Open Channel Characteristics on Different Land Cover for Neponset River, Boston, MA*

Lee, Jawon**

상이한 토지이용에서 나타나는 하천의 특성에 관한 연구: 메사추세츠 보스턴의 네폰셋강의 사례연구*

이 자 원**

Abstract : The study examines two different sites to analyze the difference of stream channel profile between two different landuse areas on Neponset River, Boston, MA. Landuse represents the current status of land in terms of human, agricultural or forest, industry and environmental activity types. According to the previous research, forest and urban area are significantly distinguished in chemical characteristic, shape and bed load of the stream. On the chosen sites, I look at the cross-section profile, the slope, velocity, and roughness of the channels. With the data collected at the site I determined the value for the channel bed material using Manning's equation, and compared with the result of HEC-RAS model with the cross-section profile data I measured.

In the forest area, water surface elevation and bed material obtained through Manning's equation are very close to HEC-RAS model result. However, in the resident area the Manning's 'n' value calculated much higher than assumption which was considered as cobble whose 'n' value is 0.03-0.06. The difference could be caused by unusual steep elevation on the site and the dam present down further. With the steep elevation upside of dam, there is critical-depth condition occurs. The difference of Manning's 'n' value reflects the difference of depth. HEC-RAS model was run to analyze the difference and the result shows that depth is 0.36 much less than 0.688 what I computed when the Manning's n value is 0.03(cobble) instead of the result of the study (0.13292). Beside, dam is a major source of fragmentation and degradation of stream, and it's possibly inferred upstream water levels are increased and stream velocity is decreased.

This study is meaningful for introduction of HEC-RAS in geography field to analyze different sites with channel bed material, and it is going to be used more actively to manage river and river side.

Key Words : Neponset river watershed, landuse, cross-section profile, water surface elevation, Manning's equation, Manning's 'n' value, HEC-RAS model

요약 : 미국 메사추세츠주 보스턴시의 네폰셋 강의 서로 다른 토지이용지역을 사례지역으로 선정하여, 강의 밀집으로 토지이용의 차이를 분석할 수 있는지 실험하였다. 네폰셋 강은 거주지역, 산업지역, 농업과 삼림지역 등으로 토지이용이 구분되는데, 토질의 화학적 특성이 가장 차이가 나는 거주지역과 삼림지역 두 곳을 찾아 매닝의 'n'값과 HEC-RAS 모델의 결과치를 비교하여 두 지역의 차이를 분석하였다. HEC-RAS는 US Army Corp에서 개발한 모델로 강의 윤곽 및 흐름, 진행 및 경사 등을 면밀하게 분석할 수 있다. 거주지역 분석 결과는 매닝의 계수와 HEC-RAS 결과치가 매우 다르게 나타나는데, 이는 인공적으로 설치된 강 하류의 댐과 일반적이지 않은 경사에 기인한다고 판단되었다. 일반적인 경사를 지닌 댐상류에는 임계수위가 나타나는데, 매닝의 'n' 계수가 서로 다른 깊이를 반영해주고 있다. 댐은 강의 분리와 유속에 많은 영향을 미치고 있고, 상류 수위는 증가하는 대신 유속은 감소하게 된다. HEC-RAS 모델은 강의 구조와 형태 및 행태 등을 분석하는데 좋은 기법으로, 현재 많은 연구의 대상이 되고 있는 도시 내 강의 관리와 지역개발에 지리학적으로도 크게 활용할 수 있을 것이라 예상된다.

