1.1m$ B 0.945,

$\Delta B = 0.1\ \ R_h = hydraulic\ radius.$

Also stating that

$R_e = \frac{4Vr}{\delta}$

Substituting the value of velocity in equation 2.15 into equation 2.33 gives

$$\frac{1}{\sqrt{f}} = clog\left(\frac{4R\sqrt{8gRS}}{b\delta}\right) \qquad 5.5$$

$where\ \delta = kinematic\ viscosity$. This equation 5.5 will be used in place of equation 2.32 of chapter to eliminate the double iteration problem.

Table 5.35 Summary of calculations for f_{bed} in smooth bed with bank irregularities.

Q(m^3/h)	Q(m^3/s)	Depth(m)	A_{bf} (m^2)	Area (m^2)	$R(m)$	S_f	f_{bed}
51.4	0.0143	0.0680	0.0037	0.0646	0.0593	0.0006	0.0257
83.7	0.0233	0.0891	0.0049	0.0846	0.0748	0.0006	0.0235
106	0.0295	0.1042	0.0057	0.0990	0.0852	0.0006	0.0223
129	0.0358	0.1203	0.0066	0.1143	0.0956	0.0006	0.0213
151	0.0418	0.1344	0.0073	0.1277	0.1042	0.0006	0.0207
60.0	0.0167	0.0740	0.0040	0.0703	0.0638	0.0006	0.0250
40.0	0.0111	0.0600	0.0033	0.0570	0.0531	0.0006	0.0270
50.0	0.0139	0.0660	0.0036	0.0627	0.0578	0.0006	0.0261
70.0	0.0194	0.0800	0.0044	0.0760	0.0683	0.0006	0.0244
80.0	0.0222	0.0870	0.0047	0.0827	0.0733	0.0006	0.0237

Procedure for table 5.35.

Discharge was given and depth was determined by trying to obtain uniform flow by adjusting the tail gate. A_{bf} (m^2) was obtained by multiplying the depth by the weighted width of the obstructions 0.0545 (i.e. the total length of flume which is 12.1m divided by the total length of irregularities which is 6.6m to get a factor of 1.83 which is then used to divide the width of the obstructions. Area was obtained by multiplying the depth by 0.945 (effective width of channel with obstructions i.e. 1-0.0545 = 0.945). Hydraulic radius R was obtained by dividing the area by (0.945+2(eff. depth)). S_f was obtained experimentally. f_{bed} was computed using equation 5.5.

Procedure for tables 5.36

Discharge was given and depth was determined by trying to obtain uniform flow by adjusting the tail gate. A_{bf} (m^2) was obtained by multiplying the effective depth by the weighted width of the obstructions 0.0545 (i.e. the total length of flume which is 12.1m divided by the total length of irregularities which is 6.6m to get a factor of 1.83 which was then used to divide the width of the obstructions to obtain 0.0545). Area was obtained by multiplying the effective depth by 0.945 (effective width of channel and obstructions i.e. 1-0.0545 = 0.945). f_{Mr} was obtained from equation 2.41 Hydraulic radius R was obtained by dividing the area by (0.945+2(eff. depth)). f_{bed} was obtained using equation 5.5 f_{total} = f_{bed} + f_{Mr} f (observed) was obtained from equation 2.14. n was obtained using equation 2.15.

This average absolute error of 18.646 seen in table 5.36 would be from observation in the laboratory. The average absolute error is obtained by subtracting the observed f from the predicted f or vice-versa since it is absolute error that is used. Then the result from the subtraction is divided by the one from which the other is subtracted and finally multiplied by 100%.

Table 5.36 Summary of calculations for f_{Mr} and f_{total} in smooth bed with bank irregularities.

Q(m^3/h)	Q(m^3/s)	Depth (m)	A_{bf}	Area(m^2)	$R(m)$	f_{Mr}	f_{bed}	f_{total}	observed f	% error	n	n_{bed}	f_{form}
51.4	0.0143	0.0680	0.0037	0.0643	0.0595	0.0161	0.0260	**0.0421**	0.0630	33.225	0.0145	0.0114	**0.0031**
83.7	0.0233	0.0891	0.0049	0.0842	0.0750	0.0213	0.0230	**0.0443**	0.0500	11.465	0.0154	0.0111	**0.0043**
106	0.0295	0.1042	0.0057	0.0986	0.0854	0.0242	0.0210	**0.0452**	0.0490	7.6835	0.0159	0.0109	**0.0051**
129	0.0358	0.1203	0.0066	0.1137	0.0959	0.0272	0.0210	**0.0482**	0.0500	3.5877	0.0168	0.0111	**0.0057**
151	0.0418	0.1344	0.0073	0.1271	0.1047	0.0297	0.0210	**0.0507**	0.0490	3.4500	0.0174	0.0112	**0.0062**
60.0	0.0167	0.0740	0.0040	0.0700	0.0640	0.0182	0.0250	**0.0432**	0.0580	25.592	0.0148	0.0113	**0.0035**
40.0	0.0111	0.0600	0.0033	0.0567	0.0533	0.0151	0.0270	**0.0421**	0.0710	40.692	0.0142	0.0114	**0.0028**
50.0	0.0139	0.0660	0.0036	0.0624	0.0579	0.0164	0.0261	**0.0425**	0.0600	29.109	0.0145	0.0113	**0.0031**
70.0	0.0194	0.0800	0.0044	0.0756	0.0685	0.0194	0.0244	**0.0438**	0.0530	17.329	0.0151	0.0113	**0.0038**
80.0	0.0222	0.0870	0.0047	0.0823	0.0735	0.0209	0.0237	**0.0446**	0.0520	14.326	0.0154	0.0112	**0.0042**
									average	18.646			

5.9.4 Analysis of resistance due to Obstacles

Figures 3A and 15A in the appendix show the arrangement of the obstacles in the smooth bed and rough bed flume respectively. The combined resistance of bed shear and form roughness presented by equations 2.24 to 2.27 accounts for the two contributions (i.e. bed resistance and resistance due to the obstacles also known as the obstacle form resistance) at a mutually consistent level of resolution: bed shear is represented by a friction factor related to K_s (dependent on bed material size) and form drag which is represented by a similar coefficient related to C_D (dependent on form element size, shape and spacing) James (2012).

