Stream Gauging Field Work Report

Arayat Station, Pampanga

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1.0 **Preface**

As part of the requirements in Stream Gauging II: Discharge Measurement in the Hydrologist Training course conducted by PAGASA, all the participants in the said course were required to undergo a 10-day field work from October 15-25, 2013 under the guidance of the Pampanga River Flood Forecasting and Warning Center (PRFFWC). Field activities include visits to various dams within the Pampanga River Basin and a visit to a local disaster risk reduction unit (Municipal Disaster Risk Reduction Management Council of Calumpit, Bulacan) but the most important activities were the investigative survey and discharge measurements of the Pampanga River done around the vicinity of PRFFWC's Arayat station located alongside San Agustin Bridge of Brgy. Camba, Arayat, Pampanga. This report will detail the various methods of discharge measurements that were done.

2.0 **Site Description**

Discharge measurements of the middle main section of the Pampanga River were done within the vicinity of PRFFWC's Arayat Station. The said gaging station is located at the right bank of the Pampanga River, downstream of San Agustin Bridge along the GSO highway at Brgy Camba, Arayat, Pampanga. Weather was fine during the 10-day field work period, allowing relatively favourable conditions for data gathering and survey work. Pampanga was hit by typhoon Santi the week prior and the whole class was tasked to survey the area inundated by the river during the event.

Downstream Reach of Pampanga River on the first day of measurements, taken at San Agustin Bridge.

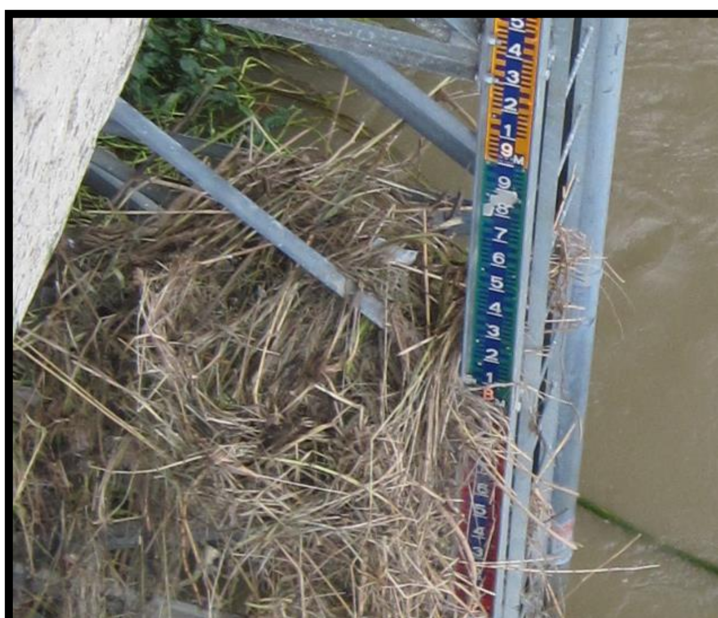
Aerial View of the site from Google earth

Our group took the measurements for all methods of discharge at the downstream side of the bridge. The river's left bank downstream of the bridge had a steep slope with visible signs of erosion and was covered with tall grass, reeds and trees. There were also grass and reeds that run along the river's right bank near the water edge, but beyond that, terrain was relatively flat and agricultural with a number of trees dotting the

Arayat Gaging station located at the right bank agricultural field. The soil at both banks were a mixture of clay and silt, although it was later found out when water level receded enough that part of the river bed's soil was a mixture of silt, clay, gravel, sand and pebbles.

Downstream Reach

By visual inspection, the downstream reach appears to contract several hundred meters from the bridge, after which it bends to the right. At the time, there were traces of debris and mud on structures and trees from the flood brought about by typhoon Santi. One of the floodmarks worthy of mention was that located on the center pier of the bridge where the staff gage was attached, which apparently indicates that the water at the time of



Flood mark on staff gage during the first day of measurements the flooding reached at least 8 meters on the staff gage.

3.0 <u>Methods of Discharge Measurements</u>

The class was divided into 4 groups, each gathering data for different methods of discharge measurement. For our group, we were tasked to obtain data for slope-area measurements on Day 1 (October 17), ADCP measurements on Day 2 (October 18), current meter measurements on Day 3 (October 21) and measurement by float on Day 4 (October 22). Details of the measurements, computations, as well as inferences and comments will be presented in that order.

3.1 <u>Slope-Area Method</u>

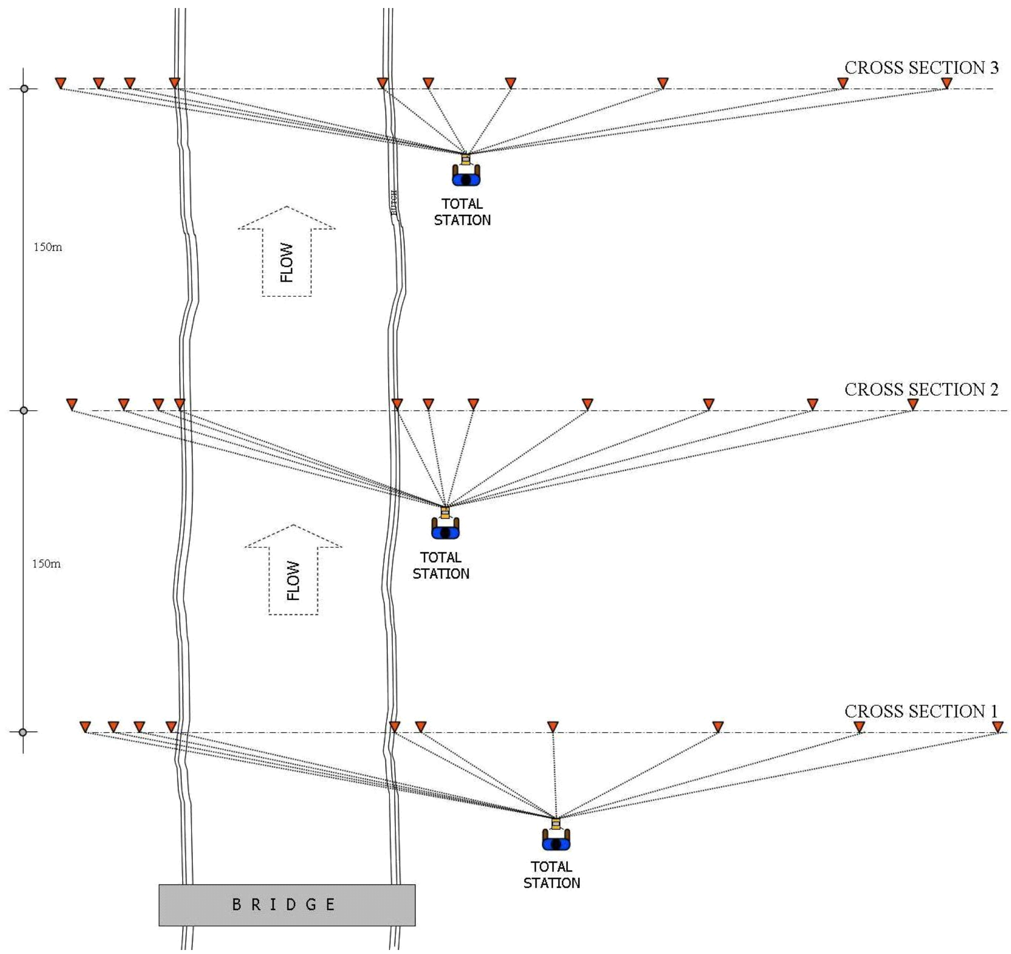
Slope-area method is a type of indirect method of computing discharge which is particularly useful in estimating discharge at flood events. It consists of using the slope of the water surface in a uniform reach of channel and the average cross-sectional area of that reach to compute for discharge. Given that data, the discharge may be computed from several formulas, but the one used by the USGS and PAGASA is the Manning formula. Manning formula also requires "roughness" factors which describe the character of the channel. In order for the equation to give the best results, certain selection criteria must be considered:

1. The reach must be fairly straight and contracting.
2. There must be at least 3 cross sections within that reach, while the length of the whole reach must be greater than or equal to 75x the mean depth.
3. The fall of the reach must be greater than 0.15 meters.

Since information about the slope of the water surface and the cross sectional area of the reach are needed, the highest traces of flood marks on both banks would need to be identified in a certain reach and a survey of the reach is also required.

3.1.1 <u>Cross section survey</u>

A benchmark located at the left bank at about 100 meters northwest from San Agustin Bridge was used for the survey. The benchmark has an elevation of 9.114 AMSL, within the vicinity of the old gaging station and was located at the concrete foundation of an antenna post that was no longer there. Benchmark was run across the right bank downstream of the bridge, where a reach starting at 53 meters from the bridge and with a total length of 300 meters was surveyed for the slope-area measurements. The reach surveyed was divided into three cross-sections 150 meters apart. The 53 meter distance from the bridge was determined by tape (by the group performing float measurements) and the subsequent intervals of 150 meters up to 300 meters were determined by a range-finder.



In each cross-section, points were established from the flood mark to the right bank and from the left bank to the flood mark (on the other side of the river). In each point up to the river banks, elevation was determined through the use of a Total Station and the distance between points were evaluated from the horizontal distance and angle read out by the instrument. The elevation profile of the river bed, on the other hand, was taken by measuring depths at various distances along the cross-section of the river through an echo sounder and subtracting those depths from the elevation at the water edge of the right bank. The tables in the following pages show the summary of the survey that was done for each cross section, going from *left bank to right bank*:

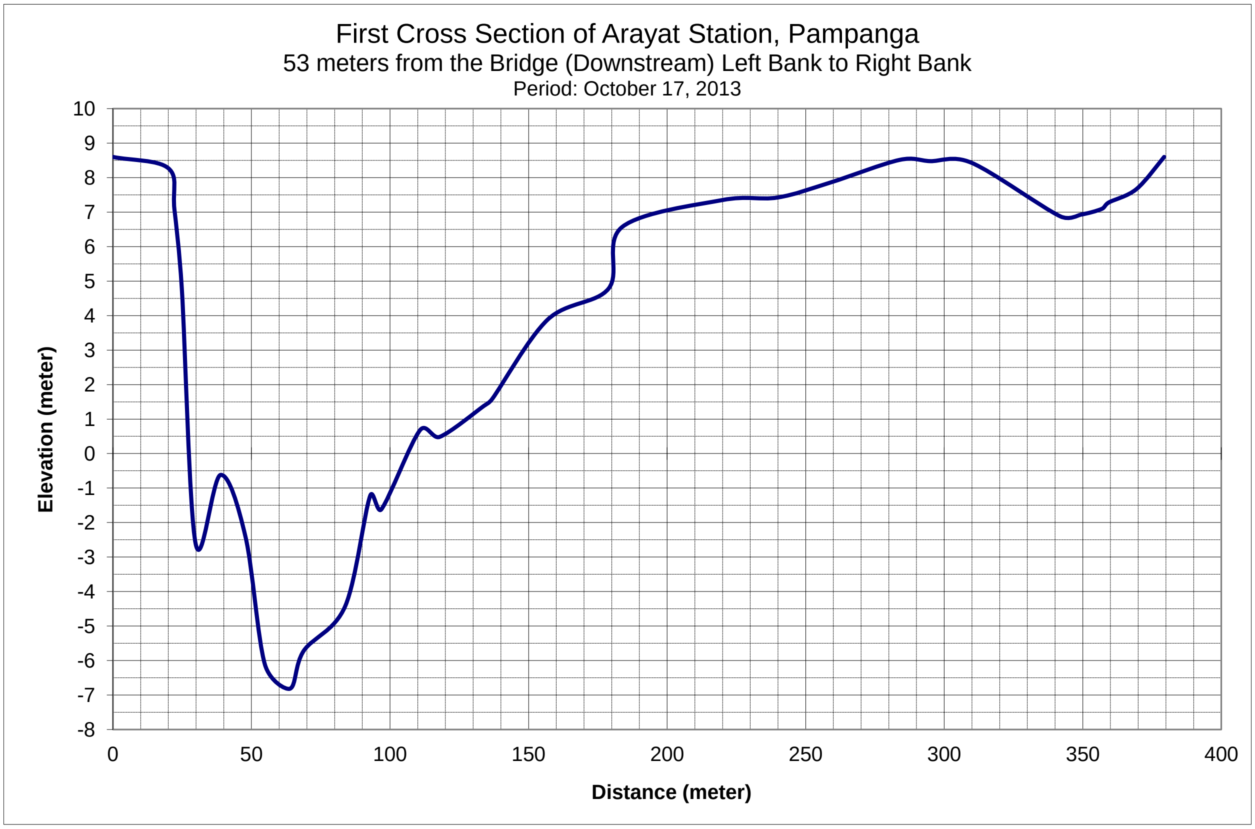
FIRST CROSS-SECTION				
POINT	DISTANCE			ELEVATION
	ACTUAL	CORRECTED	ACCUMULATED CORRECTED	
P1	0	0	0	8.6
P2	20	20.00	20	8.272
P3	2.2	2.20	22.2	7.072
P4	2.66	2.66	24.86	4.782
P5	5	5.00	29.86	-2.618
P6	9	9.00	38.86	-0.618
P7	9	9.00	47.86	-2.418
P8	7	7.00	54.86	-6.118
P9	9	9.00	63.86	-6.818
P10	5	5.00	68.86	-5.718
P11	15	15.00	83.86	-4.418
P12	9	9.00	92.86	-1.218
P13	4	4.00	96.86	-1.618
P14	14	14.00	110.86	0.682
P15	7	7.00	117.86	0.482
P16	16	16.00	133.86	1.382
P17	3	3.00	136.86	1.582
P18	20	20.00	156.86	3.882
P19	22	22.00	178.86	4.782
P20	5	5.00	183.86	6.575
P21	36	36.00	219.86	7.349
P22	20	20.00	239.86	7.424
P23	19	19.00	258.86	7.857
P24	25	25.00	283.86	8.514
P25	11	11.00	294.86	8.478
P26	15	15.00	309.86	8.431
P27	32	32.00	341.86	6.879
P28	7.5	7.50	349.36	6.928
P29	7.5	7.50	356.86	7.094
P30	2.5	2.50	359.36	7.279
P31	10	10.00	369.36	7.667
P32	10	10.00	379.36	8.6