주요어 : 넷폰셋 강, 토지이용, 하폭의 구조와 형태, HEC-RAS 모델, 매닝의 'n'계수, 임계수위

I. Introduction

1. Neponset Watershed

The Neponset River Watershed is located in eastern Massachusetts, just southwest of the city Boston. The Neponset River runs for roughly 30 miles and forms Boston's southern border with

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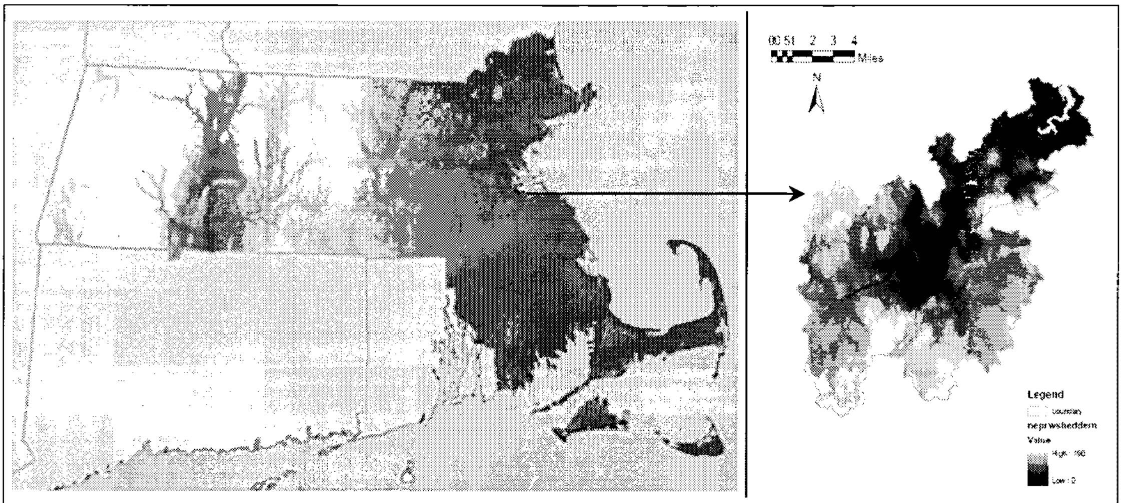
Quincy and Milton. Stretching from Foxboro to Dorchester and Quincy, the Neponset River ultimately discharges itself into the Boston harbor after passing through 14 cities and towns. The River's Watershed system covers approximately 130 sq. mi. of land, serving nearly 300,000 residents in 14 diverse communities, and providing drinking water for 200,000 homes. It comprises of several ponds and brooks and the major land use types are forest (34%) and residential (38%). The geography of Neponset Watershed is characterized by a steep elevation gradient in the upper segment of Neponset River, in Foxboro, Walpole and Norwood. The river drops about 228 feet over its first twelve miles and the flow varies significantly with season (up to 1300 ft3 s−1 in spring and down to 50 ft3 s−1 in the summer).

The drainage and water supply systems in the Neponset Watershed are managed by the Massachusetts Water Resources Authority (MWRA) which treats all wastewater coming out of the Neponset area at the Deer Island treatment facility and disposes it off 12 miles into Boston Harbor. Although this system provides the benefit of a well managed disposal system for the drainage, it does have its side effects. Most of the water that is used by the people of the Neponset Watershed comes from local wells which enters the drainage system and is ultimately dumped into the Boston Harbor. This inter−basin transfer is a major cause for low water flows in the Neponset River.

Assuming that the uniform open channel characteristics are affected by their surrounding land cover condition, we examine two different sites with different landuse or landscape on Neponset River. Many researches found that forest and residential area are significantly distinguished in chemical characteristic due to the pollutant, shape and bed load of the stream. On the chosen sites, I look at the cross−section profile, the slope, velocity, and roughness of the channels. It's possible to assume that the stream in forest area is more natural than urban or residential area, and we can expect that the forest channel is visibly different in slope while the residential channel has a higher human impact, so the slope can be affected by it. I look into the roughness of the different channels and proof the difference through running the HEC−RAS model.



Source: MassGIS

Fig 1. Digital Elevation Model of Massachusetts (1:5000) and Neponset Waters

2. Study Site

This study uses a GIS approach to search different sites from various landuse types within the watershed under consideration. A digital elevation model (DEM) is a representation of the land surface and is the fundamental piece of data needed to build a drainage system for watershed analysis. I used the 30×30 meter resolution DEM to generate the small sub-basin of the Neponset River. We delineated the sub-watershed centering Norwood climate gauge station as an outlet and found two different sites, forest and residential area using land cover data, 2002.