5.9.5. Rough bed flume with obstructions.

With a = 12 and c = 2.0. The friction factor for the rough bed f was calculated by applying the sidewall correction procedure proposed by Vanoni and Brooks (1957), K_s of 0.04 was calculated from equation 2.33. Table 5.37 below shows how K_s circled in red was calculated.

In table 5.37 this average value of K_s when only water is flowing in the flume was now used as the K_s for the flume when the bed is rough.

Procedures for tables.

In table 5.37 discharges were given and depths were determined by trying to obtain uniform flow by adjusting the tail gate S_f were obtained experimentally. R_e was obtained by $R_e = \frac{4vR}{\delta}$ K_s which has been enveloped in red was obtained using equation 2.33. f was obtained by equation 2.14 and n was obtained by equation 2.15. Hydraulic radius R was obtained by dividing the area by (1+2(eff. depth)).

For table 5.39

f_{form} were obtained using equation 2.27 $f_{total} = f_{form} + f_{bed}$. A_{bf} (m^2) was obtained by multiplying the effective depth by the weighted width of the obstructions 0.012 (i.e. the total length of flume which is 12.1m divided by the total length of irregularities which is 6.6m to get a factor of 8.64 i.e. 0.1 divided by 8.64 = 0.012 which is then used to divide the width of the obstructions. C_d was obtained by using equation 2.26 and adjusting the C_d value to obtain the best fit to the measured f. Observed f was obtained using equation 2.14. Hydraulic radius R was obtained by dividing the area by (0.98+2(eff. depth)). f_{bed} were obtained from equation 2.34. Effective depth was obtained here by subtracting 0.016 from the observed depth. (0.19-(0.19*0.16) = 0.016). This is due to the 19mm stone used. n were obtained using equation 2.15 n_{form} was obtained from equation 2.15 using f_{form}.

Table 5.37 Summary of calculations (rough bed channel with no elements except water) of f, n,R, R_e K_s

Q (m3/h)	Q (m3/s)	Depth (m)	Effective Depth(m)	Area (m2)	V(m/s)	R(m)	Sf	f	n	Re	k_s
32.6	0.009	0.081	0.065	0.065	0.139	0.058	0.0006	0.157	0.028	36222	0.043
45.0	0.013	0.095	0.079	0.079	0.159	0.068	0.0006	0.142	0.028	50000	0.044
54.3	0.015	0.104	0.088	0.088	0.172	0.075	0.0006	0.134	0.028	60333	0.046
65.5	0.018	0.113	0.097	0.097	0.187	0.081	0.0006	0.126	0.027	72778	0.045
78.8	0.022	0.124	0.108	0.108	0.203	0.089	0.0006	0.119	0.027	87556	0.046
60.0	0.017	0.108	0.092	0.092	0.181	0.078	0.0006	0.128	0.027	66667	0.044
40.0	0.011	0.089	0.073	0.073	0.152	0.064	0.0006	0.143	0.028	44444	0.042
50.0	0.014	0.098	0.082	0.082	0.169	0.070	0.0006	0.130	0.027	55556	0.040
70.0	0.019	0.116	0.100	0.100	0.194	0.083	0.0006	0.120	0.027	77778	0.043
80.0	0.022	0.126	0.110	0.110	0.202	0.090	0.0006	0.123	0.027	88889	0.049
										average	0.044

With k_s of 0.04 taking as the k_s of the flume. This k_s was then used for the future back calculations of resistance coefficients in the rough channel.

Table 5.39 Summary of calculations for f_{bed} in the rough channel with obstructions.

$Q(m^3/h)$	$Q(m^3/s)$	Depth(m)	Effective Depth (m)	$A_{bf}(m^2)$	Area(m^2)	R (m)	S_f	f_{bed}
32.5	0.0090	0.0887	0.0727	0.0012	0.0715	0.0625	0.00057	0.1395
46.5	0.0129	0.1066	0.0906	0.0015	0.0892	0.0755	0.00058	0.1215
55.8	0.0155	0.1206	0.1046	0.0017	0.1030	0.0851	0.00058	0.1116
71.1	0.0198	0.1380	0.1220	0.0020	0.1201	0.0965	0.00058	0.1023
85.3	0.0237	0.1565	0.1405	0.0022	0.1383	0.1079	0.00058	0.0947
60.0	0.0167	0.1240	0.1080	0.0017	0.1063	0.0874	0.00058	0.1096
40.0	0.0111	0.1000	0.0840	0.0013	0.0827	0.0708	0.00058	0.1273
50.0	0.0139	0.1120	0.0960	0.0015	0.0945	0.0792	0.00058	0.1174
70.0	0.0194	0.1380	0.1220	0.0020	0.1200	0.0965	0.00058	0.1023
80.0	0.0222	0.1500	0.1340	0.0021	0.1319	0.1040	0.00058	0.0971

Procedure for tables 5.38

A_{bf} (m^2) was obtained by multiplying the effective depth by the weighted width of the obstructions 0.012 (i.e. the total length of flume which is 12.1m divided by the total length of irregularities which is 6.6m to get a factor of 8.64 i.e. 0.1 divided by 8.64 = 0.012 which is then used to divide the width of the obstructions.

Area was obtained by multiplying the effective depth by 0.988 (effective width of channel with obstructions i.e. 1-0.012 = 0.988). S_f was obtained by plotting a graph of the depth against distance. f_{bed} was obtained from equation 2.33. Hydraulic radius R was obtained by dividing the area by (0.988+2(eff. depth)).

Table 5.39 Summary of calculations for f_{form} and f_{total} with obstructions in the rough bed channel.

