DISCHARGE MEASUREMENTS USING DIRECT AND INDIRECT METHODS AT THE ARAYAT STATION AT PAMPANGA RIVER

A TECHNICAL REPORT

Prepared by:

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1. INTRODUCTION

As part of the requirements in Stream Gauging II: Discharge Measurement of the Hydrological Training Course, a 10-day field work from October 15-25, 2013 under the guidance of the Pampanga River Flood Forecasting and Warning Center (PRFFWC) was carried out along the reach of the Pampanga River, with 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). The chosen spot was at Barangay Camba, Ayarat, Pampanga where one of the water level and rain gauge station of PAGASA was situated. The fieldwork was conducted 4 days after typhoon Santi ravaged central Luzon causing floods and heavy rains along the area. The main goal of the field work is to have a hands on and practical training exercises to demonstrate procedures required during hydrological field work especially on methods of river flow gauging and discharge measurement. In line with the fieldwork that involves stream gauging and discharge measurement exercises, 4 methods had been carried out primarily: Slope-Area Method, ADCP Method, Current Meter Method and Float Method.

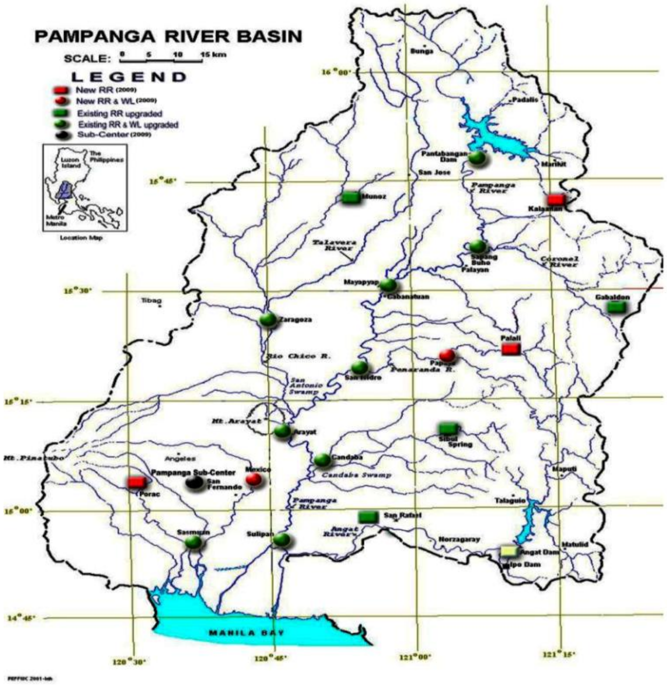
2. OBJECTIVE

The main purpose of this exercise is to:

- To be able to measure the total discharge during the occurrence of Typhoon SANTI based on traces of flood marks in Arayat
- To have a practical hands on and be able to understand the different methods of measuring discharge and its application
- To have a closer look and evaluation on the different methods of measuring discharge and had a knowledge on the limits of each applications
- To come up with an output of a rating curve, rating equation and rating table based on the data gathered from the 4 different methods of measuring discharge.

3. SITE DESCRIPTION

The PAMPANGA RIVER BASIN



The Pampanga River basin system is the 4th largest basin in the Philippines with an aggregate area of 10,434 km$_2$ (square kilometer). It is broadly divided into three sub-basins: (a) Pampanga main river basin with its catchment area of 7,978 km$_2$, (b) Pasac river basin (or alternatively known as the Pasac-Guagua allied river basin) with 1,371 km$_2$ and (c) Angat River basin with 1,085 km$_2$. These three basins originate from different mountain areas having separate river mouths to the Manila Bay but are interconnected by channels and their water resources management works are mutually and closely related. The basin spreads over the administrative area of eleven (11) provinces covering roughly 90 municipalities/cities. The substantial part of the basin area about 95% is, however, within the bounds of four provinces, namely, Nueva Ecija, Tarlac, Pampanga and Bulacan.

Right River

Fieldwork Site, Arayat, Pampanga

Right River

3.1 ARAYAT, PAMPANGA

Discharge measurements along the reach of the middle main section of the Pampanga River were done within the vicinity of PRFFWC’s Arayat Station. There are two gauging station structure within the site: the recent telemetered water level recording station (sensor cable /electronic data logger system) which is located at the right bank of the Pampanga River, downstream of San Agustin Bridge at Brgy Camba, Arayat, Pampanga(assume that the telemetered water level recorder site is on the safe height above historic highest flood mark). The other is located at upstream of bridge: it is an old water level recorder (counter weight system) structure where the station datum was established. The site has also

From the recent typhoon Santi that hit central Luzon , the rainfall intensity experienced at the basin cause the water level to rise up to 8.78m from its normal level at 4.2m which caused flooding at the area.

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. At the right bank, the presence of grass and reeds that run along the river’s water edge, but beyond that, terrain was relatively flat but muddy, both indicates the the ground was fully submerged by flood due to the recent typhoon. 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.

By visual inspection, 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 the flooding reached at least 8 meters on the staff gage.

Looking at the river channel geometry the straight river reach is not possible to identify causing the flow surface water distribution across the river channel not to be uniformly straight. Appeared at near river bank flow were ripples, eddies, stagnant which took time to recover to its stretch flow regime.