Fig 2. Field Survey for the Study Sites on Neponset River

II. Methodology

1. Landuse Data

The landuse data layer is a depiction of the current status of land in terms of human, agricultural or forest, industry and environmental activity types. It contains information about how a land parcel is used for various activities. The Landuse data files used for this study are obtained from MassGIS data repository. The Landuse file is a set of GIS polygon coverage

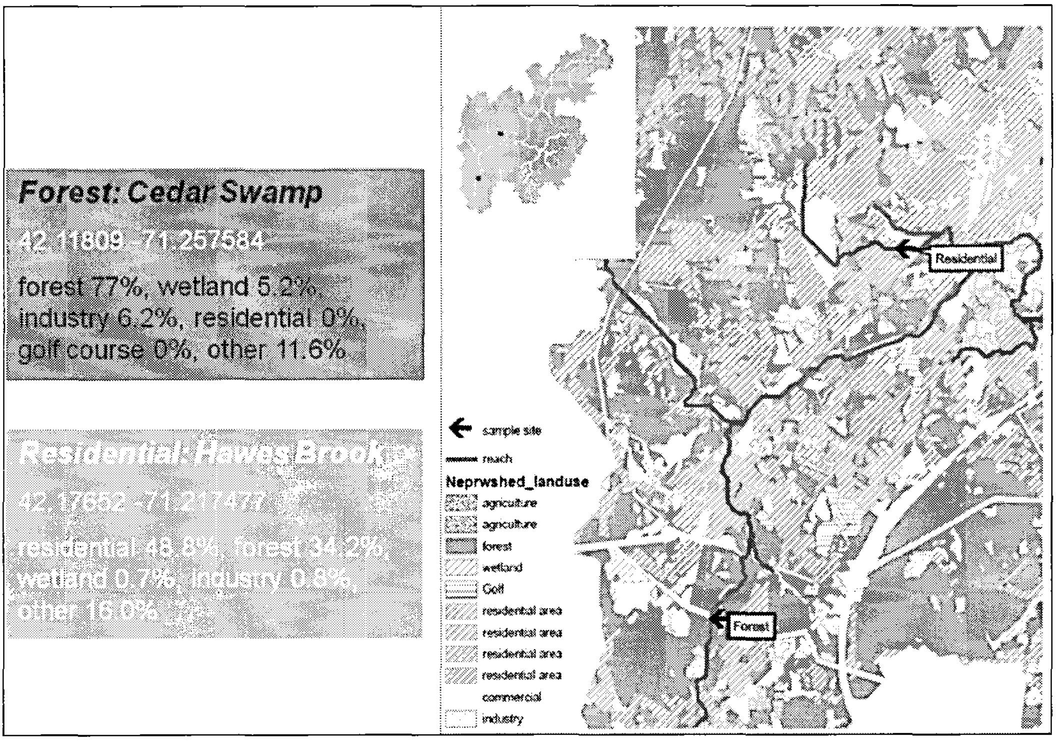


Fig 3. Study Sites on Neponset River Sub-Basin

obtained through photo interpretation and automation of 1:25,000 aerial photography and has 37 land use classifications. In order to determine the two different land use type sites, weighting factors must be established for major landuse types. Through this process I selected the two sites as shown as Figure 3, one is forest and the other is residential area.