$Q(m^3/h)$	$Q(m^3/s)$	Depth(m)	Effective Depth(m)	A_{bf} (m^2)	Area(m^2)	R (m)	c_d	f_{form}	f_{bed}	f_{total}	observed f	% error	n_{total}	n_{form}
32.5	0.0090	0.0887	0.0727	0.00087	0.0718	0.0634	1.5000	0.0729	0.1395	0.2124	0.2065	2.8450	**0.0328**	**0.0192**
46.5	0.0129	0.1066	0.0906	0.00109	0.0895	0.0766	1.5000	0.0729	0.1215	0.1944	0.1994	2.5203	**0.0324**	**0.0199**
55.8	0.0155	0.1206	0.1046	0.00126	0.1034	0.0863	1.5000	0.0729	0.1116	0.1845	0.2109	12.530	**0.0322**	**0.0203**
71.1	0.0198	0.1380	0.1220	0.00146	0.1205	0.0978	1.5000	0.0729	0.1023	0.1752	0.2068	15.293	**0.0321**	**0.0207**
85.3	0.0237	0.1565	0.1405	0.00169	0.1388	0.1094	1.5000	0.0729	0.0947	0.1676	0.2199	23.795	**0.0320**	**0.0211**
60.0	0.0167	0.1240	0.1080	0.00130	0.1067	0.0886	1.5000	0.0729	0.1096	0.1825	0.2017	9.5317	**0.0322**	**0.0203**
40.0	0.0111	0.1000	0.0840	0.00101	0.0830	0.0718	1.5000	0.0729	0.1273	0.2002	0.2130	6.0214	**0.0326**	**0.0196**
50.0	0.0139	0.1120	0.0960	0.00115	0.0948	0.0804	1.5000	0.0729	0.1174	0.1903	0.2340	18.686	**0.0323**	**0.0200**
70.0	0.0194	0.1380	0.1220	0.00146	0.1205	0.0978	1.5000	0.0729	0.1023	0.1752	0.2140	18.143	**0.0321**	**0.0207**
80.0	0.0222	0.1500	0.1340	0.00161	0.1324	0.1054	1.5000	0.0729	0.0971	0.1700	0.2170	21.671	**0.0320**	**0.0209**
											average	13.104		

5.9.6 Smooth bed flume with obstructions.

Table 5.40 Summary of calculations for f_{bed} in the smooth channel with obstructions.

Q(m^3/h)	Q(m^3/s)	Depth (m)	A_{bf}(m^2)	Area(m^2)	V(m/s)	R (m)	S_f	f_{bed}
49.6	0.0138	0.0800	0.0013	0.0788	0.1749	0.0679	0.00058	0.0244
71.1	0.0198	0.1031	0.0016	0.1015	0.1946	0.0841	0.00058	0.0224
86.8	0.0241	0.1220	0.0020	0.1200	0.2009	0.0965	0.00057	0.0213
108	0.0299	0.1431	0.0023	0.1408	0.2120	0.1095	0.00058	0.0203
126	0.0349	0.1650	0.0026	0.1624	0.2152	0.1221	0.00058	0.0195
60.0	0.0167	0.0920	0.0015	0.0905	0.1841	0.0765	0.00058	0.0233
40.0	0.0111	0.0700	0.0011	0.0689	0.1613	0.0604	0.00058	0.0257
50.0	0.0139	0.0800	0.0013	0.0787	0.1764	0.0679	0.00058	0.0245
70.0	0.0194	0.1030	0.0016	0.1014	0.1919	0.0840	0.00058	0.0225
80.0	0.0222	0.1120	0.0018	0.1102	0.2016	0.0900	0.00058	0.0219

Procedure for tables 5.41

A_{bf} (m^2) was obtained by multiplying the effective depth by the weighted width of the obstructions 0.012 (i.e. the total length of flume which is 12.1m divided by the total length of irregularities which is 6.6m to get a factor of 8.64 i.e. 0.1 divided by 8.64 = 0.012 which is then used to divide the width of the obstructions. Area was obtained by multiplying the effective depth by 0.988 (effective width of channel with obstructions i.e. 1-0.012 = 0.988). S_f was obtained by plotting a graph of the depth against distance (experimentally). f_{bed} was obtained from equation 2.33. Hydraulic radius R was obtained by dividing the area by (0.98+2(eff. depth)).

In table 5.41 the average absolute error of 9.25% could be due to observation.

Table 5.41 was obtained in the following ways

f_{form} was obtained using equation 2.26. f_{total} = f_{form} + f_{bed}. A_{bf} (m^2) was obtained by multiplying the effective depth by the weighted width of the obstructions 0.012 (i.e. the total length of flume which is 12.1m divided by the total length of irregularities which is 6.6m to get a factor of 8.64 i.e. 0.1 divided by 8.64 = 0.012 which is then used to divide the width of the obstructions. C_d was obtained by using equation 2.26 and adjusting the C_d value to obtain the best fit to the measured f. Observed f was obtained using equation 2.24. Hydraulic radius R was obtained by dividing the area by (0.98+2(eff. depth)). f_{bed} was obtained from equation 5.5.Effective depth was obtained here by subtracting 0.016 from the observed depth. (0.19-(0.19*0.16) = 0.016). This is due to the 19mm stone used. n was obtained using equation 2.15. n_{form} was obtained from equation 2.15 using f_{form}.

Table 5.41 Summary of calculations for f_{form} and f_{total} with obstructions in the smooth channel.