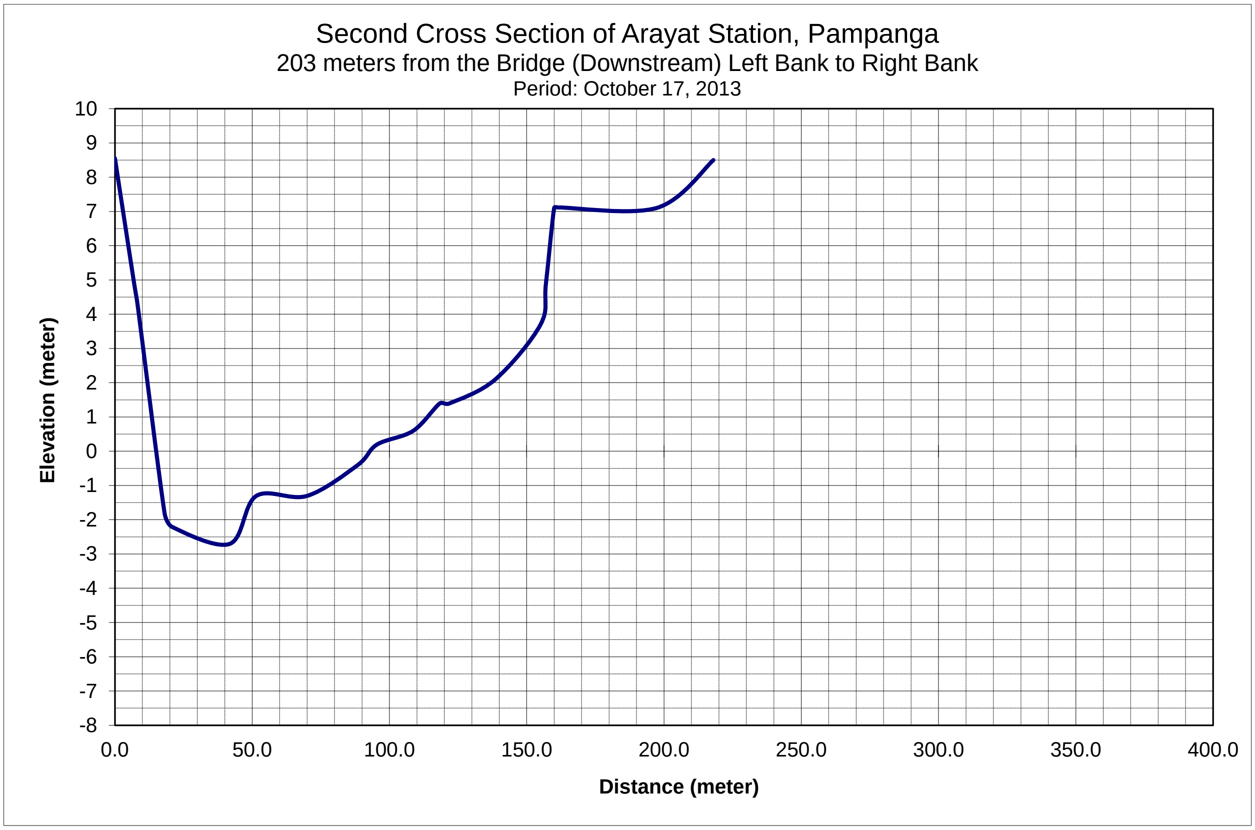
SECOND CROSS-SECTION				
POINT	DISTANCE			ELEVATION
	ACTUAL	CORRECTED	ACCUMULATED CORRECTED	
P1	0	0	0.0	8.552
P2	7.00	7.00	7.0	4.895
P3	1.41	1.41	8.4	4.185
P4	9.67	9.67	18.1	-1.805
P5	2.64	2.64	20.7	-2.205
P6	21.10	21.10	41.8	-2.705
P7	9.67	9.67	51.5	-1.305
P8	18.46	18.46	70.0	-1.305
P9	18.46	18.46	88.4	-0.405
P10	7.03	7.03	95.5	0.195
P11	13.19	13.19	108.6	0.595
P12	9.67	9.67	118.3	1.395
P13	3.52	3.52	121.8	1.395
P14	16.71	16.71	138.5	2.095
P15	16.48	16.48	155.0	3.695
P16	1.99	1.99	157.0	4.895
P17	6.00	3.00	160.0	7.103
P18	6.10	1.50	161.5	7.117
P19	36.00	36.00	197.5	7.106
P20	25.00	20.50	218.0	8.5

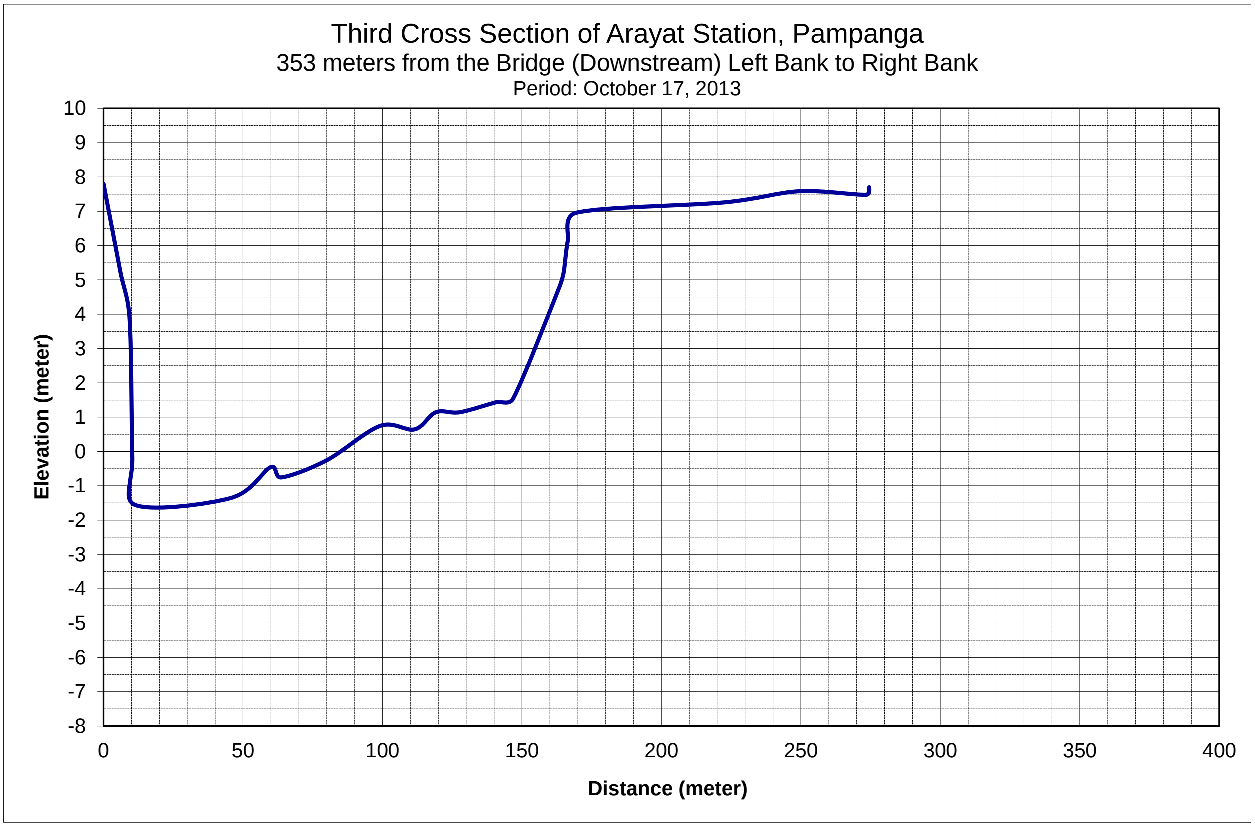
THIRD CROSS-SECTION				
POINT	HORIZONTAL DISTANCE			ELEVATION
	ACTUAL	CORRECTED	ACCUMULATED CORRECTED	
P1	0	0	0	7.797
P2	11	6.00	6	5.244
P3	3.34	3.34	9.34	3.844
P4	0.957	0.96	10.297	-0.156
P5	0.955	0.96	11.252	-1.556
P6	34.378	34.38	45.63	-1.356
P7	14.32	14.32	59.95	-0.456
P8	3.82	3.82	63.77	-0.756
P9	16.24	16.24	80.01	-0.256
P10	19.098	19.10	99.108	0.744
P11	12.412	12.41	111.52	0.644

P12	7.642	7.64	119.162	1.144
P13	8.595	8.60	127.757	1.144
P14	13.369	13.37	141.126	1.444
P15	5.73	5.73	146.856	1.544
P16	16.712	16.71	163.568	4.824
P17	1.432	1.43	165	5.244
P18	1.5	1.50	166.5	6.166
P19	3	3.00	169.5	6.958
P20	53.5	53.00	222.5	7.259
P21	30.5	27.00	249.5	7.584
P22	24.5	24.00	273.5	7.483
P23	1	1.00	274.5	7.7

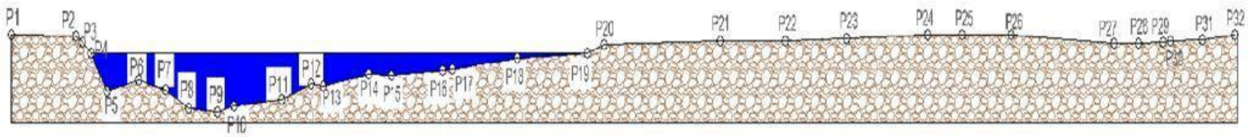
Also presented below are the illustrations for each cross section, once again shown from left bank to right bank with values for elevation referenced to Mean Sea Level:




Second Cross Section of Arayat Station, Pampanga
203 meters from the Bridge (Downstream) Left Bank to Right Bank
Period: October 17, 2013
Elevation (meter)
Distance (meter)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
0.0
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0

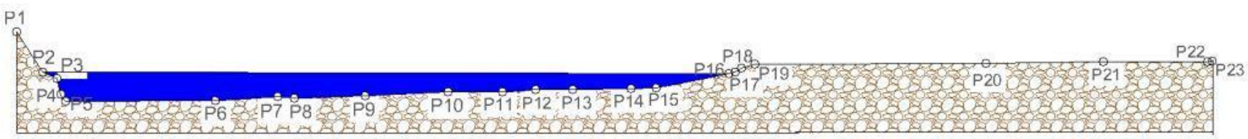

Third Cross Section of Arayat Station, Pampanga
353 meters from the Bridge (Downstream) Left Bank to Right Bank
Period: October 17, 2013
Elevation (meter)
Distance (meter)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
0
50
100
150
200
250
300
350
400

The illustrations below show the same cross sections plotted out in AutoCAD[1]:



FIRST CROSS SECTION

SECOND CROSS SECTION



THIRD CROSS SECTION

3.1.2 <u>Issues and concerns</u>

There were a number of issues and difficulties that were encountered by the group during the survey, some of which are the inherent limitations of the Slope-Area method. These are:

1. <u>Identification of flood marks</u> – In most cases during the survey, it is either difficult to assess the horizontal extent of the flood mark in the cross-section, or it may simply be inaccessible and hard to identify. In the first cross-section, we were able to identify the flood mark on the right bank but we were forced to estimate the extent of the flood because of barbed wire fences and accessibility issues. On the left bank of the same cross section, the flood mark was hard to identify so we had to ask the locals who were with us on the boat about how high the water was at that time of flooding and we also had to estimate the extent because the area was too muddy to walk through.
2. <u>Tedious nature of the survey work</u> – The whole activity was time consuming and tiring. The group had to survey the ground along 300 meters of the river downstream and on its

[1] The cross section and top view layout were also drawn in cross section sheets and can be found in the appendices of this report.

banks, stepping on mud, crawling beneath barbed wires (whenever possible and allowed) and having to ask permission from residents to access their property for the survey work.

3. Stability of the boat used during the river survey – It was hard to maintain a straight line of depth measurement across the river because of the flow. There was no tagline used at the time because the tagline available wasn't enough to reach the other bank. We were forced to assume in our calculations that we traversed along a straight line.
4. Equipment issues - For a moment during the survey, the total station suddenly went off. There was a problem with the equipment's power supply but it was fortunate that the group, together with our mentor at the time, was able to find a remedy. The range finder's readings were also inaccurate and the device cannot read the distance toward the opposite bank.
5. Terrain – The ground was still muddy on the first day of measurements. The group had a difficulty finding a stable footing on which to measure the elevation of the ground, especially along the banks. This resulted in criss-cross measurement along the cross-section which is in contrast to an ideal straight-line measurement of elevation along a cross-section.
6. General accessibility issues – The group had a hard time measuring elevation at some points in the area simply because we could not access it. Some challenges encountered were knee-deep mud, barbed wire fences and thick bushes.

3.1.3 Computations of Discharge by Slope-Area Method

Data gathered for the cross sections were entered in the Slope-Area excel suite provided by our instructor, Mr Hilton T. Hernando. The cross section data were entered from left bank to right bank. The result was:

Republic of the Philippines
Department of Science and Technology
PHILIPPINE ATMOSPHERIC, GEOPHYSICAL AND ASTRONOMICAL SERVICES ADMINISTRATION (PAGASA)
Pampanga River Flood Forecasting and Warning Center (PRFFC)
Agham Road, Diliman, Quezon City

FFB, PAGASA

Slope-Area Summary Sheet (3-Section)

Station:	*Arayat*	River:	*Pampanga River*
Flood Date:	*13-Oct-13*	Drainage Area:	*6,487*
Gauge Height:	*8.78*	Meas. #:	

X - Section Properties:

X-Sect.	Width	Area	Highwater Marks: Left Bank	Highwater Marks: Right Bank	Average Water Sfc.	d_m (mean depth)	n	r	K	K^3/A^2	α	F	State of Flow
1	379.36	1623.42	8.272	8.6	8.436	4.279	0.04	4.19	106006.9	4.5E+08	1	0.379	tranquil
2	218.00	1355.39	8.552	8.5	8.526	6.217	0.04	6.10	113808.7	8E+08	1	0.377	tranquil
3	274.50	1221.98	7.797	7.7	7.7485	4.452	0.04	4.36	81973.56	3.7E+08	1	0.494	tranquil

note: Assume no sub-divided sections, hence α is always 1!!