2. Manning's Equation

One the most commonly used equations governing Open Channel Flow is known as the Manning's Equation. It is an empirical equation that applies to uniform flow in open channels and is a function of the channel velocity, flow area and channel slope.

$$Q = VA = \left(\frac{1.49}{n}\right) AR^{\frac{2}{3}} \sqrt{S} \quad [U.S.]$$

$$Q = VA = \left(\frac{1.00}{n}\right) AR^{\frac{2}{3}} \sqrt{S} \quad [SI]$$

Where :

Q = Flow Rate, (ft3/s)
V = Velocity, (ft/s)
A = Flow Area, (ft2)
n = Manning's Roughness Coefficient
R = Hydraulic Radius, (ft)
S = Channel Slope, (ft/ft)

F_Downstream	elevation of BS=	13.935	ft	**distance of two cross section:**	**22**	**ft**
distance	backshot	foreshot	elevation			
0		9.96	3.975			
1		11.32	2.615			
3		11.755	2.18	water surface=	2.5	
5		12.35	1.585			
7		12.515	1.42			
9		12.43	1.505			
11		12.415	1.52			
13		12.32	1.615			
15		11.715	2.22			
16.5	3.935	10.86	3.075			
slope of site1	-0.003181818					
Forest						
	discharge	4.883346				
	A	10.19069				
	P	12.52052				
	R		0.813919			
	S	0.000682				
	velocity	0.479197				
	Manning's *n*	**0.07078**		**0.070777304**		
		13.935	ft			
F_Upstream	elevation of BS=	foreshot	elevation			
distance	backshot	9.55	4.385			
0		10.375	3.56			
1		11.98	1.955			
3		12.2	1.735	water surface=	2.55	
5		12.335	1.6			
7		12.5	1.435			
9		12.475	1.46			
11		12.42	1.515			
13		12.12	1.815			
15		11.65	2.285			
17		10.975	2.96			
18	3.935					

Table 1. Survey of the study sites' river profile

Under the assumption of uniform flow conditions the bottom slope is the same as the slope of the energy grade line and the water surface slope. The Manning's n is a coefficient which represents the roughness or friction applied to the flow by the channel. Manning's n-values are usually selected from tables, but can be back calculated from field measurements. In many flow conditions the selection of a Manning's roughness coefficient can greatly be affected by the environment.