Flood mark on staff gage during the first day of measurements

4.0 Methods of Discharge Measurements

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

4.1 Slope-Area

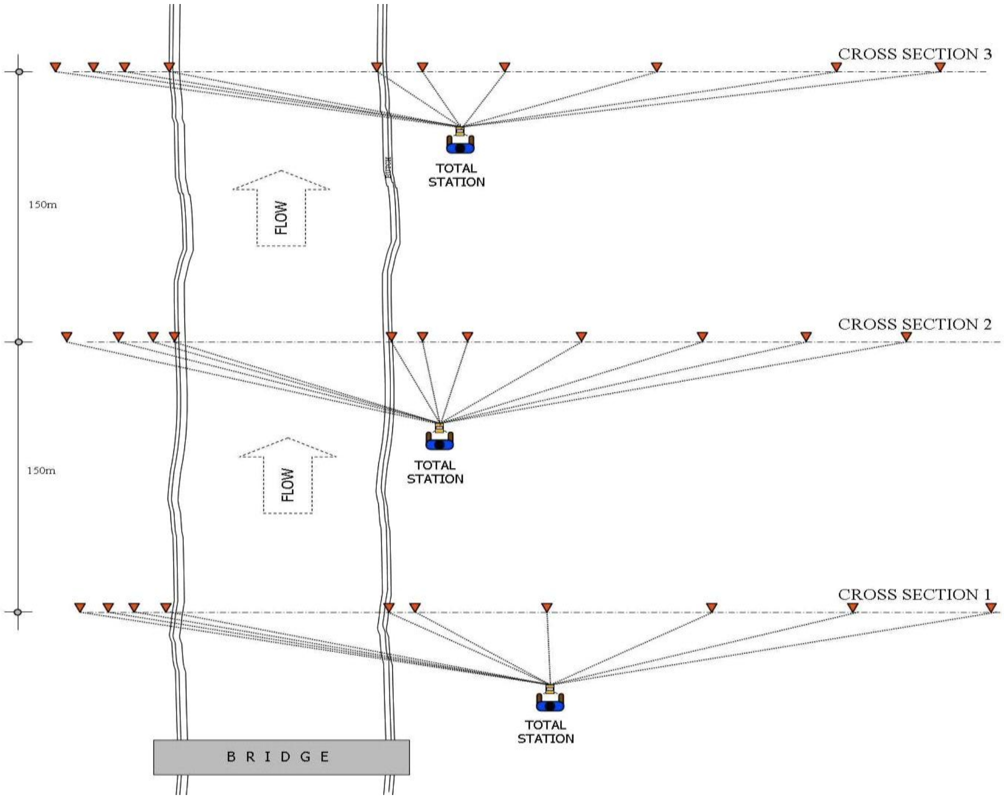
The Slope-Area method is an indirect method of obtaining peak discharge of flood event provides an approximate estimate of discharge in the streams and is used when measurement of discharge by accurate method like the area velocity method (direct method such as current meter and ADCP measurements) is not possible. The slope-area method provides a rough estimate of the discharge in spite of many limitations. 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. Based on the data being measured thru the Slope-Area method, the discharge may be computed from several formulas, but the one used by the USGS and PAGASA is the Manning equation. Manning equation also requires “roughness” factors which describe the character of the channel and the riverbed. 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 must be identified in a certain reach.

Cross section survey

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 gauging station, located at the concrete foundation of an antenna post. 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 measure 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(usin a range finder and 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*:

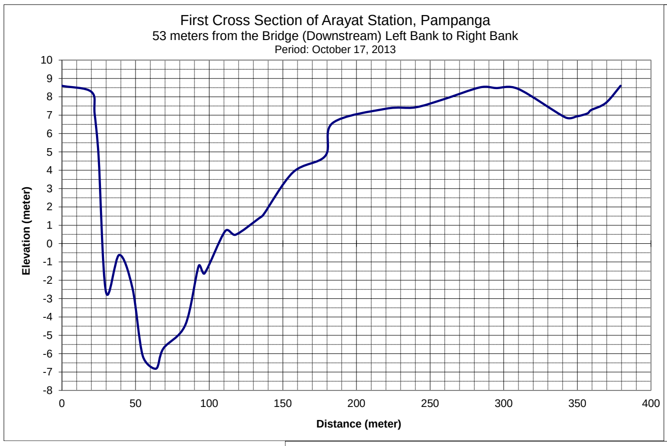
FIRST CROSS-SECTION				
POINT	**DISTANCE**			**ELEVATION**
	ACTUAL	**CORRECTED**	**ACCUMULATED CORRECTED**	
P1	0	0	0	8.6
P2	20	20.00	20	8.272
P3	2.2	2.20	22.2	7.072
P4	2.66	2.66	24.86	4.782
P5	5	5.00	29.86	-2.618
P6	9	9.00	38.86	-0.618
P7	9	9.00	47.86	-2.418
P8	7	7.00	54.86	-6.118
P9	9	9.00	63.86	-6.818
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

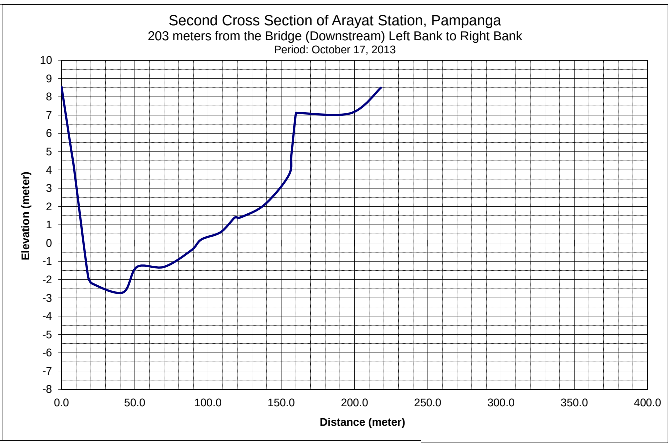
SECOND CROSS-SECTION				
POINT	**DISTANCE**			**ELEVATION**
	ACTUAL	**CORRECTED**	**ACCUMULATED CORRECTED**	
P1	0	0	0.0	8.552
P2	7.00	7.00	7.0	4.895
P3	1.41	1.41	8.4	4.185
P4	9.67	9.67	18.1	-1.805
P5	2.64	2.64	20.7	-2.205
P6	21.10	21.10	41.8	-2.705
P7	9.67	9.67	51.5	-1.305
P8	18.46	18.46	70.0	-1.305
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

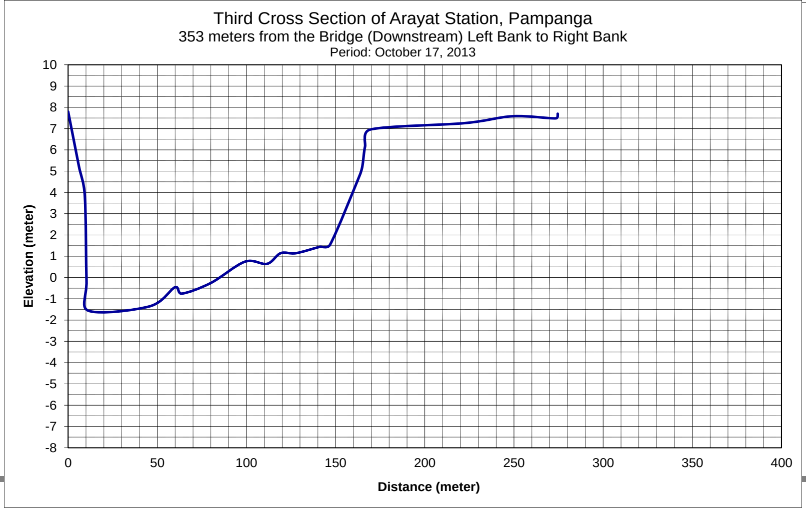
THIRD CROSS-SECTION

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

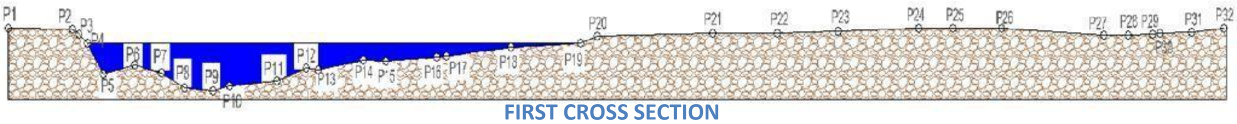
Also presented below are the illustrations for each cross section with values for elevation referenced to Mean Sea Level:



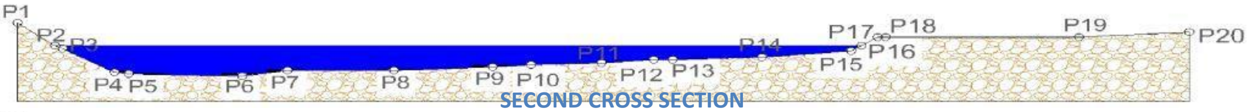




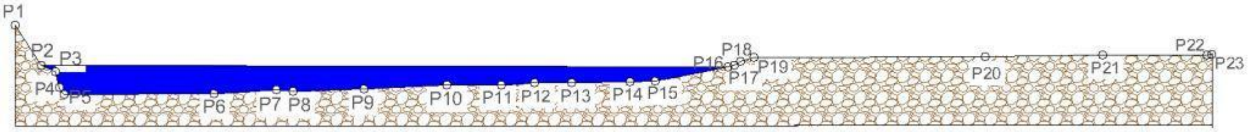
The illustrations below show the same cross sections plotted out in AutoCAD:



FIRST CROSS SECTION

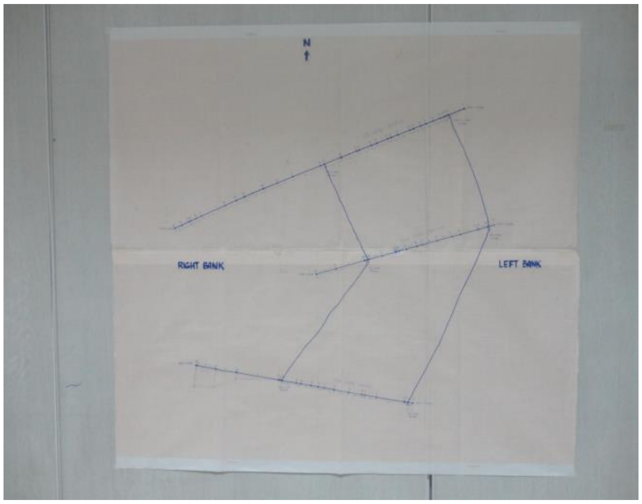


SECOND CROSS SECTION

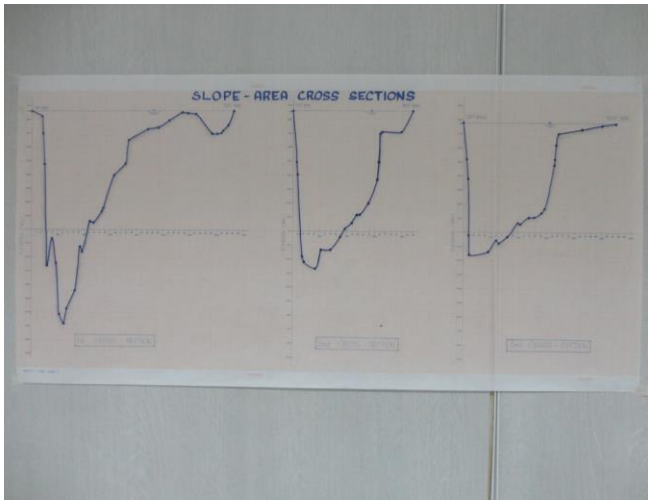


THIRD CROSS SECTION

The illustration below show the same cross-sections plotted out in a cross-section paper.



Top View of the Slope-Area Cross Section



Front View of the Slope-Area Cross Section

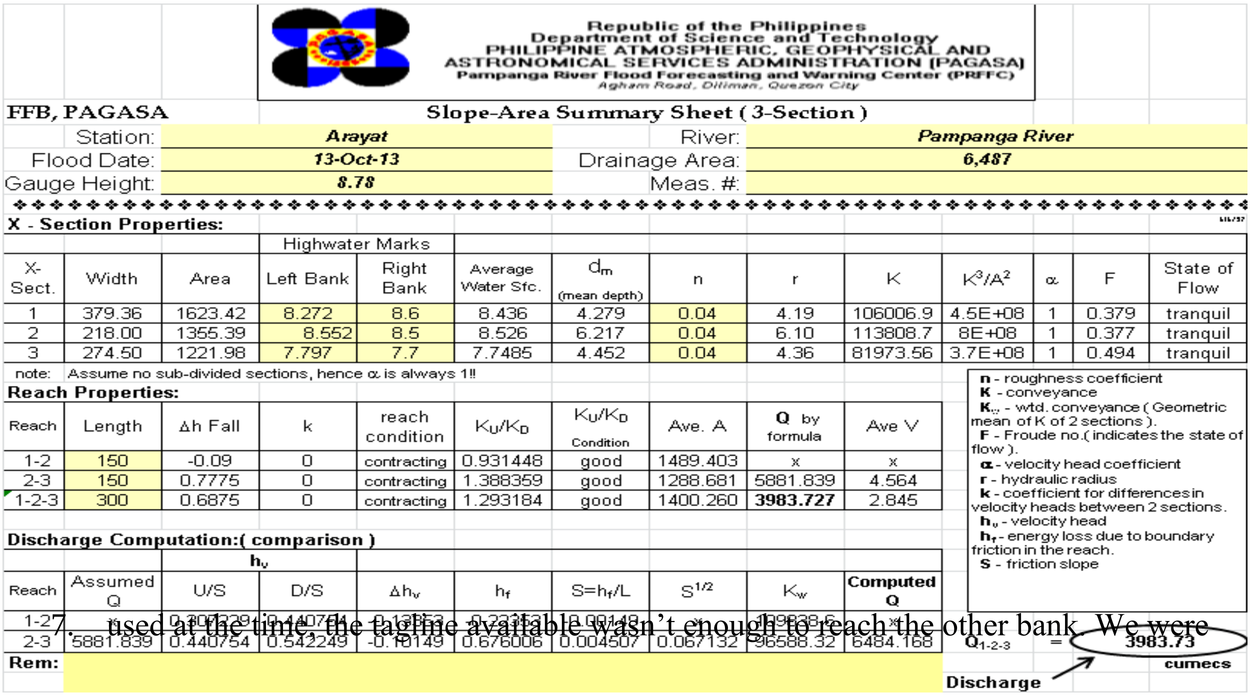
Issues and difficulties encountered

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. Identification of flood marks – 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..
2. Tedious nature of the survey work – The whole activity was time consuming and tiring.
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 because there was no tagline
4. Equipment issues - The range finder's readings were also inaccurate and the device cannot read the distance toward the opposite bank. The echo sounder has a 1m limitation, meaning it cannot measure a depth beyond 1m during depth measurement, so we use a tape measure.
5. Terrain – The ground was still muddy on the first day of measurements. The group had a difficulty finding a stable footing at 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.