Reach Properties:

Reach	Length	Δh Fall	k	reach condition	K_U/K_D	K_U/K_D Condition	Ave. A	**Q** by formula	Ave V
1-2	150	-0.09	0	contracting	0.931448	good	1489.403	x	x
2-3	150	0.7775	0	contracting	1.388359	good	1288.681	5881.839	4.564
1-2-3	300	0.6875	0	contracting	1.293184	good	1400.260	**3983.727**	2.845

n - roughness coefficient
K - conveyance
K_w - wtd. conveyance (Geometric mean of K of 2 sections).
F - Froude no.(indicates the state of flow).
α - velocity head coefficient
r - hydraulic radius
k - coefficient for differences in velocity heads between 2 sections.
h_v - velocity head
h_f - energy loss due to boundary friction in the reach.
S - friction slope

Discharge Computation:(comparison)

Reach	Assumed Q	h_v U/S	h_v D/S	Δh_v	h_f	$S=h_f/L$	$S^{1/2}$	K_w	**Computed Q**
1-2	x	0.307229	0.440754	-0.13353	-0.22353	-0.00149	x	109838.6	x
2-3	5881.839	0.440754	0.542249	-0.10149	0.676006	0.004507	0.067132	96588.32	6484.168

$Q_{1\text{-}2\text{-}3}$ = 3983.73 cumecs

Discharge

Rem:

Slope-Area Cross-Section Computation

Station:	*Arayat*			Survey Date:	*17-Oct-13*		
River:	*Pampanga*			Gage Ht.=	*5.31*	meters	
Cross-Section number ONE (1)							
Station	**Distance**	**Elevation**	**Water Sfc. elev.**	**Depth**	**Mean Depth**	**Area**	**Wetted Perimeter**
0		8.6	8.6	0			
20	20	8.272	8.6	0.328	0.164	3.28	20.00269
22.2	2.2	7.072	8.6	1.528	0.928	2.0416	2.505993
24.86	2.66	4.782	8.6	3.818	2.673	7.11018	3.509943
29.86	5	-2.618	8.6	11.218	7.518	37.59	8.930845
38.86	9	-0.618	8.6	9.218	10.218	91.962	9.219544
47.86	9	-2.418	8.6	11.018	10.118	91.062	9.178235
54.86	7	-6.118	8.6	14.718	12.868	90.076	7.917702
63.86	9	-6.818	8.6	15.418	15.068	135.612	9.027181
68.86	5	-5.718	8.6	14.318	14.868	74.34	5.11957
83.86	15	-4.418	8.6	13.018	13.668	205.02	15.05623
92.86	9	-1.218	8.6	9.818	11.418	102.762	9.551963
96.86	4	-1.618	8.6	10.218	10.018	40.072	4.01995
110.86	14	0.682	8.6	7.918	9.068	126.952	14.18767
117.86	7	0.482	8.6	8.118	8.018	56.126	7.002857
133.86	16	1.382	8.6	7.218	7.668	122.688	16.02529
136.86	3	1.582	8.6	7.018	7.118	21.354	3.006659
156.86	20	3.882	8.6	4.718	5.868	117.36	20.13182
178.86	22	4.782	8.6	3.818	4.268	93.896	22.0184
183.86	5	6.575	8.6	2.025	2.9215	14.6075	5.311765
219.86	36	7.349	8.6	1.251	1.638	58.968	36.00832
239.86	20	7.424	8.6	1.176	1.2135	24.27	20.00014
258.86	19	7.857	8.6	0.743	0.9595	18.2305	19.00493
283.86	25	8.514	8.6	0.086	0.4145	10.3625	25.00863
294.86	11	8.478	8.6	0.122	0.104	1.144	11.00006
309.86	15	8.431	8.6	0.169	0.1455	2.1825	15.00007
341.86	32	6.879	8.6	1.721	0.945	30.24	32.03761
349.36	7.5	6.928	8.6	1.672	1.6965	12.72375	7.50016
356.86	7.5	7.094	8.6	1.506	1.589	11.9175	7.501837
359.36	2.5	7.279	8.6	1.321	1.4135	3.53375	2.506836
369.36	10	7.667	8.6	0.933	1.127	11.27	10.00752
379.36	10	8.6	8.6	0	0.4665	4.665	10.04343
Total Width =		**379.36**	**meters**	**Hydraulic Radius(r) =**		**4.19**	**meters**
Total Area =		**1623.42**	**meters^2**	**Mean Section Depth =**		**4.279362**	**meters**
Wetted Perimeter(P) =		**387.344**	**meters**				

Slope-Area Cross-Section Computation

Station:	*Arayat*			Survey Date:	*17-Oct-13*		
River:	*Pampanga*			Gage ht.=	*5.31*	meters	
Cross-Section number TWO (2)							
Station	**Distance**	**Elevation**	**Water Sfc. elev.**	**Depth**	**Mean Depth**	**Area**	**Wetted Perimeter**
0.0		8.552	8.5	-0.052			
7.0	7	4.895	8.5	3.605	1.7765	12.4355	7.897699
8.4	1.4068	4.185	8.5	4.315	3.96	5.570928	1.575813
18.1	9.6718	-1.805	8.5	10.305	7.31	70.70086	11.37646
20.7	2.6374	-2.205	8.5	10.705	10.505	27.70589	2.66756
41.8	21.104	-2.705	8.5	11.205	10.955	231.1943	21.10992
51.5	9.670166	-1.305	8.5	9.805	10.505	101.5851	9.770983
70.0	18.4643	-1.305	8.5	9.805	9.805	181.0424	18.4643
88.4	18.4643	-0.405	8.5	8.905	9.355	172.7335	18.48622
95.5	7.034018	0.195	8.5	8.305	8.605	60.52773	7.059562
108.6	13.18878	0.595	8.5	7.905	8.105	106.8951	13.19485
118.3	9.671775	1.395	8.5	7.105	7.505	72.58667	9.704805
121.8	3.517009	1.395	8.5	7.105	7.105	24.98835	3.517009
138.5	16.70579	2.095	8.5	6.405	6.755	112.8476	16.72045
155.0	16.47719	3.695	8.5	4.805	5.605	92.35464	16.55469
157.0	1.98711	4.895	8.5	3.605	4.205	8.355798	2.321337
160.0	3	7.103	8.5	1.397	2.501	7.503	3.724952
161.5	1.5	7.117	8.5	1.383	1.39	2.085	1.500065
197.5	36	7.106	8.5	1.394	1.3885	49.986	36
218.0	20.49956	8.5	8.5	0	0.697	14.28819	20.5469
Total Width =	**218.00**	**meters**	**Hydraulic Radius(r) =**		**6.10**	**meters**	
Total Area =	**1355.39**	**meters^2**	**Mean Section Depth =**		**6.21737**	**meters**	
Wetted Perimeter(P) =	**222.194**	**meters**					

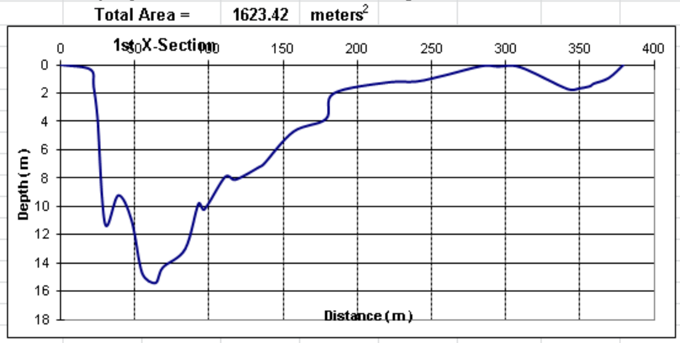
Slope-Area Cross-Section Computation

Station:	*Arayat*			Survey Date:	*17-Oct-13*		
River:	*Pampanga*			Gage ht.=	*5.31*	meters	
Cross-Section number THREE (3)							
Station	**Distance**	**Elevation**	**Water Sfc. elev.**	**Depth**	**Mean Depth**	**Area**	**Wetted Perimeter**
0.0		7.797	7.7	-0.097			
6.0	6	5.244	7.7	2.456	1.1795	7.077	6.520568
9.3	3.34	3.844	7.7	3.856	3.156	10.54104	3.621547
10.3	0.957	-0.156	7.7	7.856	5.856	5.604192	4.112888
11.3	0.955	-1.556	7.7	9.256	8.556	8.17098	1.694705
45.6	34.378	-1.356	7.7	9.056	9.156	314.764968	34.37858
60.0	14.32	-0.456	7.7	8.156	8.606	123.23792	14.34825
63.8	3.82	-0.756	7.7	8.456	8.306	31.72892	3.831762
80.0	16.24	-0.256	7.7	7.956	8.206	133.26544	16.2477
99.1	19.098	0.744	7.7	6.956	7.456	142.394688	19.12416
111.5	12.412	0.644	7.7	7.056	7.006	86.958472	12.4124
119.2	7.642	1.144	7.7	6.556	6.806	52.011452	7.65834
127.8	8.595	1.144	7.7	6.556	6.556	56.34882	8.595
141.1	13.369	1.444	7.7	6.256	6.406	85.641814	13.37237
146.9	5.73	1.544	7.7	6.156	6.206	35.56038	5.730873
163.6	16.712	4.824	7.7	2.876	4.516	75.471392	17.03084
165.0	1.432	5.244	7.7	2.456	2.666	3.817712	1.492322
166.5	1.5	6.166	7.7	1.534	1.995	2.9925	1.760706
169.5	3	6.958	7.7	0.742	1.138	3.414	3.102783
222.5	53	7.259	7.7	0.441	0.5915	31.3495	53.00085
249.5	27	7.584	7.7	0.116	0.2785	7.5195	27.00196
273.5	24	7.483	7.7	0.217	0.1665	3.996	24.00021
274.5	1	7.7	7.7	0	0.1085	0.1085	1.023274
Total Width =		**274.50**	**meters**	**Hydraulic Radius(r) =**		**4.36**	**meters**
Total Area =		**1221.98**	**meters^2**	**Mean Section Depth =**		**4.451640036**	**meters**
Wetted Perimeter(P) =		**280.062**	**meters**				

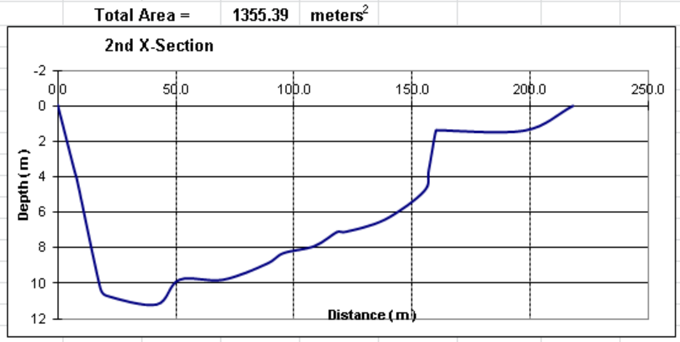
Station: *Arayat* **Date:** *17-Oct-13*

River: *Pampanga* **Gage Ht.** 5.31 **meters**

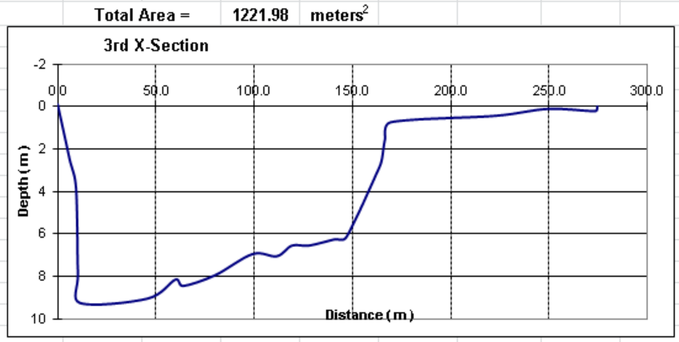
Total Area = 1623.42 meters^2



Total Area = 1355.39 meters^2



Total Area = 1221.98 meters^2



The roughness coefficient, n, that was used by the group was 0.04. This is the roughness coefficient of vegetation, chosen because at the time of the flood, the wetted perimeter included the trees, reeds and bushes surrounding both banks. **The estimated discharge at the time of the flood, by slope area method, was 3983.73 cubic meters per second.**

3.1.4 Inferences and Conclusions

The discharge determined by slope area method is, at best, only an approximate. This is due to the following reasons:

1. The reach under survey was not exactly straight. It gradually bends to the right when looking downstream of the bridge.
2. The rangefinder readings were inaccurate. This was later found out when the width of the river as computed from the readings of the total station and the width of the river measured with a range finder and measuring tape (used by members on the boat as the rangefinder cannot read out the distance toward the opposite bank at the time) were different. It was also by the use of the rangefinder that we established the 150 meter distance between the three cross-sections, which introduces another error in our calculations since it was these readings that were used in the excel suite.
3. The path traversed on the river was not actually straight. The tagline available that was supposed to guide the boat was not long enough to reach the other bank at the time. In the calculations, the group *assumed* a straight path of depth measurements across the river, with the cross section perpendicular to the flow.
4. Due to terrain restrictions mentioned previously (section 3.1.2), the elevation readings were not made exactly along the cross section established by a line connecting the right and left bank (with the exception of the first cross section). As a correction, we have to project a line from the actual readings perpendicular to the line of the cross section, marking the intersection and measuring the distance between intersections on a cross section sheet. This was how our corrected horizontal distances were established, based on the assumption that elevation is the same along a straight line perpendicular to the cross-

section. This, of course, does not reflect what is exactly on field and affects the representativeness of the discharge measurement to some degree.

5. The horizontal extent of the flood mark on the right and left banks of the first cross section was only estimated due to accessibility issues. The flood mark on the left bank of the same cross section, on the other hand, was not identified on site because the area was too muddy to walk through. The group had to ask the locals who were with us on the boat about the height of the water on the left bank, and then the group estimated the horizontal extent visually.
6. The roughness coefficient chosen might actually be inaccurate, since it is only an estimate done through visual inspection.

Though only an approximate value, the group believes that the value for discharge at the time of the flooding obtained by slope-area method is fairly accurate.

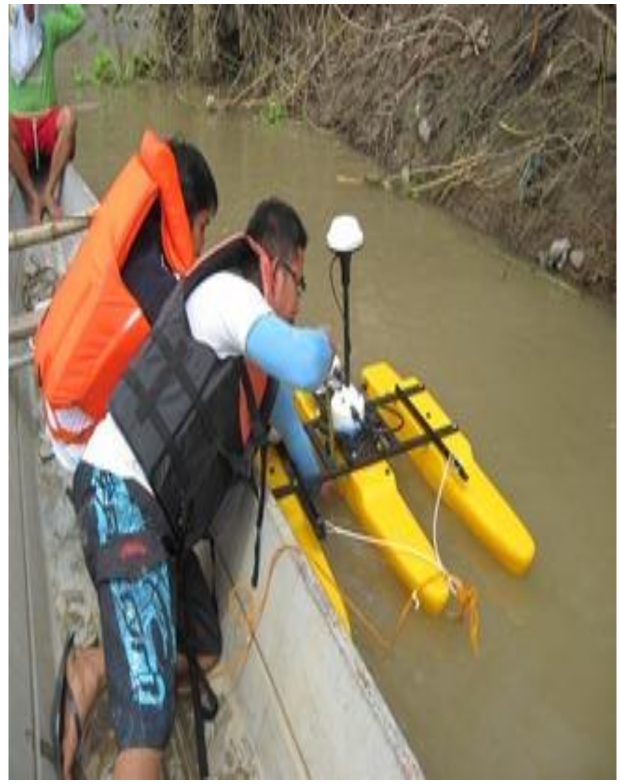
3.2 Measurement via Acoustic Doppler Current Profiler (ADCP)

Measurement of streamflow through ADCP was fairly straightforward. With proper set-up, the equipment read the total discharge at the cross section traversed, as well as the boat speed and the water velocities across an entire water column from the bottom all the way up to the surface in the cross section. It conveniently displayed all the results in a graphical format, plotting out the profile of the cross section as well as represented the velocities at various depths.