3. HEC- RAS Model

HEC-RAS model was developed by U.S. Army-Corp and have been used for river

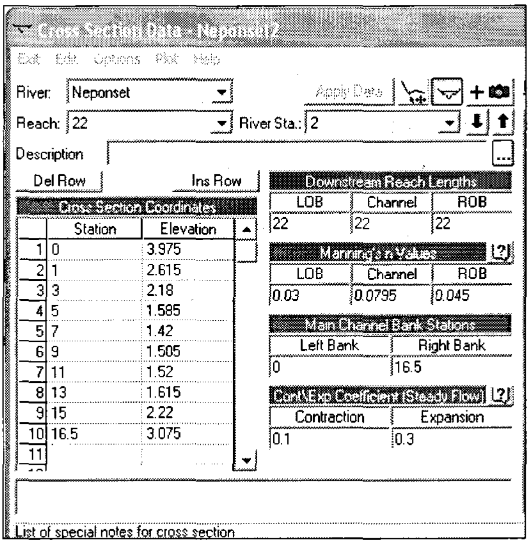
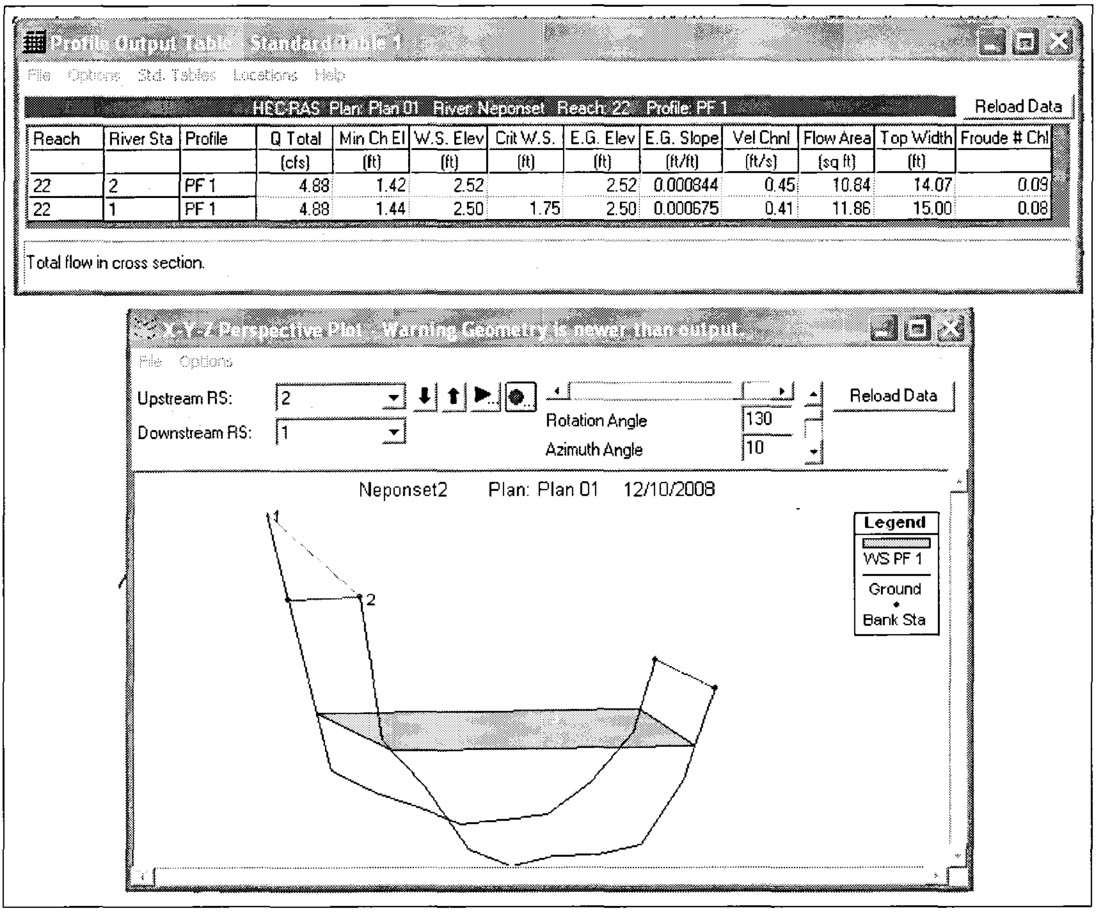


Fig 4. DATA Input of HEC-RAS Model


Profile Output Table - Standard Table 1

HEC-RAS Plan: Plan 01 River: Neponset Reach: 22 Profile: PF 1

Reach	River Sta	Profile	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Crit W.S. (ft)	E.G. Elev (ft)	E.G. Slope (ft/ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude # Chl
22	2	PF 1	4.88	1.42	2.52		2.52	0.000844	0.45	10.84	14.07	0.09
22	1	PF 1	4.88	1.44	2.50	1.75	2.50	0.000675	0.41	11.86	15.00	0.08

Total flow in cross section.

Fig 5. Profile Output of HEC-RAS Model

analysis such as steady flow water surface profile computation, unsteady flow simulation, movable boundary sediment profile computation, or water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines.

HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. This study looks at the water surface profile of the forest area as a sample to compare the result and the HEC-RAS model response.

The data from the field survey is stored into flow files under separate categories of project, plan, geometry, steady flow, unsteady flow, and sediment data, and then output data are predominantly stored in separate binary files.

The output can be made in Graphics which include X-Y plots of the river system schematic, cross-sections, profiles, rating curves, hydrographs, and many other hydraulic variables. A three-dimensional plot of multiple cross-sections is also produced with tabular output.