Q(m^3/h)	Q(m^3/s)	Depth(m)	A_{bf}(m^2)	Area(m^2)	R (m)	c_d	f_{form}	f_{bed}	f_{total}	observed f	% error	n_{total}	n_{form}
49.6	0.0138	0.0800	0.0010	0.0791	0.0689	1.5000	0.0729	0.0243	0.0972	0.1029	5.5641	**0.0225**	**0.0195**
71.1	0.0198	0.1031	0.0012	0.1015	0.0850	1.5000	0.0732	0.0223	0.0955	0.1024	6.7669	**0.0231**	**0.0202**
86.8	0.0241	0.1220	0.0015	0.1200	0.0974	1.5000	0.0732	0.0213	0.0945	0.1091	13.409	**0.0235**	**0.0207**
108	0.0299	0.1431	0.0017	0.1408	0.1105	1.5000	0.0732	0.0202	0.0934	0.1123	16.856	**0.0239**	**0.0212**
126	0.0349	0.1650	0.0020	0.1624	0.1232	1.5000	0.0732	0.0194	0.0926	0.1222	4.2054	**0.0242**	**0.0215**
60.0	0.0167	0.0920	0.0011	0.0905	0.0772	1.5000	0.0732	0.0233	0.0965	0.1042	7.4177	**0.0229**	**0.0199**
40.0	0.0111	0.0700	0.0008	0.0689	0.0611	1.5000	0.0732	0.0255	0.0987	0.0232	9.0365	**0.0223**	**0.0192**
50.0	0.0139	0.0800	0.0010	0.0787	0.0686	1.5000	0.0732	0.0243	0.0975	0.0229	9.6153	**0.0225**	**0.0195**
70.0	0.0194	0.1030	0.0012	0.1014	0.0849	1.5000	0.0732	0.0223	0.0955	0.0243	10.090	**0.0231**	**0.0202**
80.0	0.0222	0.1120	0.0013	0.1102	0.0909	1.5000	0.0732	0.0217	0.0949	0.0242	9.5368	**0.0233**	**0.0205**
										average	9.2498		

5.9.7 Vegetation formulation.

The vegetation formulation has been carried out in the following ways as seen in tables 5.42 and 5.43 for the rough and smooth bed flume respectively.

Procedure for tables 5.42

f_{bed} was obtained from equation 2.33. V_{inf} was obtained by the equation 2.25. V_{veg} was obtained by equation 2.35. n was obtained from equation 2.15. f_{total} was obtained by equation 2.38 but with the modification of f_{side} because the vegetation was arranged on one side of the wall. R was obtained by dividing area by (0.98+2*area). Effective depth was obtained here by subtracting 0.016 from the observed depth. (0.19-(0.19*0.16) = 0.016). This is due to the 19mm stone used. f was obtained from equation 2.14. S_f was obtained experimentally.

For tables 5.43

f_{bed} was obtained from equation 5.4. V_{inf} was obtained by the equation 2.24. v_{veg} (m/s) was obtained by equation 2.35. Area was obtained by the average of (0.96*effective depth +1*effective depth . i.e. 4 rods each having a diameter of 0.01m, therefore 1-0.04 = 0.96) or just multiplying the effective depth by 0.98. n was obtained from equation 2.15. f_{total} was obtained by equation 2.38 however, with the modification of f_{side} because the vegetation was arranged on one side of the wall only. R was obtained by dividing area by (0.98+2*area). f was obtained from equation 2.14. S_f was obtained experimentally.

The average absolute error of 9.15 in table 5.42 could be due to observation but is negligible.

Thus analysis **number five** stated in section 5.1was achieved.

5.9.8 Rough bed flume with vegetation

Table 5.42 Summary of calculations of $V_{inf}^2 \left(\frac{m}{s}\right)$, f_v and f_{total} for the rough bed flume with vegetation.

Q (m^3/s)	Depth (m)	Depth (m)	Area (m^2)	R (m)	S_f	f_{bed}	$V_{inf}^2 (\frac{m}{s})$	v_{veg} (m/s)	V_{inf}^2 * 0.0135 / (D*Vveg)	0.18 log(11)	f_v = (0.1+ col. 11)	f_{total}
0.0090	0.0865	0.0705	0.0691	0.0617	0.00057	0.1557	0.0205	0.0202	9.6426	0.1772	0.2772	0.1632
0.0125	0.1004	0.0844	0.0827	0.0720	0.00059	0.1404	0.0272	0.0184	12.798	0.1993	0.2993	0.1519
0.0156	0.1136	0.0976	0.0956	0.0814	0.00058	0.1299	0.0340	0.0171	15.993	0.2167	0.3167	0.1451
0.0181	0.1237	0.1077	0.1056	0.0883	0.00058	0.1234	0.0395	0.0163	18.579	0.2284	0.3284	0.1416
0.0236	0.1373	0.1213	0.1188	0.0972	0.00058	0.1165	0.0470	0.0154	22.154	0.2422	0.3422	0.1385
0.0167	0.1160	0.1000	0.0980	0.0831	0.00058	0.1282	0.0353	0.0169	16.606	0.2196	0.3196	0.1442
0.0111	0.0960	0.0800	0.0784	0.0688	0.00058	0.1447	0.0250	0.0189	11.771	0.1927	0.2927	0.1549
0.0139	0.1060	0.0900	0.0882	0.0760	0.00058	0.1355	0.0300	0.0178	14.136	0.2071	0.3071	0.1486
0.0194	0.1240	0.1080	0.1058	0.0885	0.00058	0.1233	0.0396	0.0163	18.649	0.2287	0.3287	0.1415
0.0222	0.1350	0.1190	0.1166	0.0957	0.00058	0.1176	0.0458	0.0155	21.548	0.2400	0.3400	0.1389

Continuation of table 5.42

Ob served f	% error for f	n_{total}	f_{form}	n_{form}	n_{bed}	Q (m^3/hr)
0.1846	11.583	**0.0293**	0.0075	**0.0063**	0.0286	32.5
0.1697	10.511	**0.0291**	0.0115	**0.0080**	0.0280	45.0
0.1651	12.109	**0.0292**	0.0153	**0.0095**	0.0276	56.2
0.1663	14.850	**0.0293**	0.0182	**0.0105**	0.0274	65.1
0.1400	1.0440	**0.0296**	0.0220	**0.0118**	0.0271	85.0
0.1567	8.0079	**0.0292**	0.0160	**0.0097**	0.0275	60.0
0.1810	14.426	**0.0292**	0.0102	**0.0075**	0.0282	40.0
0.1646	9.7092	**0.0291**	0.0131	**0.0086**	0.0278	50.0
0.1453	2.5967	**0.0293**	0.0182	**0.0105**	0.0274	70.0
0.1489	6.6842	**0.0295**	0.0214	**0.0116**	0.0271	80.0
average	9.1522					

5.9.9 Smooth bed flume with vegetation.

Table 5.43 Summary of calculations of $V_{inf}^2(\frac{m}{s})$, f_v and f_{total} for the smooth bed flume with vegetation.