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 as follows:



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. #:	

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X - Section Properties:

			Highwater Marks										
X-Sect.	Width	Area	Left Bank	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)

		h_v							
Reach	Assumed Q	U/S	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_{1-2-3} = **3983.73** **cumecs**

Discharge

Rem:

7. used at the time, the tagline available wasn't enough to reach the other bank. We were

The estimated discharge at the time of the flood, by slope area method, was 3983.73 cubic meters per second.

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

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 and bushes.

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

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**

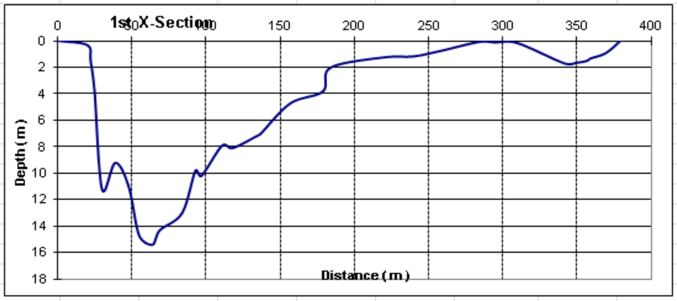
Total Area = 1355.39 meters^2 **Mean Section Depth = 6.21737 meters**

Wetted Perimeter(P) = 222.194 meters

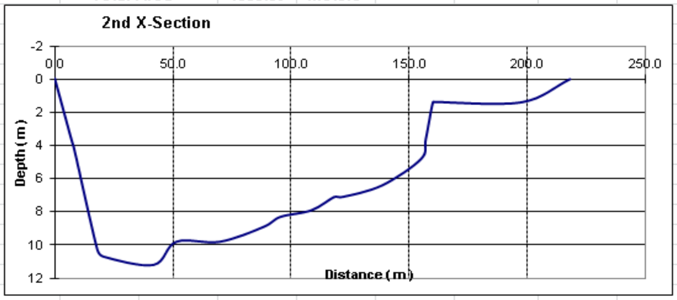
Station: *Arayat* **Date:** *17-Oct-13*

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

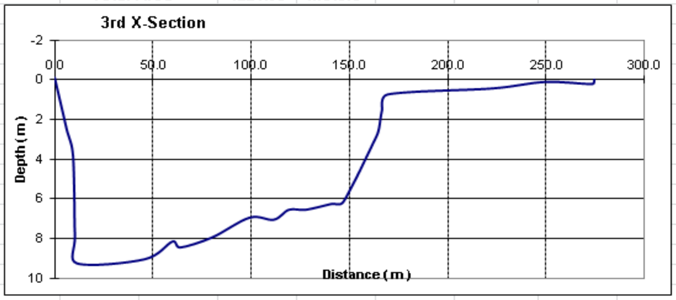
Total Area = 1623.42 meters^2



Total Area = 1355.39 meters^2



Total Area = 1221.98 meters^2



Inferences and Conclusion

The discharge that the group 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.
2. Inaccuracy rangefinder readings.
3. The path traversed on the river was not actually straight.
4. Due to terrain restrictions.
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.
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.

4.2 Acoustic Doppler Current Profiler Method

The use of Acoustic Doppler Current Profiler (ADCP) made possible the development of a discharge-measurement system capable of more accurately measuring unsteady or tidally affected flow. In most cases, an ADCP discharge-measurement system is dramatically faster than conventional discharge-measurement systems and has comparable or better accuracy. In many cases, an ADCP discharge measurement system is the only choice for use at a particular measurement site.

An ADCP uses the principles of the Doppler Effect to measure the velocity of water. The Doppler Effect to determine water velocity by sending a sound pulse into the water and measuring the change in frequency of that sound pulse reflected back to the ADCP by sediment or other particulates being transported in the water. The change in frequency, or Doppler Shift, that is measured by the ADCP is translated into water velocity. The sound is transmitted into the water from a transducer to the bottom of the river and receives return signals throughout the entire depth. The ADCP also uses acoustics to measure water depth by measuring the travel time of a pulse of sound to reach the river bottom at back to the ADCP.

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 or until the software tells passed calibration. After the calibration, the ADCP was positioned 50 meters from the bridge in the downstream towards the left bank coinciding with area of the first cross section of the previous-day slope-area measurements of the group.

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, other data's such as the gauge height (4.65 meters) and the distance to water edge were entered on the user interface, this is necessary to set a starting point of were to the measurement of depth, distance and velocity should start. After inputing the requires data's 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.

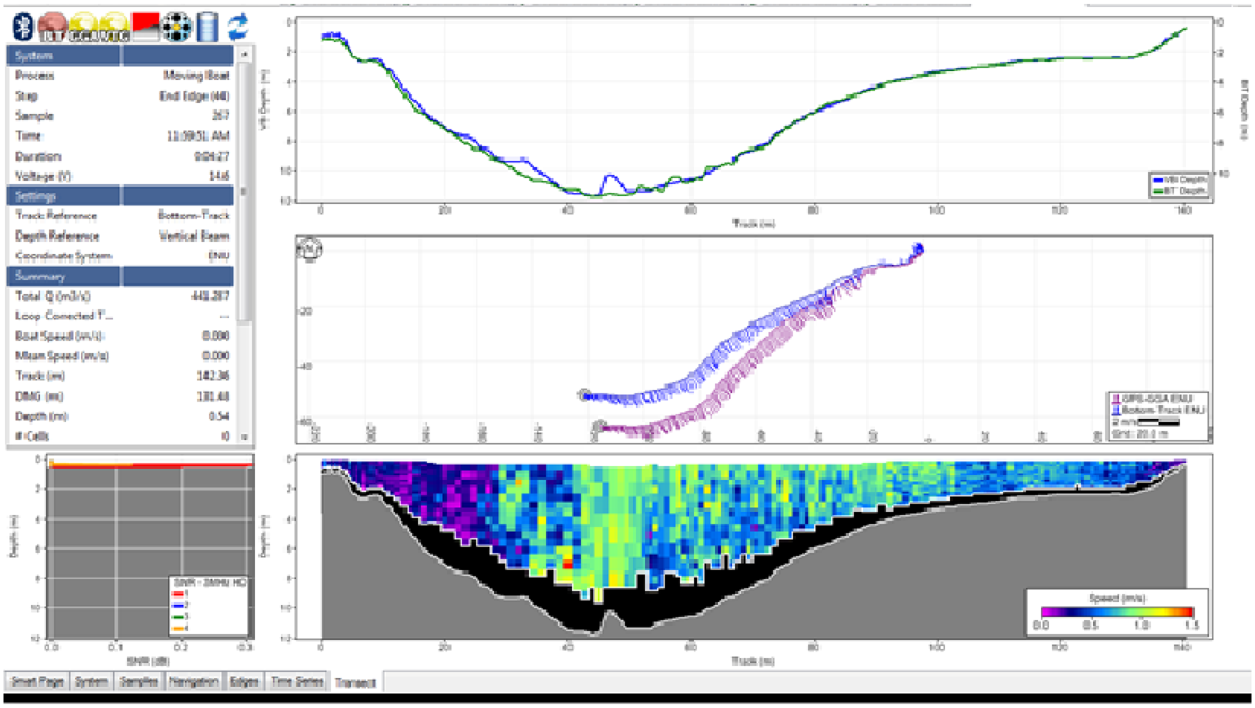
The ADCP actually measures the following values:

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.

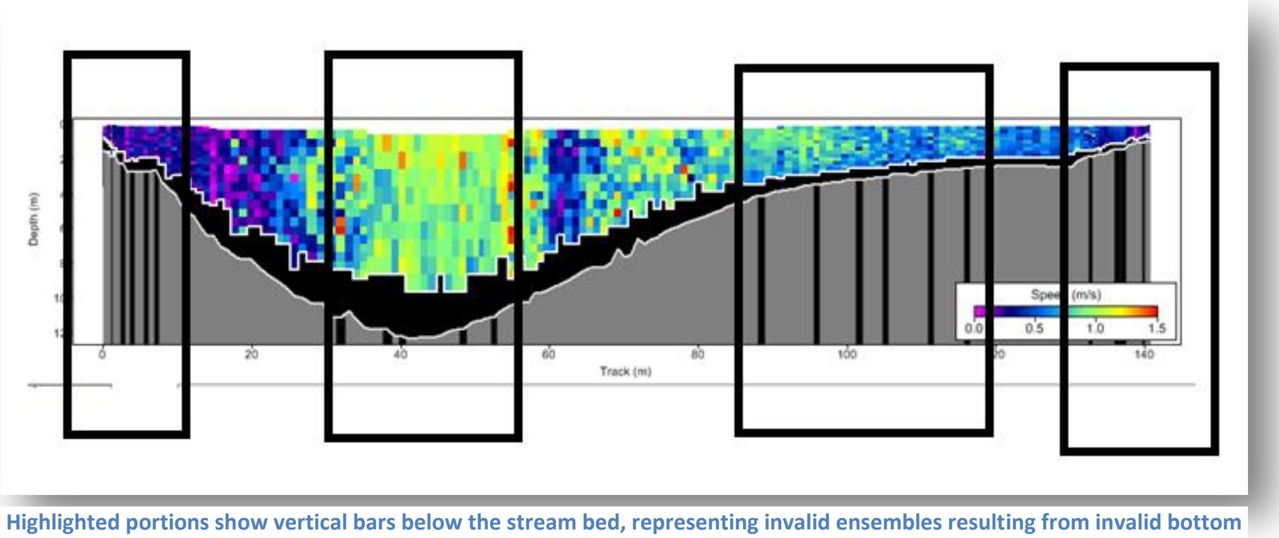
The results were shown graphically on the user interface. Data gathered could also be exported to a text file, for storage or documentation.



System	
Process	Moving Boat
Step	End Edge (48)
Sample	267
Time	11:09:51 AM
Duration	0:04:27
Voltage (V)	14.6
Settings	
Track Reference	Bottom-Track
Depth Reference	Vertical Beam
Coordinate System	ENU
Summary	
Total Q (m3/s)	441.287
Loop Corrected T...	---
Boat Speed (m/s)	0.000
Mean Speed (m/s)	0.000
Track (m)	142.36
DMG (m)	131.48
Depth (m)	0.54
# Cells	0

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.

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. The sensors are also easily affected by debris and vegetation which is present during the measurement that hamper the data and yields to inaccuracy of the discharge measurement. This factors should be avoided to yield the best results
6. It is expensive. Extra care should be emphasize when using the equipment in the river.

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 measurements methods. It also gives the most accurate results.

4.3 <u>Discharge measurement via Current Meter</u>

The current meter measures velocity at a point. The method of making discharge measurements at a cross section requires determination of the mean velocity in each of the selected verticals 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.

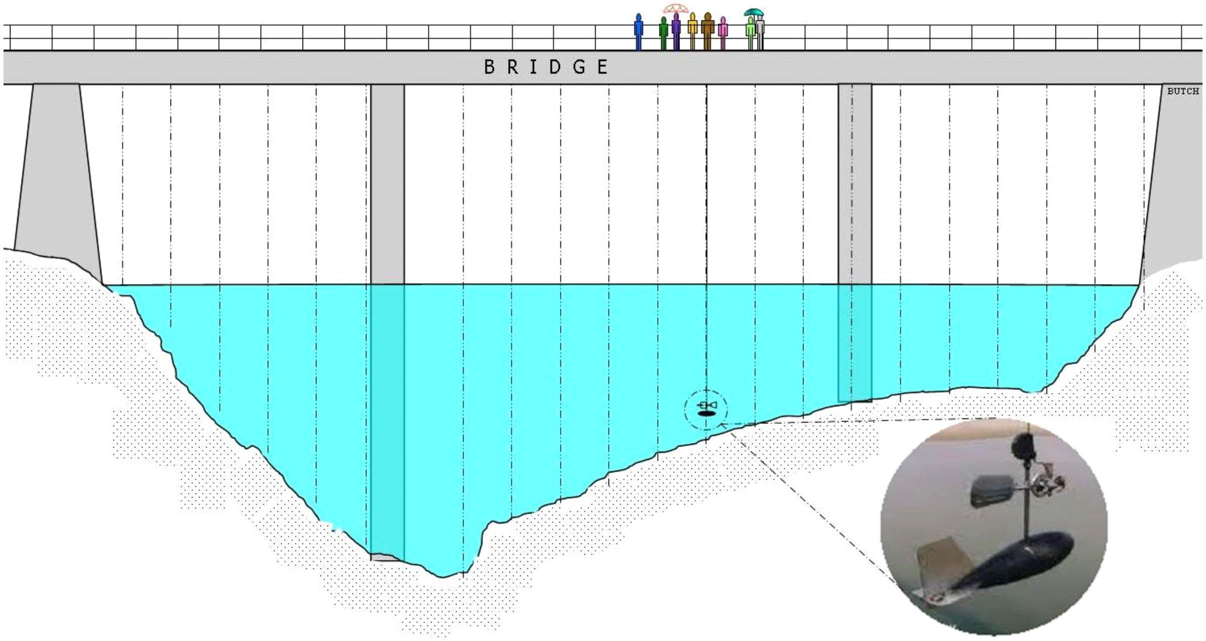
When velocity profiles are relatively normal, it has been found that average velocity can be adequately estimated by averaging velocities at .2 and .8 of the depth below the water surface.