Ⅲ. Results

1. Surveying Elevation

Using an AutoLevel was determined the elevation

Table 2. Forest Area Cross-Section Profile

Forest Cross-section 1					Forest Cross-section 2			
Elevation of BS = 13.935 ft					Elevation of BS = 13.935 ft			
distance along tag line(ft)	BS	FS	Elevation (ft)	distance of two cross sections (ft)	distance along tag line(ft)	BS	FS	Elevation (ft)
16.5	3.935	10.86	3.075	22	18	3.935	10.975	2.96
15		11.715	2.22		17		11.65	2.285
13		12.32	1.615		15		12.12	1.815
11		12.415	1.52		13		12.42	1.515
9		12.43	1.505		11		12.475	1.46
7		12.515	1.42		9		12.5	1.435
5		12.35	1.585		7		12.335	1.6
3		11.755	2.18		5		12.2	1.735
1		11.32	2.615		3		11.98	1.955
0		9.96	3.975		1		10.375	3.56
					0		9.55	4.385

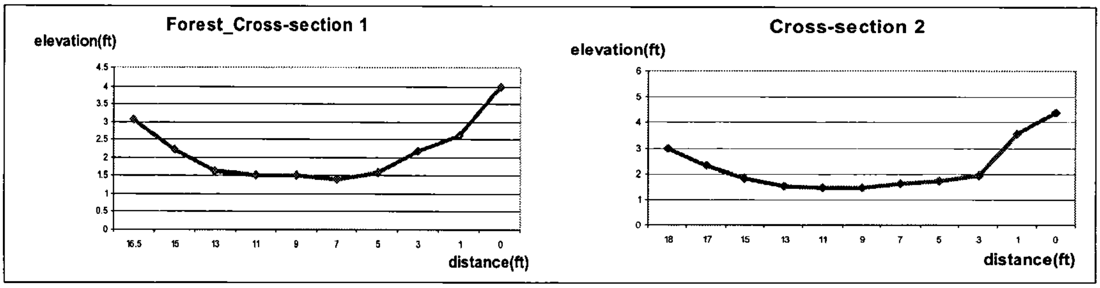


Fig 6. Cross-Section Profile, Forest Area

Table 3. Residential Area Cross-Section Profile

Residential Cross-section 1					Residential Cross-section 2			
Elevation of BS = 13.635 ft					Elevation of BS = 13.635 ft			
distance along tag line(ft)	BS	FS	Elevation (ft)	distance of two cross sections (ft)	distance along tag line(ft)	BS	FS	Elevation (ft)
0	3.635	6.76	6.875	15	0	3.635	7.115	6.52
1		6.76	6.875		1		7.315	6.32
3		6.85	6.785		3		7.275	6.36
5		6.8	6.835		5		7.21	6.425
7		6.695	6.94		7		7.475	6.16
9		7.1	6.535		9		7.635	6
11		7.2	6.435		11		7.475	6.16
13		7.035	6.6		13		7.115	6.52
15		6.72	6.915		14.5		6.975	6.66

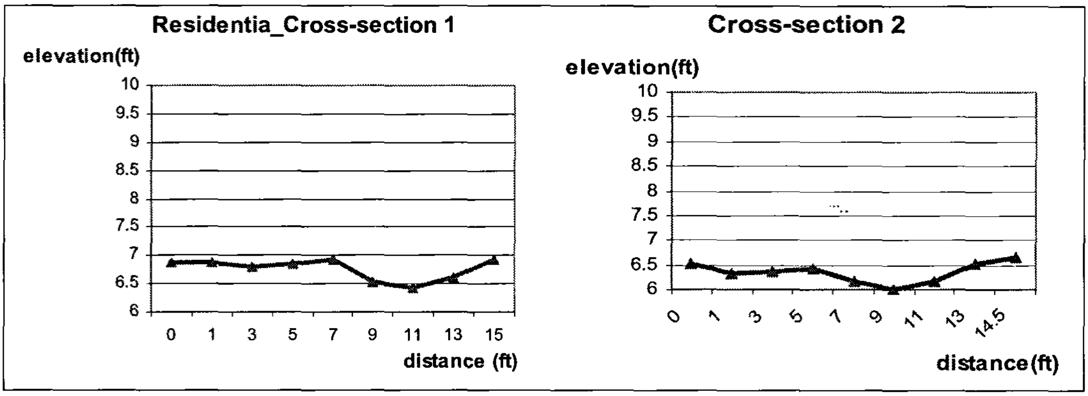


Fig 7. Residential Cross-Section Profile

at selected locations along two cross-sections. The data collected and the two cross sections determined are presented in the tables 2 and 3 and Figures 6 and 7. The elevation for the first BS was assumed to be 10 ft. For the both cross sections the slope was determined as the difference between the deepest point in the two cross-sections divided by the length between them. The slope computed was 0.0007 for forest area and 0.029 for residential area.