ADCP's basically use transducers to transmit sound into the water and listen to the change in the return sound to measure a velocity in the direction of each transducer. The discharge is then automatically determined by taking into account the velocity of the water and profile of the cross section measured by the device through sounding.

3.2.1. ADCP Set-up

The equipment was carefully assembled by mounting the sensors and transmitter on a meter long, yellow-colored plastic vessel. After synchronizing with a laptop computer, the ADCP was calibrated on its pitch, roll and yaw axes by actually yanking the assembled equipment to various orientations for at least a minute. After the calibration, the ADCP was positioned towards the left bank downstream of the bridge, coinciding with the first cross section of the previous-day slope-area measurements of the group.



3.2.2. Discharge measurements by ADCP

Before the actual discharge measurements were taken, the distance from the transducer to the water edge on the left bank was first measured by a measuring tape and the information relayed to the team on the bridge in charge with the user interface of the ADCP. After the gauge height (4.65 meters) and the distance to water edge were entered on the user interface, the team using the computer signals the team on the boat to start moving across the river, towing the ADCP from left bank to right bank. Upon arriving at the opposite bank, the distance from the transducer to the water edge on the right bank was also taken and relayed to the team handling the computer. At that point, measurement was done and after a brief moment, results were displayed on the computer. Note that no tagline was used.

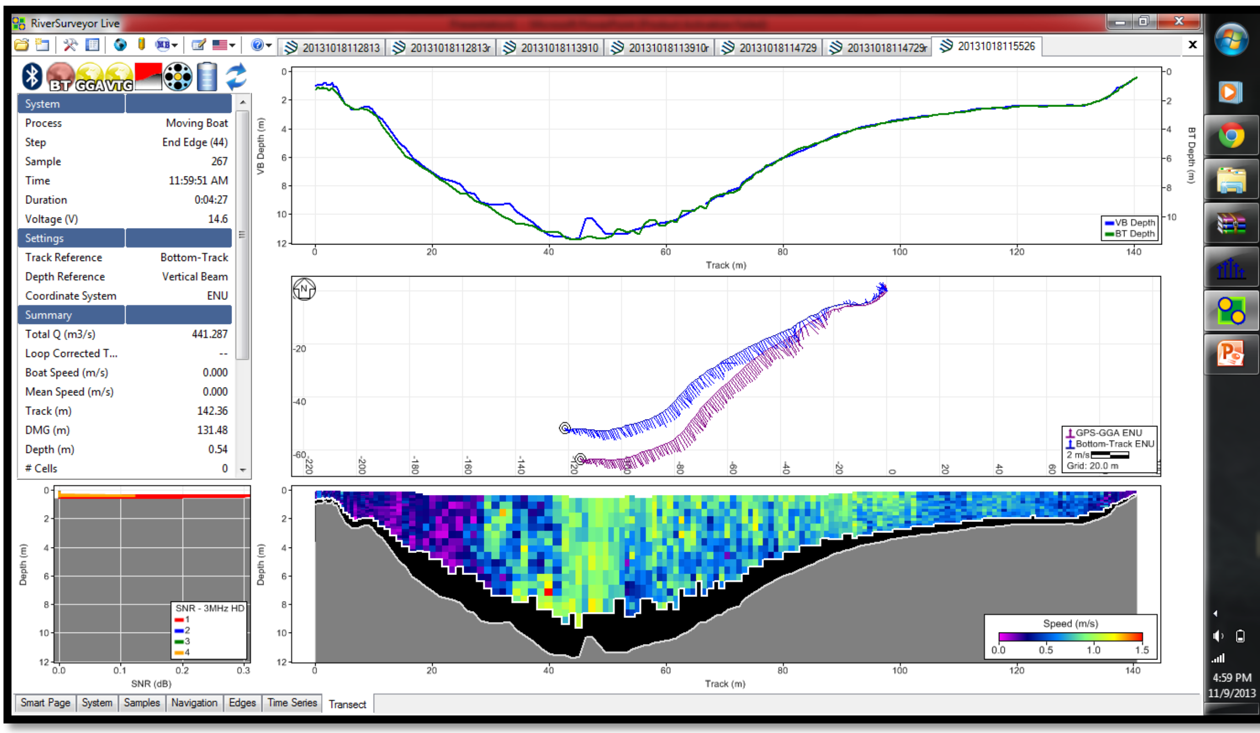
The ADCP actually measures the following values:

a. Location of sampling verticals 1, 2, 3,...n across the stream in reference to the distance from an initial point;

b. Stream depth, d, at each observation vertical;

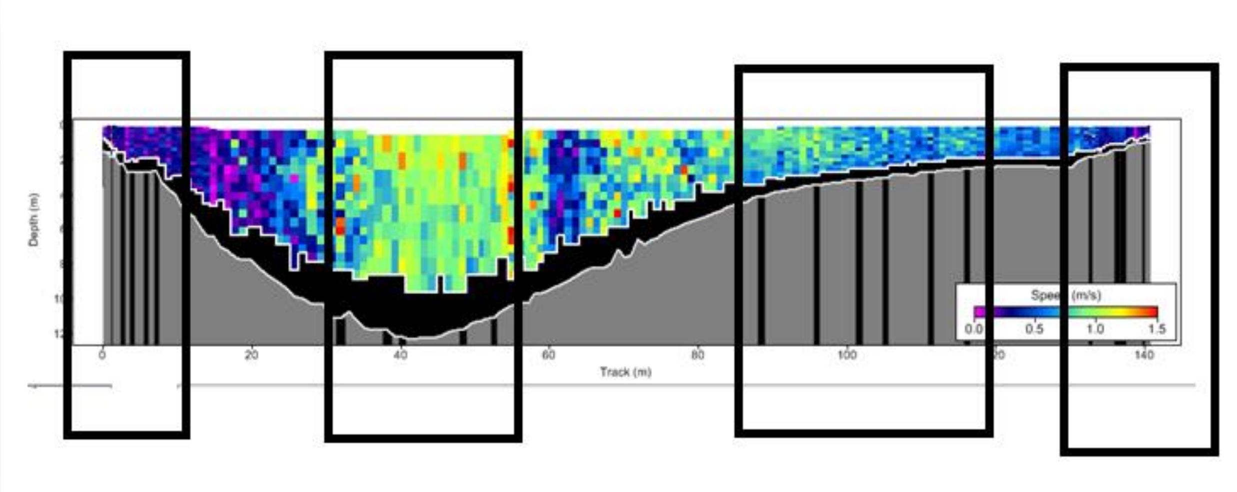
c. Stream velocity, V, perpendicular to the cross section at each observation vertical.

The results were shown graphically on the user interface. Data gathered could also be exported to a text file, for storage or documentation.



ADCP Results of Group 3

The group made four transects along the cross section, three of which have regions of invalid ensembles resulting from invalid bottom tracking. The last transect (shown above) has no invalid ensembles and was more accurate than the first three. **Discharge measured at this transect was <u>441.287 cubic meters per second</u>, at gauge height equal to 4.65 m.**



Highlighted portions show vertical bars below the stream bed, representing invalid ensembles resulting from invalid bottom tracking. Image taken from the first transect.

3.2.3 Inferences and Conclusions

By far, ADCP is the most convenient means of measuring discharge. Nonetheless, it has certain drawbacks:

1. High frequency pulses ("pings") yield more precise data, but low frequency pulses travel farther in the water. The discharge measurement team must make a compromise between the distance that the profiler can measure and the precision of the measurements. This is clearly illustrated by the black area above the stream bed in the ADCP output picture. Although velocities were accurately measured in most areas, the black areas show no velocity readings just above the stream bed. The obvious solution to this is to make the frequency of the pings lower so as to maximize the depth covered by the beam, but that would also affect the precision of the measurements.
2. Setting the ADCP at higher frequencies would deplete the batteries quickly.
3. Just the same as with measurements by current meter while on a boat, a tagline would greatly help in the accuracy of the data by ensuring that the measurements follow a straight line towards the other bank. In the group's measurement, no tagline was used.
4. For the river surveyor model that was used, mishaps can happen in securing the transducer to the floater assembly. Even when fastened properly, there is still a possibility that the transducer will fall-off because it was merely inserted and fastened

in place by a locking mechanism that does not entirely secure the whole instrument from falling off while in transit. This may be a limitation in the design of the model that was used.

5. It is expensive.

As can be seen on the output of the ADCP, water velocities at the edges are lower compared to the water velocities in the water column right above the thalweg. The output gives an illustration of the distribution of velocities within the cross section.

Measurements are all done via a computer, so the human elements of error in the calculations are eliminated. Care must be taken in the assembly, set-up, and actual traverse of the boat so as to yield optimum results. When all these are taken into consideration, ADCP measurements could serve as a benchmark for other traditional discharge measurement methods. It also gives the most accurate results.

3.3 Discharge measurement via Current Meter

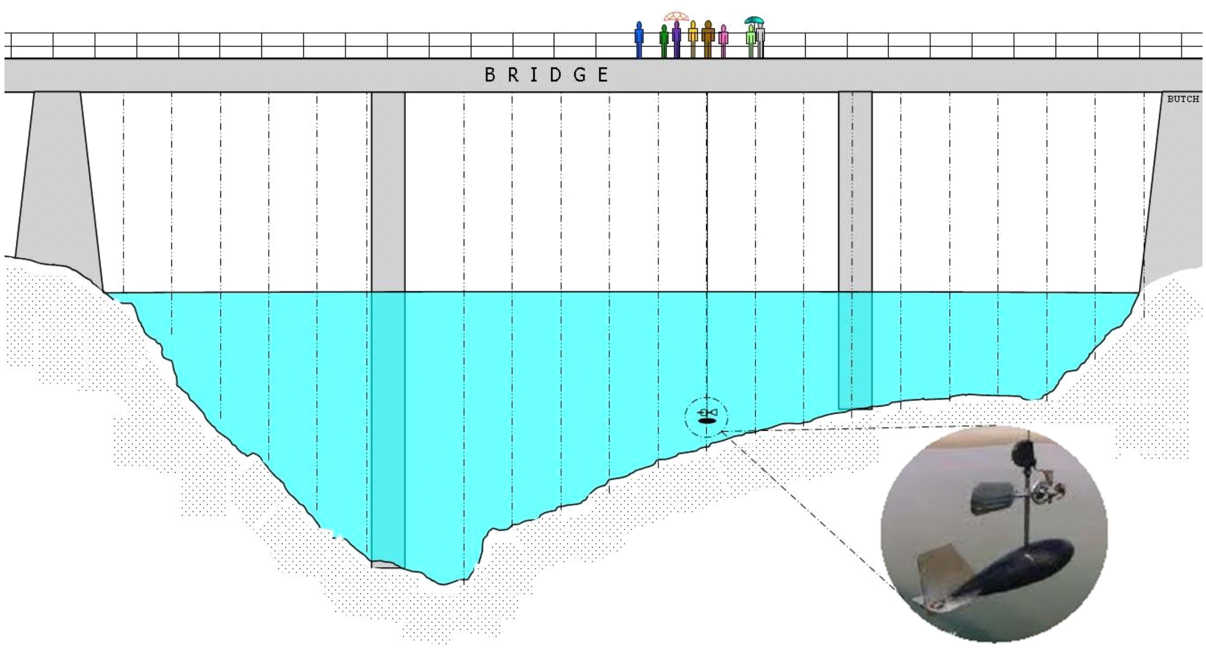
Measurement of discharge via current meter involves measuring water velocities at various segments and depths in a river cross section to compute for discharge. By sub-dividing a river cross section into segments (sometimes referred to as partial areas or panels) and measuring the depth and average velocity in a vertical within each segment, partial discharges can be calculated by the determining the product of the average velocity and the partial area. The total discharge for the cross section would then be the sum of all the partial discharges. This is the basic idea of the current meter method.

3.3.1 Identifying the segments

Measurements were done on the cross section directly below the bridge facing downstream. At the bridge, points were established starting from the left bank where the water edge was directly under. The group established several points where the measurements were to be taken based on the width of the river. The cross section was sub-divided into 24 segments having a 5 meter interval from the banks while switching to a 3 meter interval as the group approached the middle portions of the river, in anticipation of greater depths. This was done so that the partial discharges may not exceed 10 percent of the total.

Depths at each point were then measured using an echo sounder prior to the actual measurement of velocities. This was done in order to know beforehand the depths at which we are required to measure velocity by 2-point method, considering the sounding reel's cable length. Apparently, the sounding reel available could not reach the bottom of the river as relayed by the previous groups who had done the current meter method.

3.3.2 Velocity measurements



After the locations of the verticals have been established, the price current meter was checked for proper calibration. The bucket wheel was spun and the duration of the spinning noted. For a well-calibrated price AA current meter, the spinning should last to 2 minutes. The current meter available, on the other hand, was only spinning for less than a minute. This would indicate that the price current meter was already due for calibration and maintenance.

The sounding reel was then set-up. Current meter parts were assembled by coupling the meter and the columbus weight thru a hanger bar and attached to the cable from the sounding reel. The depth indicator for the sounding reel and the current meter beeper (which counts every revolution of the rotor made) were then connected to the whole assembly. *The price current meter was set to give a beep for every 5 revolutions.*

The current meter assembly was positioned at the points earlier identified. The current meter was lowered so that it aligns with the bridge road, after which the depth indicator was set to zero. After setting to zero, the meter was again lowered down until it reached the water surface and the corresponding depth recorded as the height of the bridge to the water surface.

After lowering the current meter up to the water surface, the depth indicator is once again set to zero and afterwards the current meter was lowered to 20% and 80% of the depth at that vertical, guided by the procedures of the two-point method of current meter measurements (These depths were already predetermined by the depth measurements done with an echo sounder prior to the velocity measurements. See section 3.3.1). The angle formed by the cable from the normal was also measured, as these would have to be taken into consideration in discharge calculations. The count of the current meter beeper within a 60-70 second interval was then recorded at those depths within the vertical.

Velocity measurements are done at all the verticals identified until the whole cross section under the bridge was covered.