Q (m^3/s)	Depth (m)	Area (m^2)	R (m)	S_f	f_{bed}	$V_{inf}^2(\frac{m}{s})$	v_{veg} (m/s)	V_{inf}^2 * 0.0135 / (D*Vveg)	0.18 log(11)	fv = (0.1+ col. 11)	f_{total}	Ob served f	% error for f	n_{total}	f_{form}	n_{form}	n_{bed}	Q(m^3/hr)
0.009	0.060	0.059	0.053	0.0006	0.027	0.100	0.021	52.44	0.310	0.410	0.048	0.075	36.73	**0.015**	0.020	**0.010**	0.0114	32.5
0.013	0.068	0.067	0.060	0.0006	0.026	0.119	0.019	62.28	0.323	0.423	0.050	0.066	24.33	**0.016**	0.024	**0.011**	0.0113	45.0
0.016	0.078	0.076	0.067	0.0006	0.025	0.144	0.018	75.06	0.338	0.438	0.052	0.061	13.94	**0.016**	0.028	**0.012**	0.0113	56.2
0.018	0.085	0.083	0.072	0.0006	0.024	0.161	0.017	84.30	0.347	0.447	0.055	0.063	13.71	**0.017**	0.031	**0.013**	0.0112	65.1
0.024	0.100	0.098	0.083	0.0006	0.023	0.200	0.016	104.7	0.364	0.464	0.059	0.066	9.860	**0.018**	0.037	**0.014**	0.0112	85.0
0.017	0.080	0.078	0.069	0.0006	0.024	0.149	0.018	77.67	0.340	0.440	0.053	0.068	21.93	**0.017**	0.029	**0.012**	0.0113	60.0
0.011	0.064	0.063	0.057	0.0006	0.026	0.110	0.020	57.31	0.316	0.416	0.049	0.080	39.37	**0.015**	0.022	**0.010**	0.0114	40.0
0.014	0.072	0.071	0.063	0.0006	0.025	0.129	0.019	67.33	0.329	0.429	0.051	0.072	29.63	**0.016**	0.025	**0.011**	0.0113	50.0
0.019	0.088	0.086	0.075	0.0006	0.024	0.169	0.017	88.28	0.350	0.450	0.055	0.065	14.66	**0.017**	0.032	**0.013**	0.0112	70.0
0.022	0.096	0.094	0.080	0.0006	0.023	0.190	0.016	99.15	0.359	0.459	0.058	0.064	9.350	**0.018**	0.035	**0.014**	0.0112	80.0
												average	21.35					

5.10 Retesting of the formulas that account for the total resistance in a channel using the predicted resistance results.

5. 10.1 SCS method

These average absolute errors printed in red show that the SCS method is not so correct and should not be used except where no other alternatives exist. The errors have been a bit exaggerated here because of the errors due to approximation when computing using the various prediction methods.

Procedure for table 5.44

Columns 2, 3 and 4 are the values seen in tables 5.39, 5.43 and 5.34 highlighted in bold respectively for the Manning's form roughness's. Column 5 is the bed resistance computed from the observed discharges and depths as seen in table 24A of the appendix. Column 7, 10, 13 and 16 are the total Manning's resistances calculated from the observed discharges and depths of the respective combinations as seen in tables 42A, 36A and 39A of the appendix of the appendix. Columns 6, 9, 12 and 15 are the predicted Manning's resistance values computed using the SCS method.

These average absolute errors in tables 5.44 and 5.45 printed in red show that the SCS method is not so correct and should not be used except where no other alternatives exist. The errors have been a bit exaggerated here because of the errors due to approximation when computing using the various prediction methods.

Procedure for table 5.45

Columns 2, 3, 4 and 5 the values seen in tables 5.41, 5.43 and 5.36 highlighted in bold respectively for the Manning's form roughness's. Column 5 is the bed resistance as seen in table 4.3 of chapter 4. Column 7, 10, 13 and 16 are the total Manning's resistances calculated from the observed discharges and depths of the respective combinations as seen in tables 18A, 12A and 15A of the appendix of the appendix. Columns 6, 9, 12 and 15 are the predicted manning's resistance values computed using the SCS method

5.10.2 SCS method retested with the predicted resistance result for rough bed flume

	Table 5.44 Summary of predicted values of Manning's resistance for rough channel for SCS method															
1 Q(m^3/hr)	2 Obst form	3 Veg form	4 Ireg form	5 bed	6 Obst, bed & Veg Perdicted	7 obst& Veg observed	8 % error	9 Obst, bed &irr predicted	10 Obst, bed &irr observed	11 % error	12 Irreg, bed & veg predicted	13 Irreg, bed & veg observe d	14 % error	15 obs, bed, veg &irr pedicted	16 obs, bed, veg &irr observed	17 % error
40	0.020	0.008	0.010	0.027	0.054	0.039	39.49	0.06	0.040	42.50	0.045	0.036	24.72	0.065	0.052	24.04
50	0.020	0.009	0.011	0.027	0.056	0.040	39.75	0.06	0.041	41.95	0.047	0.036	30.00	0.067	0.056	19.29
60	0.021	0.010	0.012	0.027	0.058	0.044	31.82	0.06	0.043	39.30	0.049	0.036	35.00	0.070	0.059	17.97
70	0.021	0.011	0.012	0.027	0.059	0.045	30.67	0.06	0.045	34.00	0.050	0.036	38.33	0.071	0.063	12.38
80	0.021	0.012	0.013	0.027	0.060	0.048	24.79	0.06	0.047	29.79	0.052	0.037	39.46	0.073	0.060	21.00
						average	**33.30**			**37.51**			**33.50**			**18.93**