2. Stream gauging

After the survey elevation the velocity was measured in the cross sections at each two feet distance along the cross-section. The calculations were made with the assumption that the stream channel form has a rectangular and a triangle shape. The perimeter was calculated as a sum of small areas with a regular shape.

The data and the results are provided in Table 4 and 5.

To calculate the area it was assumed that the shape of the cross-sections for the forest is trapezium. In forest Area, downstream has up-line 14.2, down-line 6, 0.9925 height, area

Table 4. Stream Flow Profile, Forest Area

Forest Cross-section 1 / Forest Cross-section 2

Distance along tag line (ft)	Depth (ft)	Velocity (ft/s)	Area (ft^2)	Discharge (cfs)	Distance along tag line (ft)	Depth (ft)	Velocity (ft/s)	Area (ft^2)	Discharge (cfs)
0	0				0	0			
2	1.1808	0			2	0.656	0		
		-0.13	1.1808	-0.153504			-0.03	0.656	-0.01968
4	1.6236				4	1.7712			
		-0.07	2.8044	-0.196308			-0.01	2.4272	-0.024272
6	1.7056				6	2.0008			
		0.04	3.3292	0.133168			0.35	3.772	1.3202
8	1.968				8	2.0992			
		0.22	3.6736	0.808192			0.72	4.1	2.952
10	1.6072				10	1.968			
		0.7	3.572	2.50264			0.41	4.0672	1.667552
12	1.7712				12	1.9024			
		0.55	3.378	1.85812			-0.11	3.8704	-0.425744
14	1.6728				14	0.3936			
		0.23	0.8364	0.192372			-0.04	0.1968	-0.007872
15	0				15	0			
		0.348	Total Q	5.494492			0.493333	Total Q	4.2722

Table 5. Stream Flow Profile, Residential Area

Distance along tag line (ft)	Depth (ft)	Velocity (ft/s)	Area (ft^2)	Discharge (cfs)
0	0			
2	0.164	0		
		0.01	0.164	0.00164
4	0.328			
		0.23	0.492	0.11316
6	0.164			
		0.23	0.492	0.11316
8	0.164			
		0.24	0.328	0.07872
10	0.6888			
		0.75	0.8528	0.6396
12	0.6888			
		0.54	1.3776	0.743904
14	0.3608			
		-0.19	0.1804	-0.034276
15	0			
		0.33	Total discharge	1.69

10.02425, and length 11.43663, while upstream has up-line 15.3, down-line 6, 0.9725 height, area 10.35713, length 13.60441, and overall the forest area's cross-section area was calculated 10.19069 square ft with length of 12.52052ft.

On the other hand, the cross-section of residential area was determined as a sum of two small triangles. The reasoning for doing so is that the channel is almost separated in two sections due to the presence of a big boulder in the middle of the stream which almost touches the water surface. Downstream has up-line is 4.7, down-line 6, height 0.065, area 0.15275, length 4.701798, and upstream has up-line 8, down-line 6, height 0.5, area 2, length 7.071068. On the whole, residential area's cross-section profile area is computed 2.618625 square ft with 12.9764 ft length. These computed data lead to

Table 6. Computation of Manning's n Value

	Discharge (cfs)	A (ft2)	P (ft)	R (ft)	S	n
Forest	4.88	10.19	12.52	0.81	0.0007	0.07
Residential	1.69	2.62	12.98	0.20	0.029	0.14

Table 7. Channel bed Material for forest area

Very weedy reaches, deep pools or floodways with heavy stand of timber and underbrush	Manning's Equation *n*	HEC -RAS model *n*
0.075 - 0.15	0.0707	0.0795

Table 8. Channel bed Material for residential area

Cobble	Manning's Equation *n*	HEC -RAS model *n*
0.03 - 0.06	0.135	0.006

calculation of Manning's 'n' value.