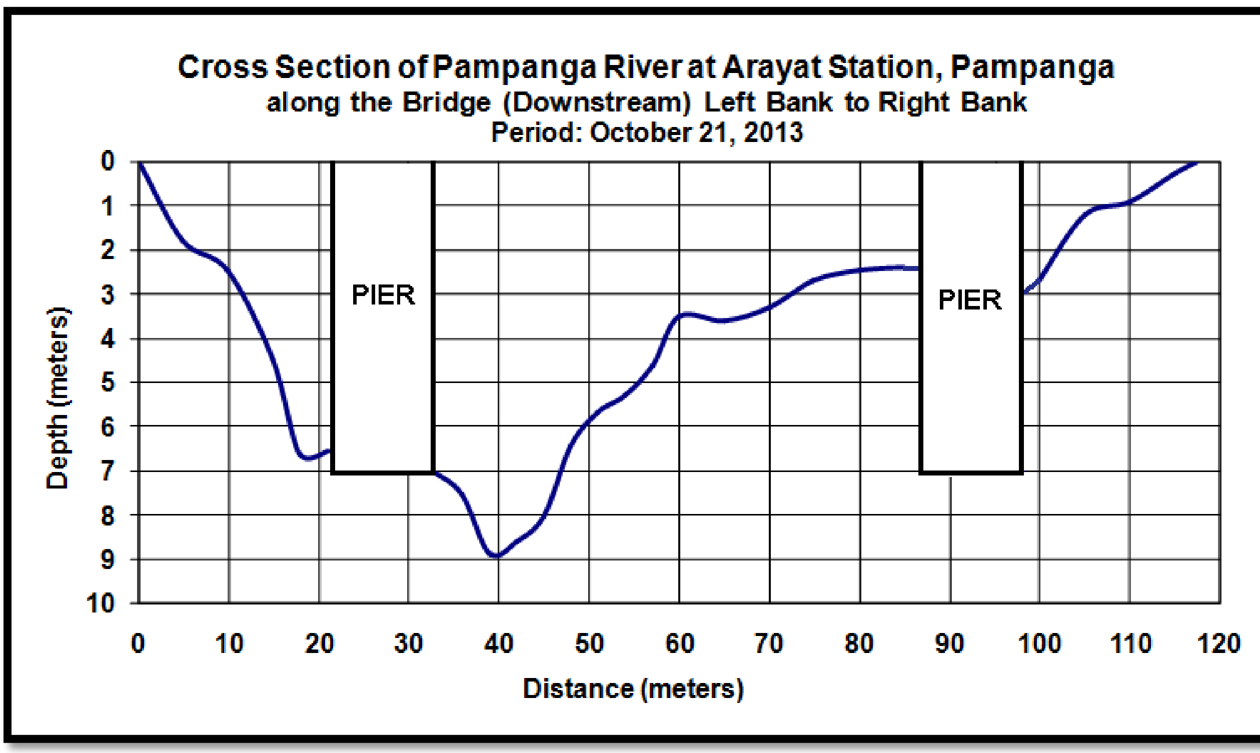
3.3.3 <u>Discharge Calculations</u>

All the data gathered were entered in the excel suite for current meter discharge calculations provided by our instructor, Mr Hilton T. Hernando. The program used the mid-section method for discharge calculations and the group used the two-point method of velocity measurement (taking velocity measurements at 0.2 and 0.8 depths). Velocity formula for the current meter used was V=0.702N+0.013. Since the current meter was set to 1 beep per 5 revolutions, all the values for revolutions were multiplied by 5 prior to data entry. The summary of all data and calculations are shown below.

Discharge Measurement (Current Meter) for :		ARAYAT STATION		River:	PAMPANGA RIVER		PRFFC
DM #:	03	Date:	October 21, 2013	Team:	Group 3		FFB
Gage Height: Start:	3.16	End:	3.11	Inst. # :	1	Wx: Fair	PAGASA
Observation Time: Start:	11:15	End:	14:42	Calibration Eqtn.: V =	0.702 N+ 0.013	note: just input negative value	hth/ 97
Vertical dist. to water surface (m) =			12.32			for latter if eqtn. is minus.	
Total Area (m^2) =	394.47		Ave. Gage Height =	3.14		Sectional Width (m) =	117.5
Total Q (m^3/s) =	293.42		Ave. Vel. (m/s) =	0.744			

Dist. from Initial point	Width (mts.)	Depth (ep for pier) (mts.)	Vert. Angle 4^0-36^0	Angle Corrected Depth	Observation Depth 0.2 Rev.	0.2 Time	0.6 Rev.	0.6 Time	0.8 Rev.	0.8 Time	Velocity at point for 0.6 only	Mean (0.2,0.6 & 0.8) or (0.2 & 0.8)	Area (m^2)	Q (cumecs)	Remarks Excellent, Good Fair, Poor
0				0											
5	5	2.2	14.5	1.777	60	62.0			60	65	x	0.677	8.89	6.01	
10	5	3.6	23	2.464	90	60.7			60	63.94	x	0.863	12.32	10.63	
15	4	6	26	4.451	50	61.5			25	61.33	x	0.442	17.81	7.86	
18	3	7.7	21.5	6.602	90	62.2			80	60.62	x	0.984	19.81	19.50	
21	3.5	7.6	21	6.549	85	62.1			85	64.44	x	0.957	22.92	21.93	
25	2.85														PIER
26.7	4														PIER
33	4.65	8.4	24	7.020	80	60.82			45	65.35	x	0.716	32.64	23.38	
36	3	8.7	22	7.522	80	61.92			60	61.62	x	0.808	22.57	18.24	
39	3	9.3	13.5	8.874	85	63.71			60	62.39	x	0.819	26.62	21.80	
42	3	8.8	9.5	8.593	80	64.51			65	61.63	x	0.818	25.78	21.10	
45	3	8.1	6.5	8.007	80	63.45			50	65.27	x	0.724	24.02	17.40	
48	3	6.6	8.5	6.442	75	64.55			70	64.52	x	0.802	19.33	15.49	
51	3	6	12.5	5.660	75	61.17			60	65.6	x	0.764	16.98	12.98	
54	3	5.3		5.300	75	64.23			60	63.98	x	0.752	15.90	11.96	
57	3	4.6		4.600	80	63.35			60	64.26	x	0.784	13.80	10.82	
60	4	3.5		3.500	80	63.55			60	62.32	x	0.793	14.00	11.10	
65	5	3.6		3.600	75	61.99			55	61.06	x	0.754	18.00	13.57	
70	5	3.3		3.300	75	62.48			50	63.29	x	0.712	16.50	11.74	
75	5	2.7		2.700	75	64.57			55	63.57	x	0.724	13.50	9.78	
80	5	2.5	4	2.468	75	65.2			55	64.65	x	0.715	12.34	8.83	
85	7.4	2.4		2.400	70	61.5			55	65	x	0.710	17.76	12.60	
94.8	5.75														PIER
96.5	2.6														PIER
100	4.25	2.7		2.700	50	61.87			30	63.84	x	0.462	11.48	5.30	
105	5	1.2		1.200	25	62.54			20	88.39	x	0.233	6.00	1.40	
110	5	0.9		0.900			0	0			x	x	4.50	x	
115	3.75	0.27		0.270			0	0			x	x	1.01	x	
117.5	x	0		0.000			0	0			x	x	x	x	
											Total Area =		394.47		
Rem:											Total Discharge =			293.42	
											Ave. Velocity =			0.744	

Computation of Mean Gage Height by Q weighting Process						
Station :	ARAYAT STATION			Date :	October 21, 2013	
River :	PAMPANGA RIVER					
DM # :	03			M.G.H.	3.12	meters
Time (0000)	Gage Height Reading	Ave. Gage Height		Qtotal ending at Time	Ave. G.H. * Q	Remarks
1115	3.15					
1200	3.12	3.135		65.93	206.69	
1300	3.12	3.120		101.93	318.01	
1400	3.11	3.115		97.44	303.52	
1442	3.08	3.095		28.12	87.04	
		x			x	
		x			x	
		x			x	
		x			x	
		x			x	
		x			x	
		x			x	
		x			x	
		x			x	
			Totals =	293.42	915.26	
		Mean Gage Height =		3.12	meters	



The group also noted that starting at 110 meters from the origin towards the water edge of the right bank, the current meter no longer registers a beep. Consequently, velocities at those points were recorded as 0. **The discharge at the cross section under the bridge on the downstream side, as measured by current meter method at an <u>average gage height of 3.14</u>, was <u>293.42 cubic meters per second</u>.**

3.3.4 Inferences and Conclusions

Next to the ADCP, the current meter method of computing discharge is a reliable means of determining streamflow. The method can be used in low to high flows, but that depends on the situation. It is classified as a direct method of discharge measurement.

Like any other methods, current meter method also has its drawbacks:

1. The Price AA current meter used in the activity was a vertical axis current meter. This type of meter is prone to obstruction by rubbish that would stick either on its bucket wheel or on the shaft where it rotates. This could hinder the rotation and consequently give inaccurate results.
2. As mentioned earlier, the current meter may no longer register beeps at very low velocities. This also affects the accuracy of the calculations because at very low flows, velocity is taken as 0.
3. It is only optimal at depths greater than 2.5 feet (0.762 meters).
4. As with any other device, poor condition or calibration of the current meter may lead to error in the measurements. In fact, the price meter used in the activity was due for maintenance and/or recalibration; it failed the spin test.
5. When measuring atop a bridge, major errors are caused by the effects of the pier on the water current. Due to turbulence, velocities near the structure were no longer measured.

Generally, the discharge made by the group would have been optimum if the current meter passed the spin test. But the computed discharge was, at best, already a good approximate.

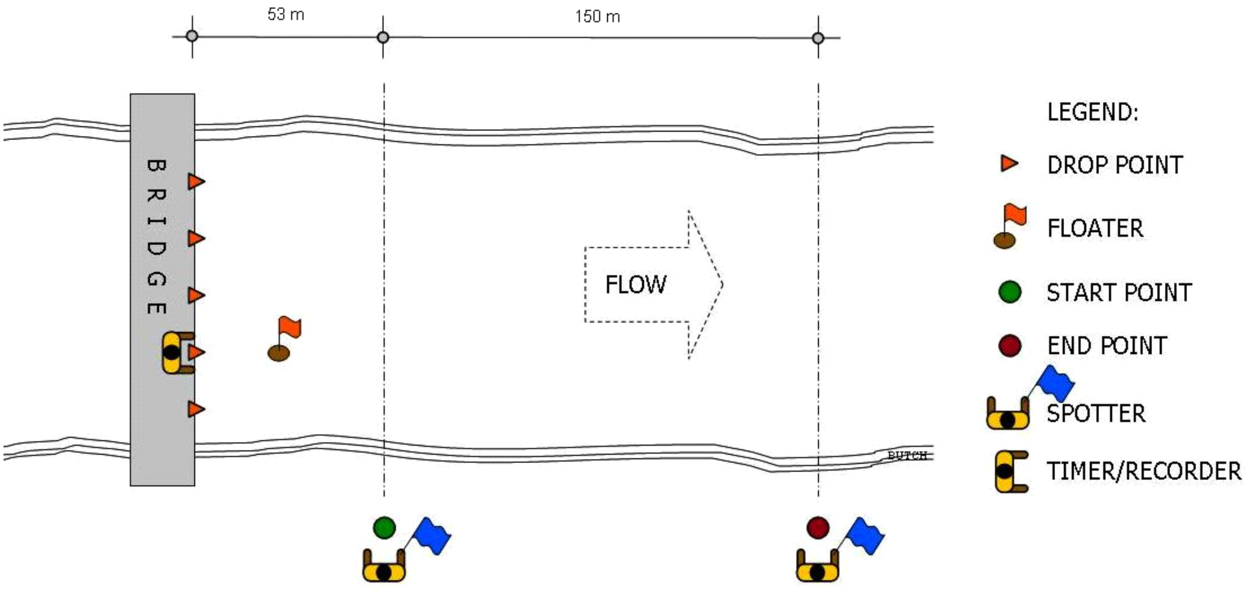
3.4 Discharge measurement via Float Method

In float method of discharge measurement, floats are thrown into the river and the time it takes to reach a specified distance downstream from a starting point is measured. Since a predetermined distance is known, velocity can be measured from the travelling time. This method actually measures surface velocity; mean velocity is then estimated by multiplying surface velocity by a correction factor.

Much like the slope-area method, this indirect method of computing streamflow is generally applied for floods where discharge observation by current meter and ADCP is difficult.

Measurement of water depth during floods is difficult, so only water surface elevation is recorded (or gauge height, depending on the datum used) and a cross section survey must be conducted soon after the flood to estimate the discharge area. Since float method requires velocity in the calculations, it has a higher accuracy compared to slope area method.

3.4.1 Measurement of transit time



The group used the 1st and 2nd cross sections in their slope area measurements as boundaries of the actual measurement section; the approach section was about 53 meters (from the bridge to the 1st cross section) and measurement section at 150 meters (1st to the 2nd cross section). The group was divided into two teams; the 1st team drops the bamboo floater off the bridge and the 2nd team acts as spotters on the 1st and 2nd cross sections. There must be communication at all times during the activity since at all three points (bridge, start point, end point), the time measured must ideally be in sync.

The team on the bridge divided the river width into five (5) unequal intervals, taking into consideration the contracting feature of the river. It was inside these intervals that the bamboo floaters were dropped. The team on the bridge notifies everyone that the float was dropped in a given section, the spotter on the 1st cross section notifies everyone to start timing, and lastly, the spotter on the 2nd cross section signals everyone to stop the time. Individual records for the start as well as the end time were averaged, and the time elapsed computed for a given section.

There were a total of five (5) drop points and measurements were first done from the right bank towards the left bank and the gage height for the whole duration of the first pass was at 2.78 meters, which meant that the water level during the first set of measurements was at 2.862 meters AMSL (0 gage height at 0.082m AMSL). The bamboo floater resurfaced at all drop points during the first pass.

The second set of measurements was done from the left bank towards the right bank. Unlike the first pass, however, the floater did not resurface on the 1st and 2nd drop while floater did not move at the 5th drop. It was during this time frame that the water level at the arayat station started to significantly reduce due to the closure of the nearby dam (cong dadong dam). Due to the circumstances, readings on the 2nd pass were disregarded during the computations.