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.

<u>Identifying the segment</u>

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 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.

Since the sounding reel’s cable length has a limited reach, 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.



Velocity measurements

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 then 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. 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.

Discharge Calculations

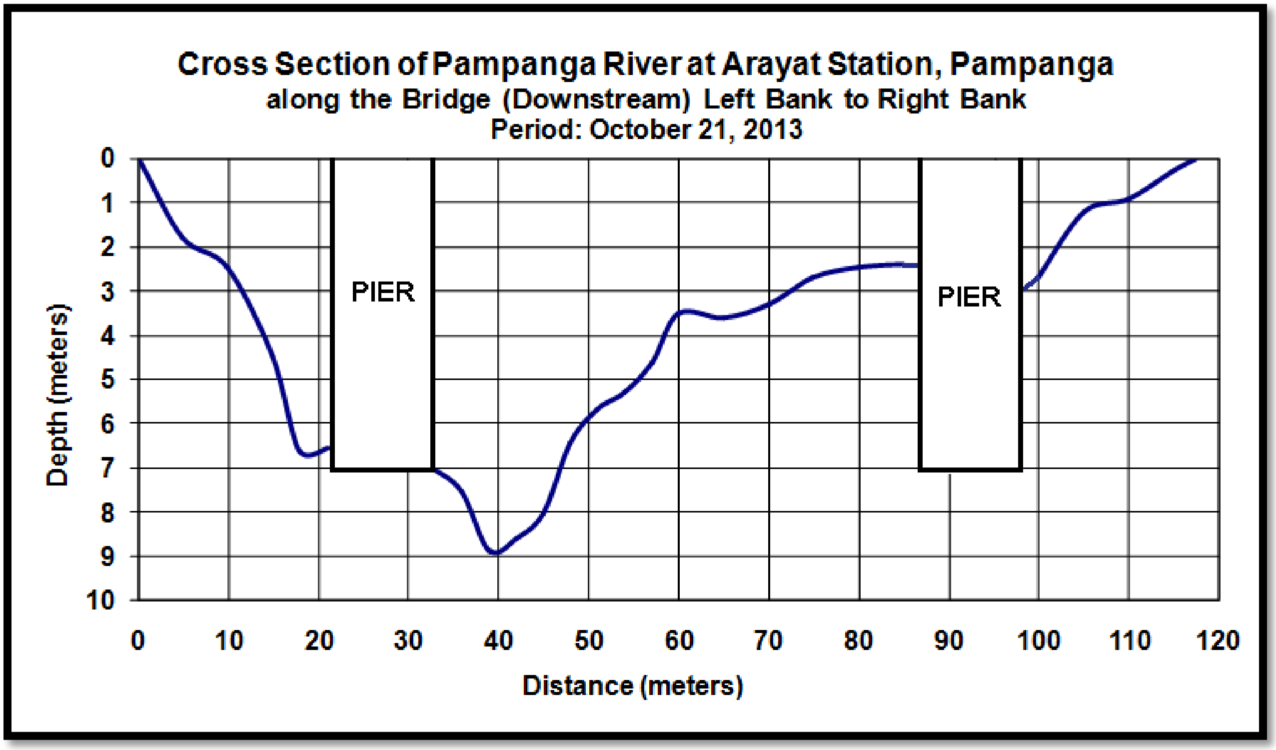
All the data gathered were entered in the excel suite for current meter discharge calculations provided by our instructor, Mr Hilton T. Hernando. The program used the mid-section method for discharge calculations and the group used the two-point method of velocity measurement (taking velocity measurements 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						Velocity		Area (m^2)	Q (cumecs)	Remarks Excellent, Good Fair, Poor
					0.2		0.6		0.8		at point for 0.6 only	Mean (0.2,0.6 & 0.8) or (0.2 & 0.8)			
					Rev.	Time	Rev.	Time	Rev.	Time					
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**		**Q_{total} 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>.**

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.

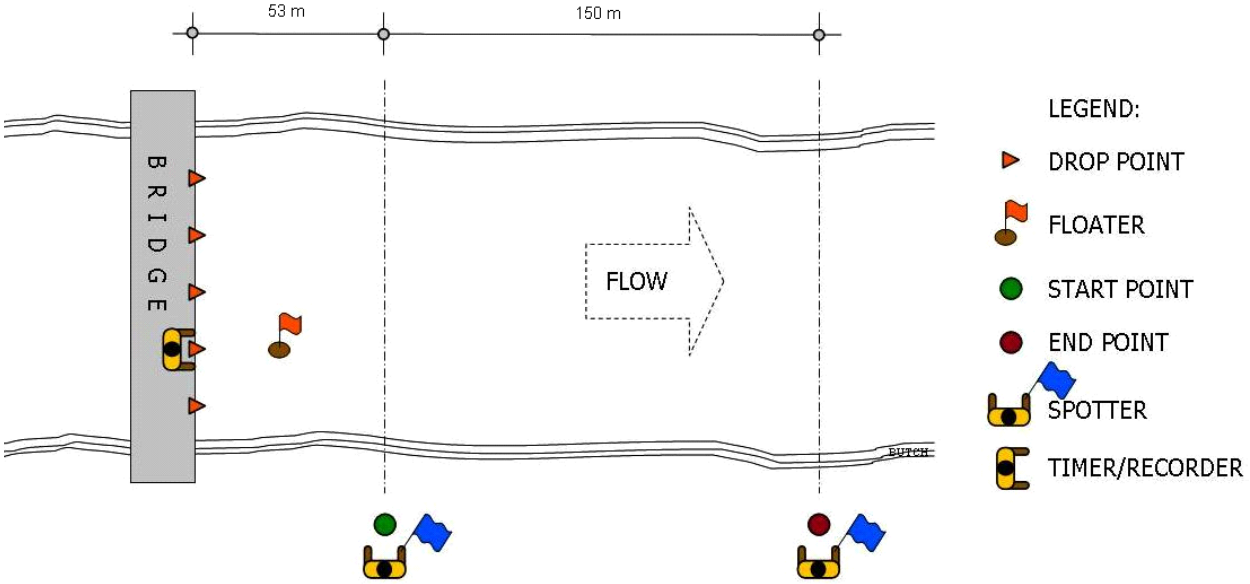
Like any other methods, current meter method also has its drawbacks:

1. The Price AA current meter used in the activity was a vertical axis current meter. This type of meter is prone to obstruction.
2. 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.
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 Float Method

A simple way of measuring the velocity of flow is by means of floats. This method is the easiest, most practical and cost-effective method for discharge measurements during high flow. It gives good estimates when no equipment is available. The float method is an indirect method generally applied for floods which discharge observation by current meter and all other techniques like ADCP's are impractical to use. As the name of the method implies, floats are thrown from bridges down into the river and the time traverse in a certain cross section(mostly 53m from the bridge, to give time for the bamboo to emerge and float freely in the river) to another cross section(let's say 150m from the 1st cross section) of the river is measured thus, the average velocity in the section can be estimated .



In order for the float method to give the best results, certain selection criteria must be considered:

1. The Float method must be carried out at the top of bridge where the channel geometry of the flow is perpendicular to bridge width position, but there are emergency cases when they are thrown from the river bank.
2. There must be at least 3 persons (group) to run the float test. One should be positioned upstream and the other downstream a known distance apart, one in the middle to record data.

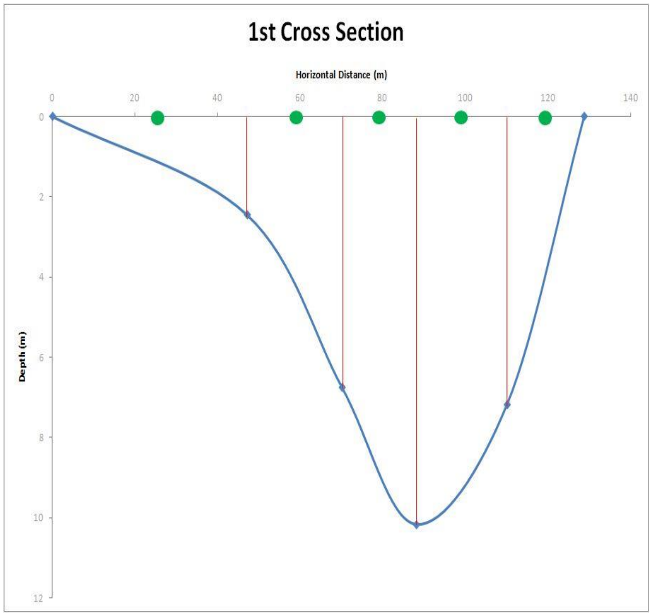
3. Use something that floats that you can retrieve or is biodegradable if you can’t retrieve it. In our cased we used are improvised using bamboo sections of about 1-meter length, filled with 3/4 –full sand with a flag marker for visibility.
4. The measurement section is from the first cross section to the second cross section in order to measure the travelling time of a float which requires at least 50-100m meters. Too long section causes error in measurement due to variation of stage for long travelling time.
5. Conduct at least 5 float tests and take an average velocity.

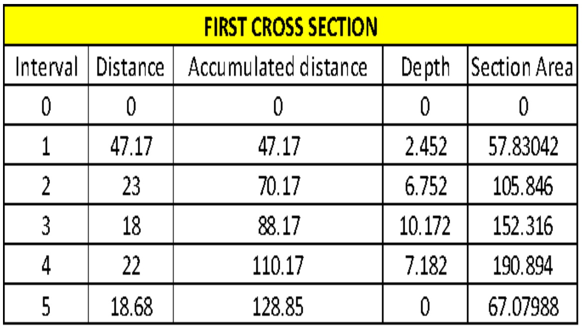
Discharge Area Estimates

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. 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.

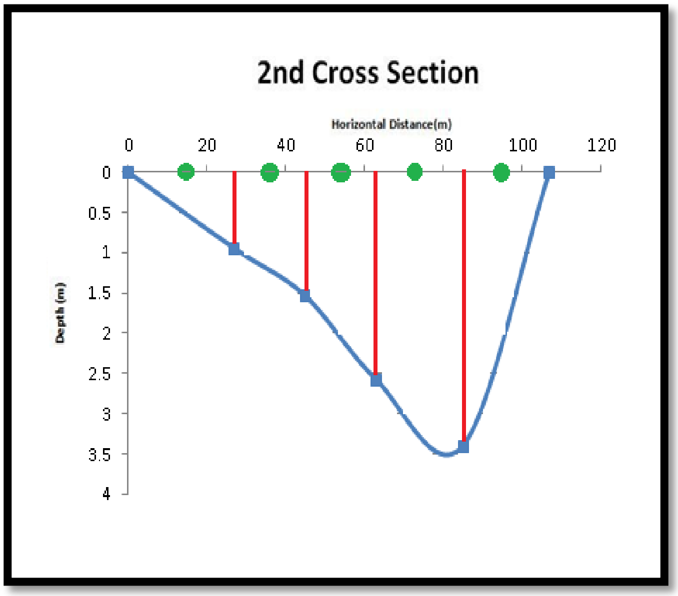
A given section area would then be computed by multiplying the distance between verticals (interval) with the average of the depths at those verticals. There are a total of 5 sections for each cross section. The profiles of the cross sections are detailed below.