5.10.3 SCS method retested with the predicted resistance result for smooth bed flume

Table 5.45 Summary of predicted values of Manning's resistance for smooth channel for SCS method

1 Q(m^3/hr)	2 Obst form	3 Veg form	4 Ireg form	5 bed	6 Obst, bed & VegPerdicted	7 obst& Veg observed	8 % error	9 Obst, bed &irr predicted	10 Obst, bed &irr observed	11 % error	12 Irreg, bed & veg predicted	13 Irreg, bed & veg observed	14 % error	15 obs, bed, veg &irr pedicted	16 obs, bed, veg &irr observed	17 % error
40	0.022	0.010	0.003	0.017	0.050	0.027	83.70	0.042	0.034	23.53	0.030	0.020	51.00	0.052	0.039	34.36
50	0.022	0.011	0.003	0.015	0.049	0.032	52.50	0.041	0.033	23.03	0.029	0.021	40.00	0.052	0.046	12.83
60	0.023	0.012	0.003	0.014	0.049	0.036	36.11	0.040	0.032	25.94	0.030	0.021	41.40	0.053	0.052	0.960
70	0.023	0.013	0.004	0.014	0.050	0.039	28.49	0.041	0.032	28.13	0.031	0.022	40.50	0.054	0.058	6.880
80	0.023	0.014	0.004	0.013	0.050	0.043	16.74	0.041	0.033	22.73	0.031	0.022	41.40	0.054	0.062	12.26
						averages	**43.51**			**24.67**			**42.90**			**13.46**

5.10.4. HR Wallingford’s method retested with the predicted resistance results for rough bed flume.

Again these averages absolute errors printed in bold show that the HR Wallingford’s method is not so correct especially for the permutation of all three different elements at once and should not be used except where no other alternatives exist as seen in tables 5.46 and 5.47. The errors have been a bit exaggerated here because of the errors due to approximation when computing using the various prediction methods

Procedure for table 5.46

Columns 2, 3 and 4 are the values seen in tables 5.39, 5.43 and 5.34 respectively in the columns highlighted in bold for the Manning’s form roughness’s. Column 5 is the bed resistance computed from the observed discharges and depths as seen in table 24A of the appendix. Column 7, 10, 13 and 16 are the total Manning’s resistances calculated from the observed discharges and depths of the respective combinations as seen in tables 42A, 36A and 39A of the appendix of the appendix. Columns 6, 9, 12 and 15 are the predicted manning’s resistance values computed using the HR Wallingford’s method.

Procedure for table 5.47

Columns 2, 3, 4 and 5 are the values seen in tables 5.41, 5.43 and 5.36 respectively in the columns highlighted in bold for the Manning’s form roughness’s. Column 5 is the bed resistance as seen in table 4.3 of chapter 4. Column 7, 10, 13 and 16 are the total Manning’s resistances calculated from the observed discharges and depths of the respective combinations as seen in tables 18A, 12A and 15A of the appendix of the appendix. Columns 6, 9, 12 and 15 are the predicted Manning’s resistance values computed using the HR Wallingford’s method.

These average absolute errors in tables 5.46 and 5.47 printed in bold show that the HR Wallingford’s method is not so correct and should not be used except where no other alternatives exist. The errors have been a bit exaggerated here because of the errors due to approximation when computing using the various prediction methods.

Table 5.46 Summary of predicted values of Manning's resistance n for **rough** bed flume using HR Wallingford's method

1 Q(m^3/hr)	2 obst	3 veg	4 irregu	5 bed	6 Obst,bed & VegPerdicted	7 Obst,bed & Veg observed	8 % error	9 Obst, bed &irr predicted	10 Obst, bed &irr observed	11 % error	12 Irreg, bed & veg predicted	13 Irreg, bed & veg observed	14 % error	15 obs, bed, veg &irr pedicted	16 obs, bed, veg &irr observed	17 % error
40	0.020	0.008	0.010	0.027	0.034	0.039	11.71	0.035	0.040	12.41	0.030	0.036	16.69	0.036	0.052	31.098
50	0.020	0.009	0.011	0.027	0.035	0.040	12.71	0.035	0.041	13.43	0.031	0.036	15.12	0.024	0.056	56.682
60	0.021	0.010	0.011	0.027	0.036	0.044	18.68	0.036	0.043	15.63	0.031	0.036	13.52	0.026	0.059	56.291
70	0.021	0.011	0.012	0.027	0.036	0.045	19.98	0.036	0.045	18.95	0.032	0.036	12.18	0.026	0.063	58.147
80	0.021	0.012	0.013	0.027	0.036	0.048	24.28	0.037	0.047	21.89	0.032	0.037	12.79	0.027	0.060	54.758
						averages	**17.47**			**16.46**			**14.06**			**51.40**

Table 5.47 Summary of predicted values of Manning's resistance n for **smooth** bed flume using HR Wallingford's method.