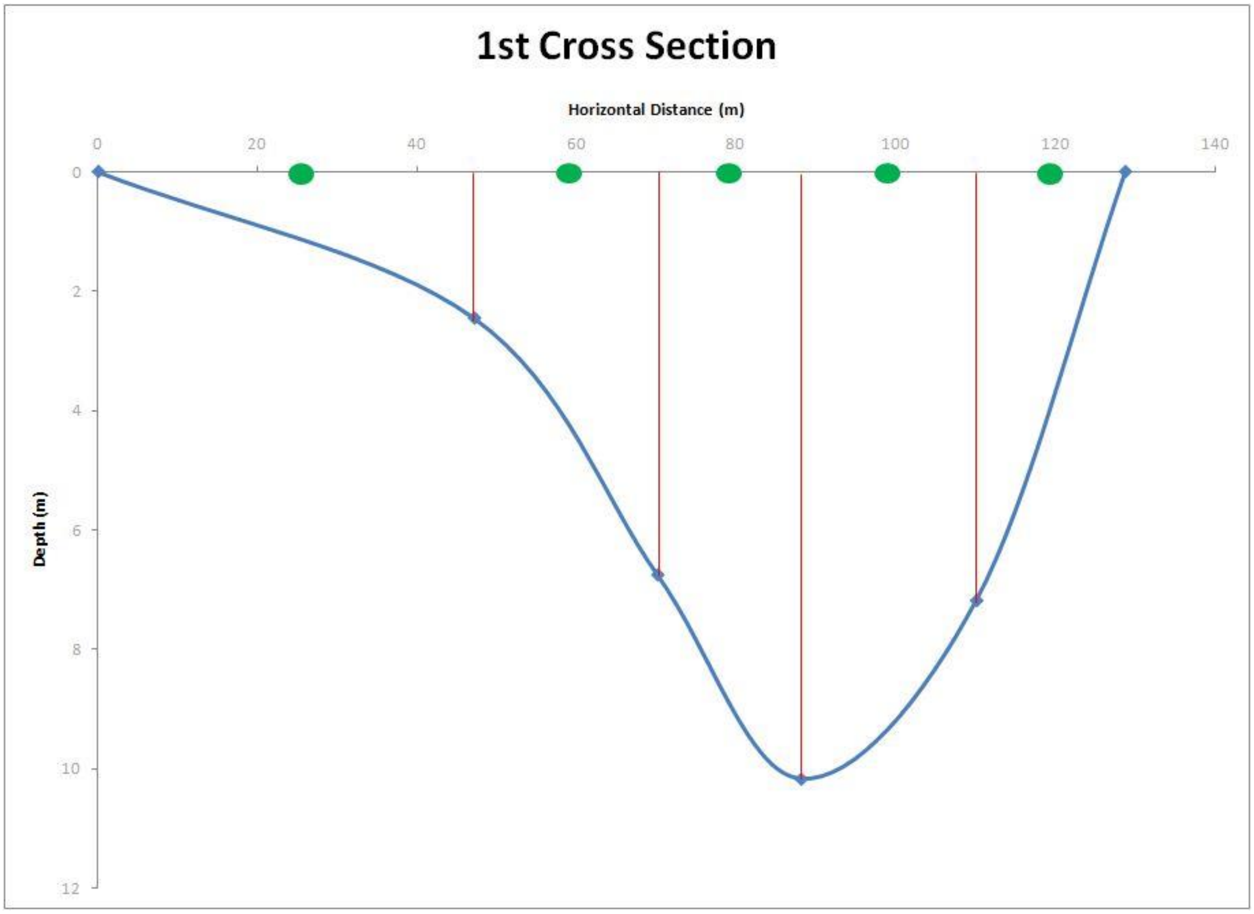
3.4.2 Discharge Area Estimates

After determining the surface velocities, the discharge area at the time of float measurements would have to be estimated. This would be based on a survey done on the first and second cross sections of the 150-meter measurement section, which coincidentally are the same first and second cross sections being surveyed by another group doing the slope-area discharge measurements. The group went with the slope-area team in surveying the river bed elevation of the 2nd cross section (by echo sounder and range finder), while the slope area team used the depths recorded by the current meter team (on boat) to survey the river bed elevation of the 1st cross section. The group afterwards utilized the data from the survey of the 1st and 2nd cross sections done by the slope area team in determining the discharge area at the time that the floaters were dropped.

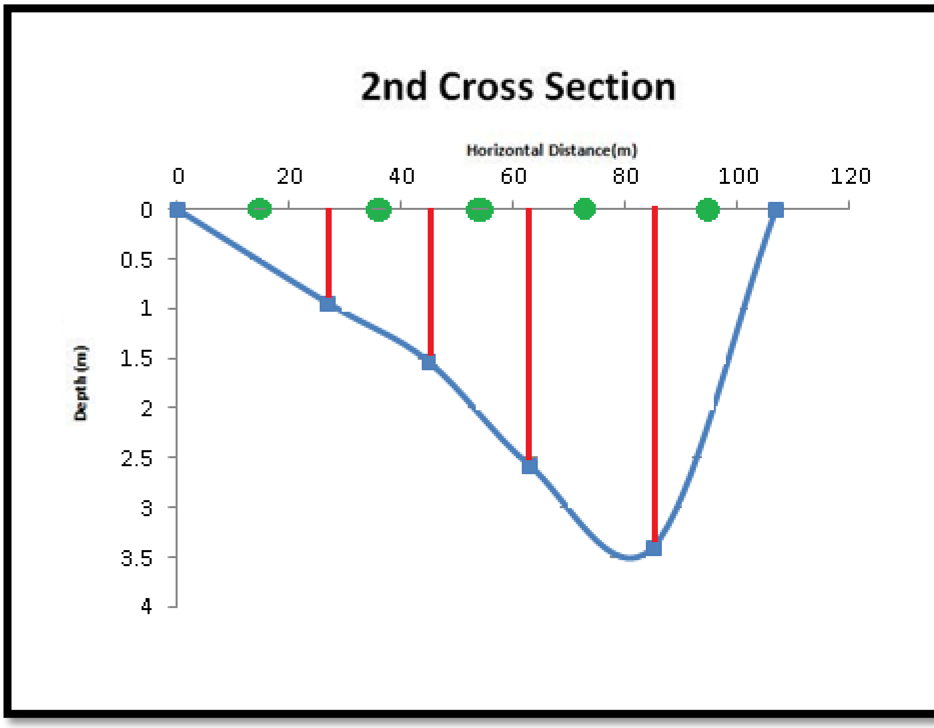
The data from the survey of the 1st and 2nd cross sections were plotted out on the cross section excel suite provided by Mr Hilton T. Hernando. The two cross sections were closed with a water surface elevation of 2.862 meters, which was the water elevation at the first set of float measurements (see section 3.4.1). The corresponding depths at the five (5) intervals were then determined from the difference between the water surface elevation and the elevation of the river bed at a given vertical/interval. The verticals/intervals are assumed to be in the same horizontal plane in both cross sections e.g. the first interval/vertical of the 1st cross section is aligned to the first interval/vertical of the 2nd cross section. However, because the river is contracting, the distance from right water edge to the first vertical and the distance from left water edge to last vertical would not be the same for the two cross sections. This means that the two cross sections would have different widths and intervals.

A given section area would then be computed by multiplying the distance between verticals (interval) with the average of the depths at those verticals. There are a total of 5 sections for each cross section. The profiles of the cross sections are detailed below.

FIRST CROSS SECTION				
Interval	Distance	Accumulated distance	Depth	Section Area
0	0	0	0	0
1	47.17	47.17	2.452	57.83042
2	23	70.17	6.752	105.846
3	18	88.17	10.172	152.316
4	22	110.17	7.182	190.894
5	18.68	128.85	0	67.07988



SECOND CROSS SECTION				
Interval	Distance	Accumulated distance	Depth	Section area
0	0	0	0	0.00
1	26.8	26.8	0.942	12.62
2	18	44.8	1.532	22.27
3	18	62.8	2.572	36.94
4	22	84.8	3.402	65.71
5	22	106.8	0	37.42



3.4.3 <u>Discharge Calculations</u>

After the areas at the time of velocity measurements have been determined for each subsection and in every cross section, the discharge can then be calculated. The surface velocity would be equal to the distance traversed (150 meters) by the floats, divided by the time elapsed. The correction coefficient used to determine the average velocity was 0.92. The summary of the computations is shown on the next page.

Result of Discharge Observation By Float									
Measuring Line	Time of Drop	Travelling Time (sec)	Velocity of Float (m/s)	Correction Coefficient	Corrected Velocity (m/s)	Divided Area (sq. meters)			Divided Q (cu. meters per second)
						Section 1	Section 2	Ave Area	
1	11:00 AM	732.07	0.20	0.92	0.19	57.83042	12.6228	35.22661	6.64
2	11:15 AM	198.95	0.75	0.92	0.69	105.846	22.266	64.056	44.43
3	11:20 AM	215.625	0.70	0.92	0.64	152.316	36.936	94.626	60.56
4	11:25 AM	194.23	0.77	0.92	0.71	190.894	65.714	128.304	91.16
5	11:30 AM	190.63	0.79	0.92	0.72	67.07988	37.422	52.25094	37.83
Total Discharge									240.62

The computed discharge by float method, at 2.78 gage height, was 240.62 cubic meters per second.

3.4.4 Issues and concerns

At the first drop point at the right bank, the flow was almost stagnant; the float in the first section took the longest time to traverse the whole 150 meter measurement section. In fact, during the second pass/measurement, the float did not move at all. This may be due to lower depths directly below the first drop point, lower velocities in that section, or both.

The second set of measurements was not considered for discharge calculations anymore because only 2 out of the 5 floats that were dropped gave reliable results. The 1st drop from the right bank did not show up on the surface, the second did show up but was upturned by the tagline at the first cross section and sank, and finally, the float did not move at the last drop point for the second set of measurements. It was also during these set of measurements that the gage height reduced significantly because of the irrigation dam that diverted the flow from the main river.

From these, the group concluded that discharge measurements by float method would not give the best results at low flows.

There were also issues regarding the track that the float follows as it traverses from the approach section and across the measurement section. The float does not follow a straight path and tends to go toward the adjacent subsection. This was especially pronounced at the first drop in the first set of measurements (first drop at the right bank) where the float significantly changed its course, going toward the second subsection instead of following a straight path from drop point. It was hard to ascertain whether it did enter the second subsection, but for ease in discharge calculations, it was assumed that all the floats went downstream in a straight line and within the subsection where it belongs.

3.4.5 Conclusion

Discharge measurements done via float method are optimal at medium to high flows. Like the slope-area method, it is an indirect method of computing discharge which can be best applied during flood events or at relatively high flows. It follows a simple and inexpensive way of measuring velocities, though a cross section survey would have to be done to estimate the discharge area so as to complete the discharge calculations.

It is less effective during low flows, where the floats (especially those of the stick-type like the bamboo used in the activity) have a high chance of being stocked on the river bed upon dropping. If the reach experiences very turbulent flow between points of measurement, the float could drastically change course, affecting the discharge measurements.

3.5 Conclusion on the various methods of discharge measurements

There are obviously different methods for computing discharge, as described in the previous sections. Each has their own merits and drawbacks. It would depend on the discharge measurement team’s discretion on what method to use that would best suit the scenario at the time of measurement.

For instance, at the time of flooding, the most reasonable method to use would be the float method. A current meter used in that scenario, if it can be used at all, would easily be destroyed. It would also be too much of a risk to use expensive equipment such as the ADCP in those situations. Even the float method has its drawbacks at high flows; the float can easily be lost from all the debris carried by floodwaters and also due to high turbulence. In the situations that cannot be covered by float-method, slope-area measurements are the best alternative in estimating discharge during flood events; the only drawback would be the tedious nature of survey work.

In scenarios other than flood events, measurements by current meters and ADCP's are the best methods to use. The ADCP gives the most accurate results with proper set-up, although current meters are the best, less costly alternative.

There is a method available for almost all scenarios. The decision on what to use for a given situation would depend on the judgment of the discharge measurement team.

4.0 Development of a Rating Curve Equation and Table

One of the goals of discharge measurement is to establish a rating curve defined by measured discharges at various water surface elevations. Based on actual discharge data, an equation can be formulated that would best describe the observations in such a way that if the equation would be plotted out in a graph, the curve that forms "best-fit" the distribution of the data. With a rating equation, a hydrologist can estimate discharges at various water levels, even those water elevations not present in the actual data. The discharge for every water level, based on the rating equation, is then presented in a rating table. This would then serve as a guide for the hydrologist.

In the following sections, a rating curve equation will be established. Values for discharge at various levels of elevation are computed through an excel suite provided by Mr Hilton Hernando, which is based on manning's equation.

4.1 Cross section survey

The cross section directly under the bridge on the downstream side will be used in estimating the discharge at various levels. For that, the elevation profile of the ground below the bridge would be needed. With the use of a sounding rope, group 1 of the HTC class did the survey for the area, measuring distances from the bridge railing to the ground below.

PAMPANGA RIVER BED PROFILING

Arayat, Pampanga

Bridge Measurements:

Start Time:	1342 HH
End Time	1405 HH
Date:	Oct. 23, 2013

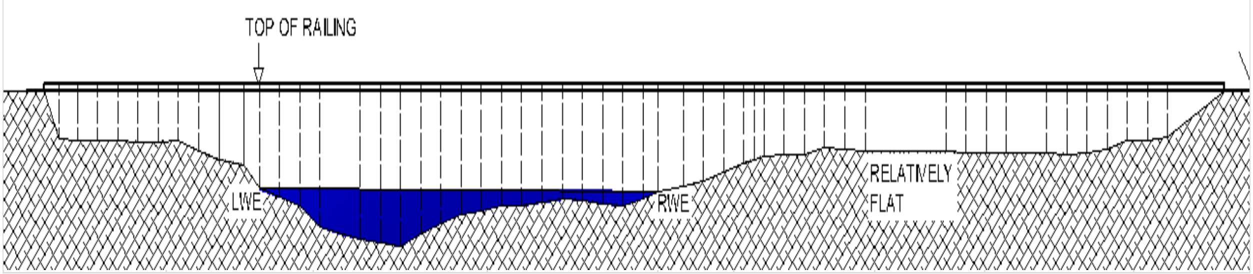
Heigth of Railing to Curb:	0.75 m
Height of Curb to Ground Level:	0.16 m

Measurements are taken from Top of the Bridge Railing, Left To Right of the Banks.

Station Interval	Depth (m)	Accumulated Horizontal Length (m)	Remarks
0	0.91	0	top of dike
3.8	7.6	3.8	Foot of dike
4.54	7.8	8.34	
5	7.8	13.34	
5	7.97	18.34	
5	7.97	23.34	
5	7.89	28.34	
5	9.26	33.34	
5	10.4	38.34	
5	11.17	43.34	
6.2	14.55	49.54	Left Water Edge
3.8	15.57	53.34	
5	16.86	58.34	
5	19.88	63.34	
5	21.63	68.34	
10	21.57	78.34	Edge of Pier
5	21.94	83.34	
5	22.48	88.34	
5	20.7	93.34	
5	19.39	98.34	
5	18	103.34	
5	17.63	108.34	
5	16.99	113.34	
5	16.79	118.34	
5	16.39	123.34	
5	15.97	128.34	
5	16.02	133.34	
5	16.51	138.34	
5	16.84	143.34	
5	15.78	148.34	
3.8	14.83	152.14	Right Water Edge

Station Interval	Depth (m)	Accumulated Horizontal Length (m)	Remarks
6.2	14.18	158.34	
5	13.36	163.34	
5	12.22	168.34	
5	10.95	173.34	
2.5	10.41	175.84	
2.5	9.93	178.34	
5	9.91	183.34	
5	9.91	188.34	
5	8.87	193.34	
5	9.16	198.34	
5	9.33	203.34	
5	9.33	208.34	
5	9.33	213.34	
5	9.33	218.34	
5	9.33	223.34	
5	9.59	228.34	
5	9.56	233.34	
5	9.56	238.34	
10	9.46	248.34	
5	9.71	253.34	
5	9.63	258.34	
5	9.05	263.34	
5	7.9	268.34	
5	7.77	273.34	
5	7.4	278.34	Foot of dike
14	0.91	292.34	top of dike

PAMPANGA RIVER CROSS SECTION
SAN AGUSTIN BRIDGE, ARAYAT PAMPANGA



The survey did by group 1 measured only the distance from bridge railing to ground; the discharge calculations require ground elevation. To convert the given depths to MSL elevations, the MSL elevation of the bridge curb measured by group 4 was taken into account. The bridge curb was at 15.562 meters AMSL, and adding the height of the railing from the curb (0.75 meters), the MSL height of the bridge railing was at 16.312 meters. The difference between this value and the corresponding depths give out the elevations of the ground below the bridge.