To determine the Q, it was use the average value of two cross-sections for forest area's river and just one cross-section's discharge for the urban area's value. The A is also the average area of two cross-sections of the forest area's river and just one cross-section's area of the urban area's river. R, the radius is got from the average area of the two cross-sections and the average perimeter of the two cross-sections for forest area's river. For urban area's river, we still use one cross-section's area and perimeter to get the radius.

The water surface profile is very close to the HEC-RAS model result. The model response that the cross-section profile looks very similar to the our measurement, the downstream water surface elevation is 2.5ft which is exactly same as the measurement from the field survey even if the upstream water surface elevations are a little lower than our measurement, and Manning's n value is 0.795 which is close to our 0.07078. On this view point, the HEC-RAS model is very effective for the water surface profile computation.

In the resident area the Manning's 'n' value calculated is much higher than the value assumed after observation at the site (cobble: n = 0.03-0.06). The difference could be caused by unusual steep elevation on the site and the dam present down further. With the steep elevation upside of dam, there is critical-depth condition. The difference of Manning's 'n' value is related to the difference of depth. HEC-RAS model was run to analyze the difference and the result shows that depth is 0.36 much less than 0.688 what we computed when the Manning's n value is 0.03(cobble) instead of ours (0.13292). Beside, dam is a major source of fragmentation and degradation of stream, and it's possibly inferred upstream water levels are increased and stream velocity is decreased.

Here what I have to consider is the slope of residential area is relatively steep. This is the case for critical depth being higher than normal depth. Therefore, upstream of the dam the flow tends to have super-critical condition with high velocity. The high velocity introduced in Manning's equation influences 'n' value.

Ⅳ. Conclusion

I had two cross-section profiles, upstream and downstream, for the forest area and residential area. I also measured water flow profiles for each cross-section, but have only one for the residential area. I observed the both sites whose landuse are different. In forest area, upstream and downstream channel beds are noteworthy distinguished in just 22 feet distance. Upstream bed is very weedy with deep pools and underbrush; while downstream has muddy bed with deep pools on one side. On the other hand, residential area has uniform stream channel having the velocity relatively constant.

The channel bed material is estimated using Manning's 'n' value for the two different sites, and compared with the result of HEC-RAS model with the cross-section profile data I measured.

In the forest area, water surface elevation and bed material obtained through Manning's equation are very close to HEC-RAS model result. However, in the resident area the Manning's 'n' value calculated much higher than assumption which was considered as cobble whose 'n' value is 0.03-0.06. The difference could be caused by unusual steep elevation on the site and the dam present down further. With the steep elevation upside of dam, there is critical-depth condition occurs. The difference of Manning's 'n' value reflects the difference of depth. HEC-RAS model was run to analyze the difference and the result shows that depth is 0.36 much less than 0.688 what we computed when the Manning's n value is 0.03(cobble) instead of ours (0.13292). Beside, dam is a major source of fragmentation and degradation of stream, and it's possibly inferred upstream water levels are increased and stream velocity is decreased.

The study found the bed material of the different stream whose landuse is different from each other on the same sub-basin. Forest area has more natural diverse bed, while the residential area has relatively uniform bed condition.

HEC-RAS model is useful method to confirm the stream gauging, and it's effective to invest for unusual channel condition as like the residential area cross-section profile of this study.

Even if the residential area of the study sites looks very flat, but there is critical-depth condition occurs due to the steep elevation.

This study was a good practice for analyzing of geographical difference with channel bed material. Recent days, river management and development of river side or river front have been taking a growing interest in many fields. HEC-RAS tool is going to be able to use very usefully to analyze different sites run alongside river and to develop the sites especially geographical field with GIS.

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