1 Q(m^3/hr)	2 obst	3 veg	4 irregu	5 bed	6 Obst, bed & Veg Perdicted	7 obst& Veg observed	8 % error	9 Obst, bed &irr predicted	10 Obst, bed &irr observed	11 % error	12 Irreg, bed & veg predicted	13 Irreg, bed & veg observed	14 % error	15 obs, bed, veg &irr pedicted	16 obs, bed, veg &irr observed	17 % error
40	0.0222	0.010	0.003	0.017	0.030	0.027	10.50	0.018	0.034	47.06	0.030	0.020	51.00	0.052	0.039	34.36
50	0.0225	0.011	0.003	0.015	0.029	0.032	8.410	0.019	0.033	42.42	0.029	0.021	40.00	0.052	0.046	12.83
60	0.0228	0.012	0.004	0.014	0.029	0.036	18.32	0.019	0.032	40.63	0.030	0.021	41.40	0.053	0.052	0.960
70	0.0231	0.013	0.004	0.014	0.030	0.039	23.13	0.019	0.032	40.63	0.031	0.022	40.50	0.054	0.058	6.800
80	0.0233	0.014	0.004	0.013	0.030	0.043	30.03	0.020	0.033	39.39	0.031	0.022	41.40	0.054	0.062	12.26
						averages	**18.08**			**42.03**			**42.90**			**13.44**

5.10.5 Empirical formula retested with predicted total resistance results.

Procedure for table 5.48

Columns 2, 3 and 4 are the values seen in tables 5.39, 5.43 and 5.34 respectively in the columns highlighted in bold for the Manning's total roughness's. Column 5 is the bed resistance computed from the observed discharges and depths as seen in table 24A of the appendix. Column 6, 9, 12 and 15 are the total Manning's resistances calculated from the observed discharges and depths of the respective combinations as seen in tables 42A, 36A and 39A of the appendix of the appendix. Columns 5, 8, 11 and 14 are the predicted Manning's resistance values computed using the empirical formulas.

Also for table 5.49 columns 2, 3 and 4 are the values seen in tables 5.41, 5.43 and 5.36 respectively in the columns highlighted in bold for the Manning's total roughness's. Column 5 is the bed resistance as seen in table 4.3 of chapter 4. Column 6, 9, 12 and 15 are the total Manning's resistances calculated from the observed discharges and depths of the respective combinations as seen in tables 18A, 12A and 15A of the appendix of the appendix. Columns 5, 8, 11 and 14 are the predicted manning's resistance values computed using the empirical formulas.

The average absolute errors seen in bold in tables 5.48 and 5.49 are the lowest errors obtained with all the different methods tried using predicted resistances. Figures 5.3 and 5.4 shows how the regression line was fitted against the perfect lines.

Finally analysis **number six** stated in section 5.1 has been thus achieved.

Table 5.48 Summary of predicted and observed values of resistance n for rough bed flume using empirical formulas

1 Q(m^3/hr)	2 Obst & bed	3 Veg & bed	4 Irr & bed	5 Obst, Veg & bed Perdicted	6 Obst, Veg & bed observed	7 % error	8 Obst, irr & bed predicted	9 Obst, bed &irr observed	10 % error	11 Irreg, bed& veg predicted	12 Irreg, bed & veg observed	13 % error	14 obs,bed, veg &irr pedicted	15 obs, bed, veg &irr observed	16 % error
40	0.033	0.029	0.028	0.044	0.039	12.03	0.043	0.040	7.570	0.041	0.036	12.76	0.052	0.052	2.326
50	0.032	0.029	0.028	0.043	0.040	8.690	0.043	0.041	4.100	0.040	0.036	11.98	0.052	0.056	7.754
60	0.032	0.029	0.028	0.043	0.044	1.210	0.043	0.043	1.070	0.040	0.036	11.99	0.052	0.059	12.55
70	0.032	0.029	0.028	0.043	0.045	3.580	0.042	0.045	5.950	0.040	0.036	12.00	0.051	0.063	18.29
80	0.032	0.030	0.028	0.044	0.048	9.330	0.042	0.047	10.09	0.040	0.037	9.180	0.052	0.066	14.11
					averages	**6.970**			**5.755**			**11.58**			**12.11**

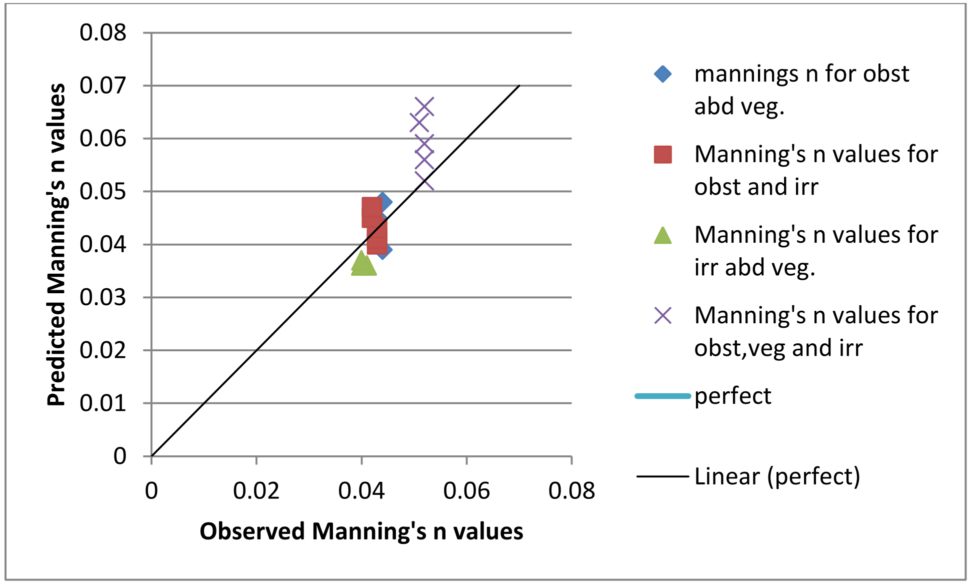

Figure 5.3. Graph showing the correlation between predicted and observed Manning's $n$values for the rough bed flume after using the empirical formulas for the prediction.