The resulting data are the entered on a cross section excel suite that computes for width, area, wetted perimeter and hydraulic radius for a given water surface elevation. Note that in this survey, the bridge was assumed to be straight with no piers obstructing the river.

4.2 <u>Discharge estimation</u>

				Date:	Oct. 23, 2013			
station	distance	elevation	water sfc.	depth	mean depth	area	wetted perimeter	remarks
0.00		15.402	15.40	0.00				
3.80	3.80	8.712	15.40	6.69	3.35	12.71	7.69	
8.34	4.54	8.512	15.40	6.89	6.79	30.83	4.54	
13.34	5.00	8.512	15.40	6.89	6.89	34.45	5.00	
18.34	5.00	8.342	15.40	7.06	6.98	34.88	5.00	
23.34	5.00	8.342	15.40	7.06	7.06	35.30	5.00	
28.34	5.00	8.422	15.40	6.98	7.02	35.10	5.00	
33.34	5.00	7.052	15.40	8.35	7.67	38.33	5.18	
38.34	5.00	5.912	15.40	9.49	8.92	44.60	5.13	
43.34	5.00	5.142	15.40	10.26	9.88	49.38	5.06	
49.54	6.20	1.762	15.40	13.64	11.95	74.09	7.06	
53.34	3.80	0.742	15.40	14.66	14.15	53.77	3.93	
58.34	5.00	-0.548	15.40	15.95	15.31	76.53	5.16	
63.34	5.00	-3.568	15.40	18.97	17.46	87.30	5.84	
68.34	5.00	-5.318	15.40	20.72	19.85	99.23	5.30	
78.34	10.00	-5.258	15.40	20.66	20.69	206.90	10.00	
83.34	5.00	-5.628	15.40	21.03	20.85	104.23	5.01	
88.34	5.00	-6.168	15.40	21.57	21.30	106.50	5.03	Thalweg
93.34	5.00	-4.388	15.40	19.79	20.68	103.40	5.31	
98.34	5.00	-3.078	15.40	18.48	19.14	95.68	5.17	
103.34	5.00	-1.688	15.40	17.09	17.79	88.93	5.19	
108.34	5.00	-1.318	15.40	16.72	16.91	84.53	5.01	
113.34	5.00	-0.678	15.40	16.08	16.40	82.00	5.04	
118.34	5.00	-0.478	15.40	15.88	15.98	79.90	5.00	
123.34	5.00	-0.078	15.40	15.48	15.68	78.40	5.02	
128.34	5.00	0.342	15.40	15.06	15.27	76.35	5.02	
133.34	5.00	0.292	15.40	15.11	15.09	75.43	5.00	
138.34	5.00	-0.198	15.40	15.60	15.36	76.78	5.02	
143.34	5.00	-0.528	15.40	15.93	15.77	78.83	5.01	
148.34	5.00	0.532	15.40	14.87	15.40	77.00	5.11	
152.14	3.80	1.482	15.40	13.92	14.40	54.70	3.92	
158.34	6.20	2.132	15.40	13.27	13.60	84.29	6.23	
163.34	5.00	2.952	15.40	12.45	12.86	64.30	5.07	
168.34	5.00	4.092	15.40	11.31	11.88	59.40	5.13	
173.34	5.00	5.362	15.40	10.04	10.68	53.38	5.16	
175.84	2.50	5.902	15.40	9.50	9.77	24.43	2.56	
178.34	2.50	6.382	15.40	9.02	9.26	23.15	2.55	
183.34	5.00	6.402	15.40	9.00	9.01	45.05	5.00	
188.34	5.00	6.402	15.40	9.00	9.00	45.00	5.00	
193.34	5.00	7.442	15.40	7.96	8.48	42.40	5.11	
198.34	5.00	7.152	15.40	8.25	8.11	40.53	5.01	
203.34	5.00	6.982	15.40	8.42	8.34	41.68	5.00	
208.34	5.00	6.982	15.40	8.42	8.42	42.10	5.00	
213.34	5.00	6.982	15.40	8.42	8.42	42.10	5.00	
218.34	5.00	6.982	15.40	8.42	8.42	42.10	5.00	
223.34	5.00	6.982	15.40	8.42	8.42	42.10	5.00	
228.34	5.00	6.722	15.40	8.68	8.55	42.75	5.01	
233.34	5.00	6.752	15.40	8.65	8.67	43.33	5.00	
238.34	5.00	6.752	15.40	8.65	8.65	43.25	5.00	
248.34	10.00	6.852	15.40	8.55	8.60	86.00	10.00	
253.34	5.00	6.602	15.40	8.80	8.68	43.38	5.01	
258.34	5.00	6.682	15.40	8.72	8.76	43.80	5.00	
263.34	5.00	7.262	15.40	8.14	8.43	42.15	5.03	
268.34	5.00	8.412	15.40	6.99	7.57	37.83	5.13	
273.34	5.00	8.542	15.40	6.86	6.93	34.63	5.00	
278.34	5.00	8.912	15.40	6.49	6.68	33.38	5.01	
292.34	14.00	15.402	15.40	0.00	3.25	45.43	15.43	
Total Width	**292.34**							
Total Area	**3363.893**							
W. P (P)	**302.21**							
Hydraulic Radius ®	**11.13098**							
Mean sect. Depth	**11.50678**							

The table on the previous page shows the summary of the elevation profile of the whole cross section, enclosed with a water surface elevation equivalent to the elevation of the bridge railing in order to compute for the width, total area, wetted perimeter, and hydraulic radius when the water reaches the bridge railing. Computations for the mentioned parameters are repeated at other water surface elevations using the cross section sheet. There will be various values of these parameters for a whole range of water elevation, which are then entered in another excel suite that estimates discharge. The group's calculations are summarized below.

Pampanga River @ Arayat							
(based on cross-section undertaken on October 2013)							
Elevation of "0" of S.G.=		0.000	m.(AMSL)				
n=	0.030	I=	0.000145				
Elevation	Equivalent	Area	Width	W.P.	hyd radius	Discharge	Remarks
MSL (m)	G.H.(m)	a (m^2)	w (m)	s	r	Q (cumecs)	
15.40	15.402	3363.89	292.34	302.21	11.13	6731.22	bank full/ level with bridge road
15.00	15.000	3247.38	291.50	300.97	10.79	6364.56	
14.00	14.000	2956.91	288.60	297.38	9.94	5488.03	
13.00	13.000	2670.61	286.30	294.09	9.08	4665.80	
12.00	12.000	2385.26	283.15	290.25	8.22	3898.89	
11.00	11.000	2104.14	281.00	287.13	7.33	3186.39	
10.00	10.000	1824.65	278.00	283.48	6.44	2534.26	
9.00	9.000	1548.21	275.30	279.97	5.53	1943.30	
8.00	8.000	1291.18	236.10	240.54	5.37	1588.87	
7.00	7.000	1053.37	162.40	166.46	6.33	1446.52	
6.00	6.000	902.84	137.90	141.81	6.37	1244.84	
5.00	5.000	769.53	128.20	131.89	5.83	1001.07	
4.00	4.000	643.90	122.10	125.45	5.13	769.04	
3.00	3.000	525.10	116.30	119.21	4.40	566.34	
2.00	2.000	412.62	108.00	110.58	3.73	398.45	
1.00	1.000	310.25	98.00	100.34	3.09	264.30	
0.50	0.500	262.09	93.50	95.73	2.74	205.88	
-1.00	-1.000	163.04	56.40	57.80	2.82	130.64	
-2.00	-2.000	110.61	40.90	42.35	2.61	84.20	
-3.00	-3.000	72.23	36.90	37.84	1.91	44.61	
-4.00	-4.000	39.10	30.70	31.30	1.25	18.20	
-5.00	-5.000	11.85	25.00	25.27	0.47	2.87	1.168m from thalweg (thalweg @ 6.168 below MSL)

4.3 The Rating Curve Equation

From the previous calculations, a set of stage and discharge are now available for the whole range of the cross section. This time, the H-Q values are entered on another excel suite that computes for the rating equation. Shown on the next page are the H-Q values used for the rating equation computations.

Rating Curve Development for				*Pampanga River*			
	Measuring Station:		***Arayat Station***				
	Drainage Area:		***6487***				
	River:		***Pampanga River***				
	Location:		***San Agustin Bridge, Arayat, Pampanga***				
	Elev. S.G."0" rdg.=		***0.000***	**meters**			

Meas. #	Day	Month	Year	S.G.(m)	Q(m^3/sec)	Remarks
				15.402	6731.219	
				14.000	5488.026	
				13.000	4665.799	
				11.000	3186.386	
				10.000	2534.263	
				9.000	1943.296	
				8.000	1588.867	
				7.000	1446.523	
				6.000	1244.836	
				5.000	1001.068	
				4.000	769.036	
				3.000	566.342	
				2.000	398.449	
				1.000	264.299	
				0.500	205.881	
				-1.000	130.644	
				-2.000	84.195	
				-3.000	44.612	
				-4.000	18.203	
				-5.000	2.871	

After the H-Q Values are entered, the value for Ho (elevation of zero flow) would have to be determined by trial and error on the “rat” tab of the same excel suite:

Summary test for Ho						
Ho	**a**	**b**	ΣX^2			
-7.50	0.26	3.239	159.0038	Minimum	$\Sigma X^2 =$	157.77577
-7.39	0.31	3.190	157.7758			
-7.28	0.36	3.140	160.9545			
-7.17	0.42	3.090	169.2081			
-7.06	0.49	3.039	183.3305			
-6.95	0.58	2.986	204.2726			
-6.84	0.68	2.933	233.1833			
-6.73	0.81	2.879	271.4649			
-6.62	0.96	2.824	320.8478			
-6.51	1.14	2.767	383.4949			
-6.40	1.35	2.708	462.1486			
-6.29	1.62	2.648	560.3451			
-6.18	1.94	2.586	682.7326			
-6.07	2.34	2.521	835.5621			

The value for Ho with the least chi square value would then be chosen as the Ho value in the final equation. In our group, Ho is equal to -7.39 by trial and error. This is then entered back on the previous sheet, under the “Assumed Ho” cell.

Assumed Ho = -7.39 meters

S.G. elev. (H)	H-Ho	Log H-Ho (X)	Log Q (Y)	X^2	XY		
15.402	22.792	1.358	3.828	1.844	5.198		
14.000	21.390	1.330	3.739	1.769	4.974		
13.000	20.390	1.309	3.669	1.715	4.804	n =	20.000
11.000	18.390	1.265	3.503	1.599	4.430	Σ(X) =	20.237
10.000	17.390	1.240	3.404	1.538	4.222	Σ(Y) =	54.273
9.000	16.390	1.215	3.289	1.475	3.994	$\Sigma(X^2)$ =	21.930
8.000	15.390	1.187	3.201	1.410	3.800	Σ(XY)=	59.554
7.000	14.390	1.158	3.160	1.341	3.660		
6.000	13.390	1.127	3.095	1.270	3.488	X_{bar} =	1.012
5.000	12.390	1.093	3.000	1.195	3.280	Y_{bar} =	2.714
4.000	11.390	1.057	2.886	1.116	3.049	$(\Sigma(X))^2$=	409.529
3.000	10.390	1.017	2.753	1.034	2.799		
2.000	9.390	0.973	2.600	0.946	2.529	b^ =	3.190
1.000	8.390	0.924	2.422	0.853	2.237	a^ =	-0.514
0.500	7.890	0.897	2.314	0.805	2.075	$a = 10^{a\wedge}$ =	0.306
-1.000	6.390	0.806	2.116	0.649	1.705	b = b^ =	3.190
-2.000	5.390	0.732	1.925	0.535	1.409		
-3.000	4.390	0.642	1.649	0.413	1.060		
-4.000	3.390	0.530	1.260	0.281	0.668		
-5.000	2.390	0.378	0.458	0.143	0.173		

After this, the completed equation will be shown:

Meas. #	Day	Month	Year	S.G.(m)	Q(m^3/sec)	Remarks
				15.402	6731.219	
				14.000	5488.026	
				13.000	4665.799	
				11.000	3186.386	
				10.000	2534.263	
				9.000	1943.296	
				8.000	1588.867	
				7.000	1446.523	
				6.000	1244.836	
				5.000	1001.068	
				4.000	769.036	
				3.000	566.342	
				2.000	398.449	
				1.000	264.299	
				0.500	205.881	
				-1.000	130.644	
				-2.000	84.195	
				-3.000	44.612	
				-4.000	18.203	
				-5.000	2.871	

Q = 0.306 [H - (-7.39)]$^{3.190}$

The Rating Curve Equation !!!

The rating curve equation, from the given set of stage-discharge values, is:

$$\mathbf{Q = 0.306\ (H+7.39)^{3.190}}$$

4.4 The Rating Table

After the rating curve equation has been computed, a rating table can be made. This is done on another excel suite that specifically creates a table based on the equation. The constants of the equation and gage height range are entered in the excel file, after which, it automatically gives the table:

Rating Table for:				***Arayat***			Date:	*October 23, 2013*		
River:		*Pampanga*		Location:		*San Agustin, Arayat, Pampanga*				
Elevation of S.G. "0" reading:			*0*							
Rating Curve Equation Coefficients: **a =**				***0.306***	**Ho=**	***-7.390***	**b^=**	***3.190***		
Range of G.H.:		Min. G.H. =		***0***	Max. possible G.H.=			***11.00***		
Remarks:	*readings based on MSL*									
G.H.(m)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	180.59	181.37	182.16	182.94	183.73	184.52	185.31	186.11	186.90	187.70
0.1	188.50	189.31	190.11	190.92	191.73	192.55	193.36	194.18	195.00	195.82
0.2	196.65	197.48	198.31	199.14	199.97	200.81	201.65	202.49	203.34	204.18
0.3	205.03	205.89	206.74	207.60	208.46	209.32	210.18	211.05	211.92	212.79
0.4	213.66	214.54	215.42	216.30	217.18	218.07	218.96	219.85	220.74	221.64
0.5	222.53	223.44	224.34	225.24	226.15	227.06	227.98	228.89	229.81	230.73
0.6	231.66	232.58	233.51	234.44	235.38	236.31	237.25	238.19	239.14	240.08
0.7	241.03	241.99	242.94	243.90	244.86	245.82	246.78	247.75	248.72	249.69
0.8	250.67	251.64	252.62	253.61	254.59	255.58	256.57	257.57	258.56	259.56
0.9	260.56	261.57	262.57	263.58	264.59	265.61	266.63	267.65	268.67	269.69
1.0	270.72	271.75	272.79	273.82	274.86	275.90	276.95	277.99	279.04	280.09
1.1	281.15	282.21	283.27	284.33	285.40	286.47	287.54	288.61	289.69	290.77
1.2	291.85	292.94	294.02	295.11	296.21	297.30	298.40	299.50	300.61	301.72
1.3	302.83	303.94	305.06	306.17	307.30	308.42	309.55	310.68	311.81	312.95
1.4	314.08	315.23	316.37	317.52	318.67	319.82	320.97	322.13	323.29	324.46
1.5	325.63	326.80	327.97	329.14	330.32	331.50	332.69	333.88	335.07	336.26
1.6	337.45	338.65	339.85	341.06	342.27	343.48	344.69	345.91	347.13	348.35
1.7	349.57	350.80	352.03	353.27	354.51	355.75	356.99	358.23	359.48	360.74
1.8	361.99	363.25	364.51	365.77	367.04	368.31	369.58	370.86	372.14	373.42
1.9	374.71	375.99	377.29	378.58	379.88	381.18	382.48	383.79	385.10	386.41
2.0	387.73	389.04	390.37	391.69	393.02	394.35	395.68	397.02	398.36	399.71
2.1	401.05	402.40	403.75	405.11	406.47	407.83	409.20	410.57	411.94	413.31

4.5 Other considerations

The values in the rating table follow closely to the H-Q values that were supplied. Upon further inspection, it can be seen that the values for discharge for a given level varies greatly when compared to actual discharge measurements outlined in the previous sections. This may be due to the many assumptions considered at the start:

1. The H-Q values used in the formulation of the rating equation are in themselves only estimates computed based on manning's equation. The error may have been magnified when the rating curve equation and the rating table are computed.
2. The bridge was assumed to be straight. In reality, the bridge's elevation varies in certain sections.
3. The bridge was assumed to have no piers when it fact, it does. Piers affect water velocity surrounding its perimeter, and consequently, also affect discharge to a certain degree. Only the elevation of the river bed without the pier was considered.
4. The roughness coefficient used may have been inaccurate.
5. There might have been an error in evaluating the Ho. Since this was done by trial and error, other values for Ho that were not tried might have given closer results.

This section illustrates how rating curve equations are formulated and how rating tables are computed. If the values entered in the rating curve equation excel suite were actual discharge measurements on field, the resulting table will yield more accurate and reliable results.

5.0 Other Activities

Aside from the discharge measurements at the Arayat site, the whole HTC class went on a number of visits to other relevant sites during the 10-day field work period. The next few pages describe the sites visited.

- **La Mesa Dam**

An earth dam located at Quezon City, Metro Manila. It is basically where Metro Manila gets most of its water supply. It is part of the Angat-Ipo-La Mesa water system, having a reservoir that can hold up to 50.5 million cubic meters occupying an area of 27 square kilometres. Its main purpose is to impound water for domestic use. It is only a control type of dam; it has no spillway and control gates and water simply overflows from the dam when it reaches the spill level. The dam management does not have any control in a high-stage scenario.

The impounded water is treated on site by the Maynilad Water Services. Security is tight within the premises.

- **Pantabangan Dam**

Pantabangan Dam is an earth-fill embankment dam in Pantabangan, Nueva Ecija. Its reservoir is said to be one of the largest in Southeast Asia. It is a multi-purpose dam which provides water for irrigation and hydroelectric power generation while its reservoir, Pantabangan Lake, affords flood control. The site has its own flood forecasting and warning unit that always monitors the water level in the dam and in the upstream rivers. Like the La Mesa and Angat Dams, security is tight. Unlike the La Mesa, it has spillway gates that allow the dam management to prepare for an incoming volume of water. Pantabangan Dam also has a network of warning stations downstream that alerts the people of possible flooding. Among the dams visited, the dam is the best in terms of design and scale. It is also the cleanest.

- **Cong Dadong Dam**

Cong Dadong Dam is a dam located upstream of the Pampanga River. The dam's main purpose is for irrigation; it diverts the waters from the Pampanga and Rio Chico Rivers to the canals leading to farms in Arayat, Sta ana, San Luis, Candaba, San Simon and Apalit Towns. When the huge gates of the dam are closed, water passes through the left side of dam then to the canals and causes the drop of water level of the streams below the dam. it is considered as the largest irrigation and diversion type of dam in Southeast Asia.

On the last day of field measurements, the dams were closed. This caused the abrupt change in water elevation that was observed by the discharge measurement teams.

- **Angat Dam**

Angat Dam is a concrete water reservoir embankment hydroelectric dam located in Bustos, Bulacan that also supplies the Manila metropolitan area with water. It is a part of the Angat-Ipo-La Mesa water system. The reservoir supplies about 90 percent of raw water requirements for Metro Manila through the facilities of the Metropolitan Waterworks and Sewerage System and it irrigates about 28,000 hectares of farmland in the provinces of Bulacan and Pampanga. Their main priority is to supply water for irrigation while supplying power to the Arayat Power Station.

Like the Pantabangan dam, it also has its own flood forecasting and warning unit. They also warn the people downstream of an impending flood in the nearby area.

We were privileged enough to see their hydroelectric power plant. Personally, it was a first for me to actually see what is inside a hydroelectric power plant and the visit was very informative and memorable.

- **Municipal Disaster Risk Reduction and Management Council of Calumpit, Bulacan**

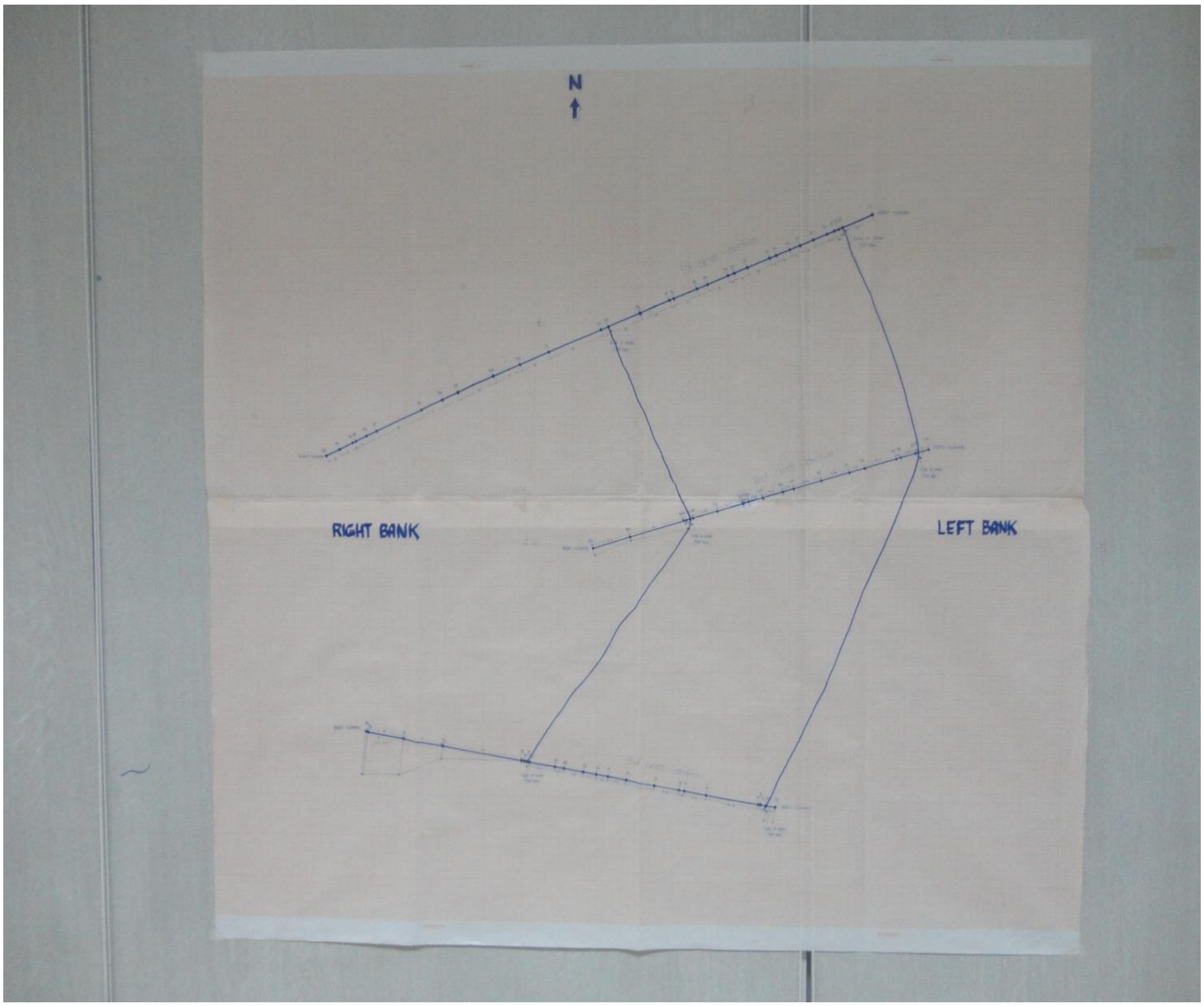
One of the highlights of the trip was the visit at the local disaster risk reduction unit of Calumpit, Bulacan. Calumpit is a flood prone area, and during rainy seasons, it is one of the most flooded parts in Bulacan. In terms of flood forecasting and monitoring, they developed an Excel-based monitoring system that enables them to be aware of the weather situation at any time. With the aid of the system, they are able to create and establish plans and conducts drills to lessen the impact of flood. It also seems that they are effective in engaging the community in constantly monitoring water levels of the river surrounding the area

On a personal note, I think the system would greatly help other municipalities in flood prone areas. If all cities/municipalities in the Philippines would adopt a system such as the one in Calumpit, Bulacan, the impact of flooding would certainly be significantly reduced especially with regards to human life.

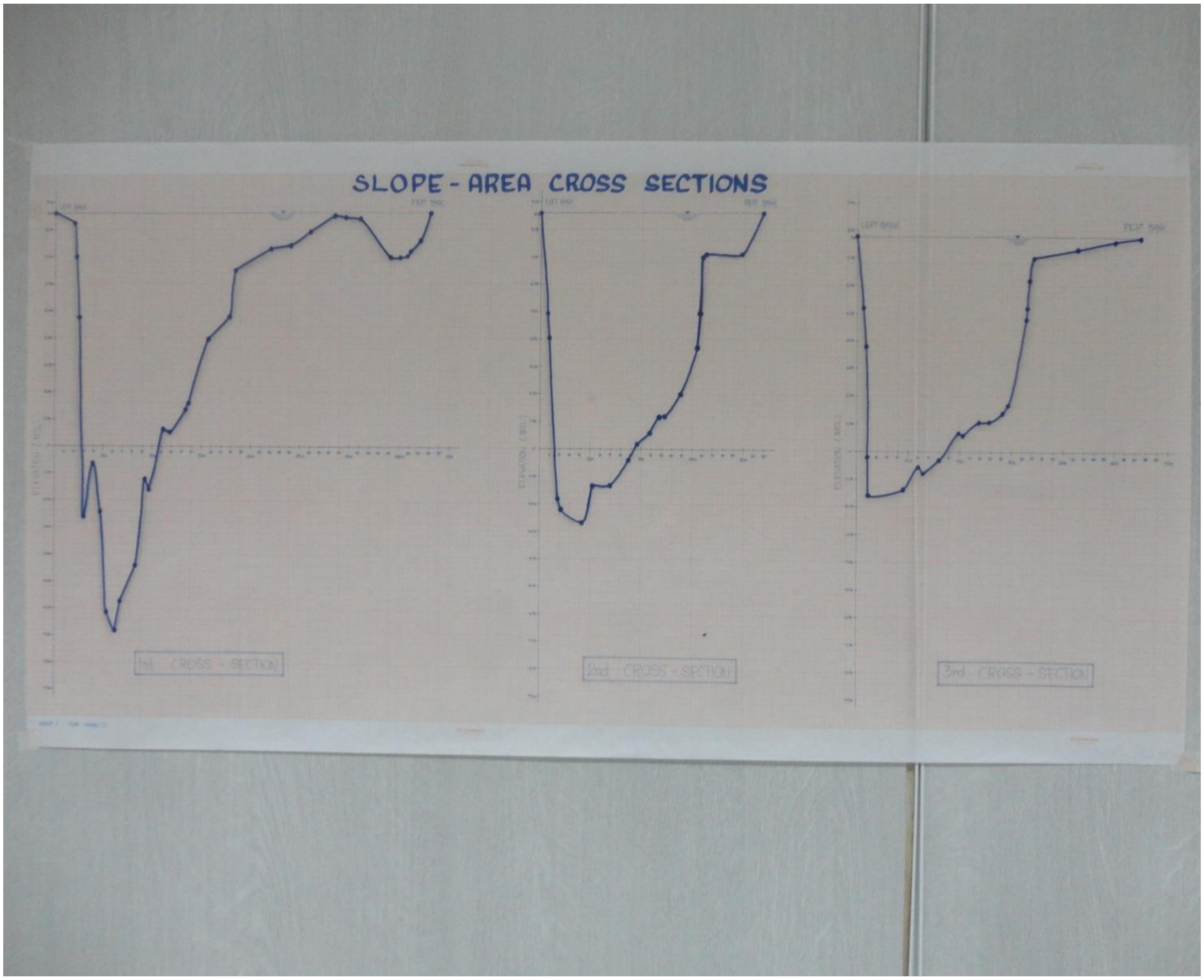
6.0 Conclusion

The 10-day field work was very effective in supporting and understanding the theories learned in the Hydrologist Training Course, specifically on the aspect of stream gaging. The group commends the training staff of PAGASA for organizing such an event; it was only during the field work that the theories taught inside the classroom were fully understood and appreciated.

7.0 Appendices



Top View of the three cross sections used in Slope-Area Method.



Plot of the three cross sections used in Slope-Area method