Table 5.49 Summary of predicted & observed values of Manning's resistance n for smooth bed flume using empirical formulas															
1 Q(m^3/hr)	2 Obst & bed	3 Veg & bed	4 Irr & bed	5 Obst, Veg & bed Perdicted	6 Obst, Veg & bed observed	7 % error	8 Obst, irr & bed predicted	9 Obst, bed &irr observed	10 % error	11 Irreg, bed& veg predicted	12 Irreg, bed & veg observed	13 % error	14 obs,bed, veg &irr pedicted	15 obs, bed, veg &irr observed	16 % error
40	0.022	0.015	0.014	0.027	0.027	0.768	0.026	0.034	22.33	0.021	0.020	3.621	0.030	0.039	22.13
50	0.023	0.016	0.015	0.028	0.032	13.72	0.027	0.033	18.89	0.022	0.021	2.823	0.031	0.046	32.21
60	0.023	0.017	0.015	0.028	0.036	21.00	0.027	0.032	15.06	0.023	0.021	7.332	0.032	0.052	38.35
70	0.023	0.017	0.015	0.029	0.039	26.46	0.028	0.032	13.93	0.023	0.022	3.053	0.032	0.058	44.20
80	0.023	0.018	0.015	0.029	0.043	31.53	0.028	0.033	15.37	0.024	0.022	7.676	0.033	0.062	46.41
					averages	**18.70**			**17.11**			**4.901**			**36.66**

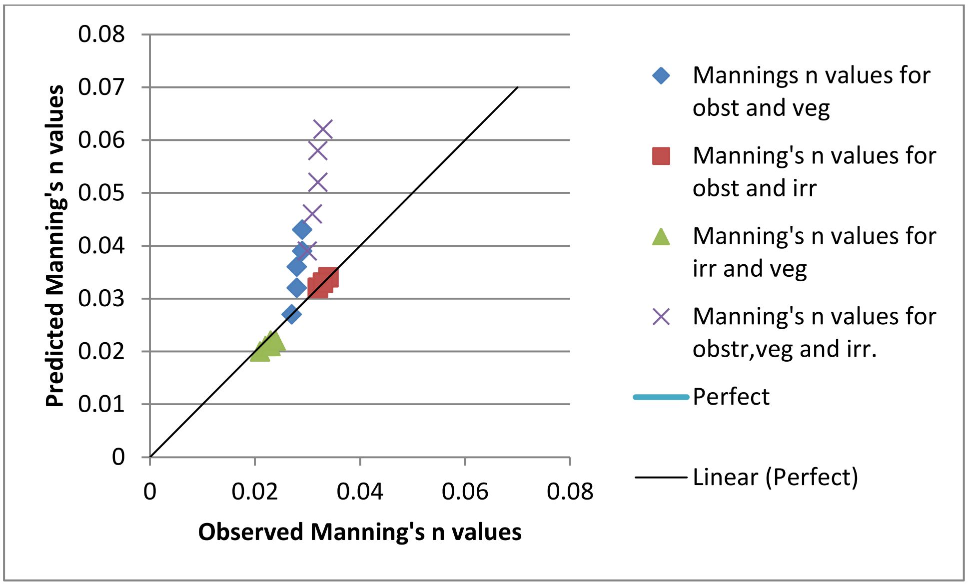

Figure 5.4 Graph showing the correlation between predicted and observed Manning's n values for the smooth bed flume after using the empirical formulas for the prediction.

5.11 Discussion

Lots of errors could be introduced in the laboratory during the experimental process ranging from error due to observation in reading the veneer to knowing the approximate duration to wait after adjusting the tail gate for the water level in the stilling pot to be stable.

The flume tends to show slight difference in the form roughness due to elements when the bed is rough than when the bed is smooth. However it is debateable that this difference is due to the approximation errors introduced during the correction process and other observational errors.

The direct addition of Darcy-Weisbach friction factors or Manning's roughness coefficient due to form roughness was not equal to the Darcy-Weibach friction factors or Manning's roughness coefficient due to form roughness computed using the measured discharges and depths in the laboratory when the obstructions or irregularities or vegetation elements were present as seen in tables 5.7 and 5.8for Darcy-Weisbach friction factor and table 5.9 and 5.10 for Manning's roughness coefficient for both the rough and smooth bed respectively. This is contrary to the suggestion of James (2012).

All the existing formulas used in accounting for the total resistance of a river have been tested and seen that they are not generally suited for all conditions but can be useful for particular conditions. The work done in this paper has been for sparse density of the elements in the flume simulating the natural conditions in a river with low flow.

Clearly, the areal concentration of elements, the flow depth and the roughness of the surface between the elements influences the relative contributions of surface shear and form drag to overall resistance. Under conditions where bed shear dominates, i.e. form roughness due to elements is negligible in comparison with bed resistance, the velocity increases with distance from the bed and the effective resistance coefficient (either f or n) decreases. This was also stated by James (2012). This makes Reynolds number very important as the higher the Reynolds number to area and depth the lower the resistance.

In general, both surface shear and form drag contributions need to be accounted for. The friction factor of the bed surface between the form roughness elements can be related to its grain size characteristics in terms of a k_s value through equations such as presented by the ASCE Task Force on Friction Factors in Open Channels (1963). Various relationships have been proposed for k_s in terms of percentile bed particle sizes Millar (1999). Back calculations of bed resistance using this k_s makes it more consistent since k_s is constant. Slight approximations in terms of decimal places changes the average absolute error values when computing Manning's roughness coefficient or Darcy-Weisbach friction factors.

In predicting total resistances in the flume with elements the two factors (bed and form resistance) that are accounted for do not necessarily accumulate linearly for one element at a time in the flume (i.e. bed resistance may not equal resistance and form resistance for form resistance) but when they are added together they tend to give a fair representation of the total resistance as was observed in the computations of resistances in the flume with vegetation.

Finally the empirical formulas (I.e. equation 5.1-5.4) are more general for the conditions (I.e. Sparse arrangement of elements in the flume with low flow) under which these experiments were conducted. These formulas were tested for the resistances computed by both the observed and predicted discharges and depths.

The rationale behind this formulas remains that the total resistances in a flume is the square root of the sum of the squares of the total Manning's resistances coefficients of the components of the flume (I.e. bed and form roughness). However a factor which is equal to the value of the square root of the square of the bed resistance is accounted for twice under conditions where two different elements are permutated in the flume and thrice when three different elements are permutated in the flume has been added to account for the effects of the area and depth which also influences the total resistance in the flume as seen in equations 5.1-5.4.