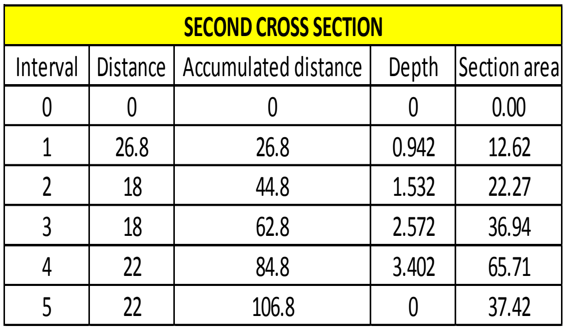




FIRST CROSS SECTION

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



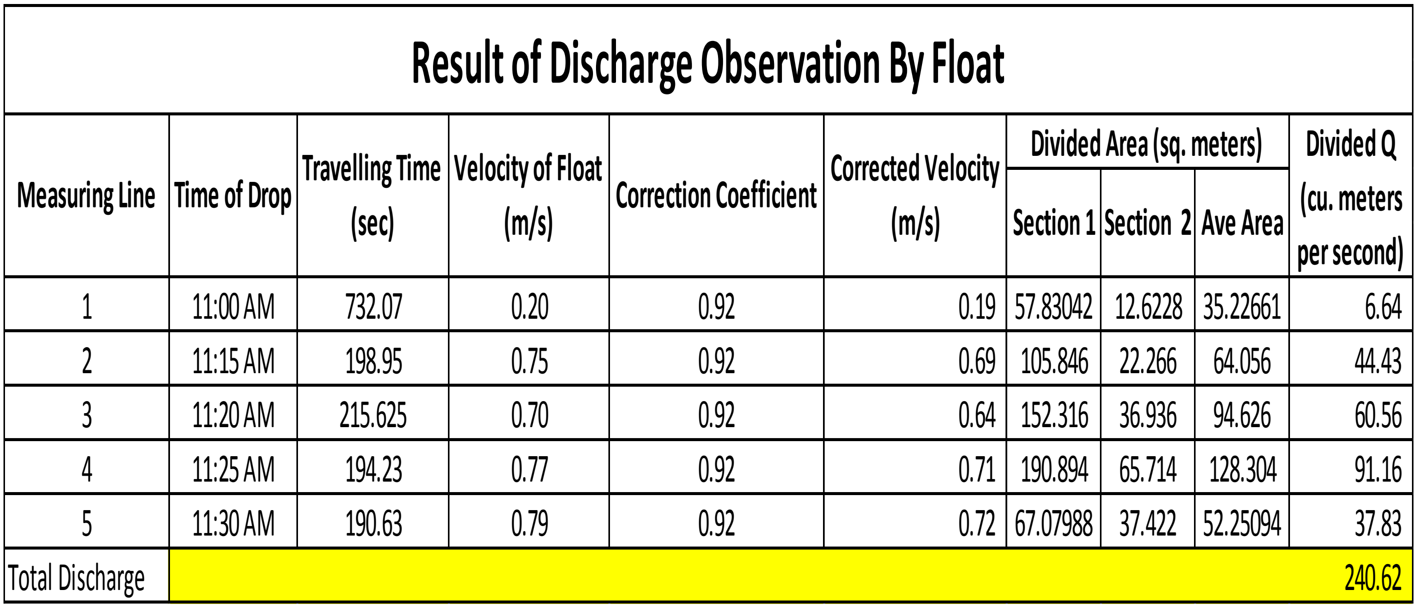


SECOND CROSS SECTION

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

Discharge Calculations

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 <u>240.62 cubic meters per second.</u>

Issues and concerns

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 Float method. These are:

1. Presence of debris and water lilies- When the bamboo float was drop, there are some instances that the float will not emerged into the surface, this is due to the fact that the float is trap below the surface by presence of vegetation and debris.

2. Effects of wind, air resistance and river surface impact – Effects cause by this factors may affect the velocity, and instability of the float. If float is not properly drop, it may break it; which make it useless.
3. Equipment issues - For a moment during the cross section survey. The range finder's readings were also inaccurate and the device cannot read the distance toward the opposite bank.
4. Presence of ripple and low flow areas – The float is very much affected by this factors, it may slow it down or make it completely immovable.

Conclusion

Discharge measurements done via float method are optimal at medium to high flows. It is an indirect method of computing discharge which can be best applied during flood events or at relatively high flows. 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.

CONCLUSION ON THE VARIOUS METHODS OF DISCHARGE MEASUREMENTS

There are obviously different methods for computing discharge, as described in the previous sections namely Slope-Area, ADCP, Current Meter and Floar Methods. Each has their own advantages and disadvantages. The methods to be used mainly depends on the Discharge-Measurement Survey team's judgment and evaluation on what method to use that would best suit the situation at the time of measurement.

For instance, during floods, the most reasonable and suitable method to use would be the float method. When a current meter and ADCP used in that scenario, if it can be used at all, would easily be destroyed or would create unreasonable and inaccurate results. During flood events only indirect methods are use like Float and Slope-Area Methods, but this methods has its drawbacks at high flows; the float can easily be lost from all the debris such as water lilies carried by floodwaters, the slope Slope-Area methods is tedious, and depends on the accessibility of the site. Since float-method usually depends on a bridge, slope-area measurements are the best alternative in estimating discharge during flood events, especially in low lying off-road river reach; the only drawback would be the tedious nature of this method.

In scenarios other than flood events, or post typhoon events, and the river is calm, direct measurements by current meters and ADCP's are the best methods to use. Among all discharge measurement methods; ADCP gives the most accurate results with proper set-up and calibration, although current meters are the best less cost and accurate alternative in measuring discharge.

In conducting discharge measurement in river: during floods or post floods events there is always a discharge measurement method suitable to use, it can be direct and indirect method. The most important thing is to gathered and obtain reasonable data's that can be the most accurate representative of a particular discharge of a particular river.

Lastly, on what method to use for a given situation the decision would depend on the judgment of the discharge-measurement surveying 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 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

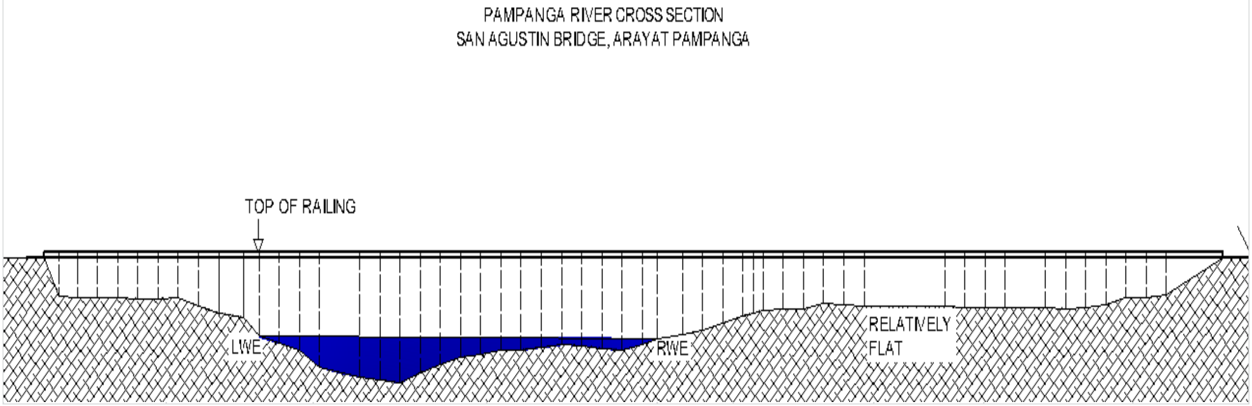
Date: Oct. 23, 2013

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.

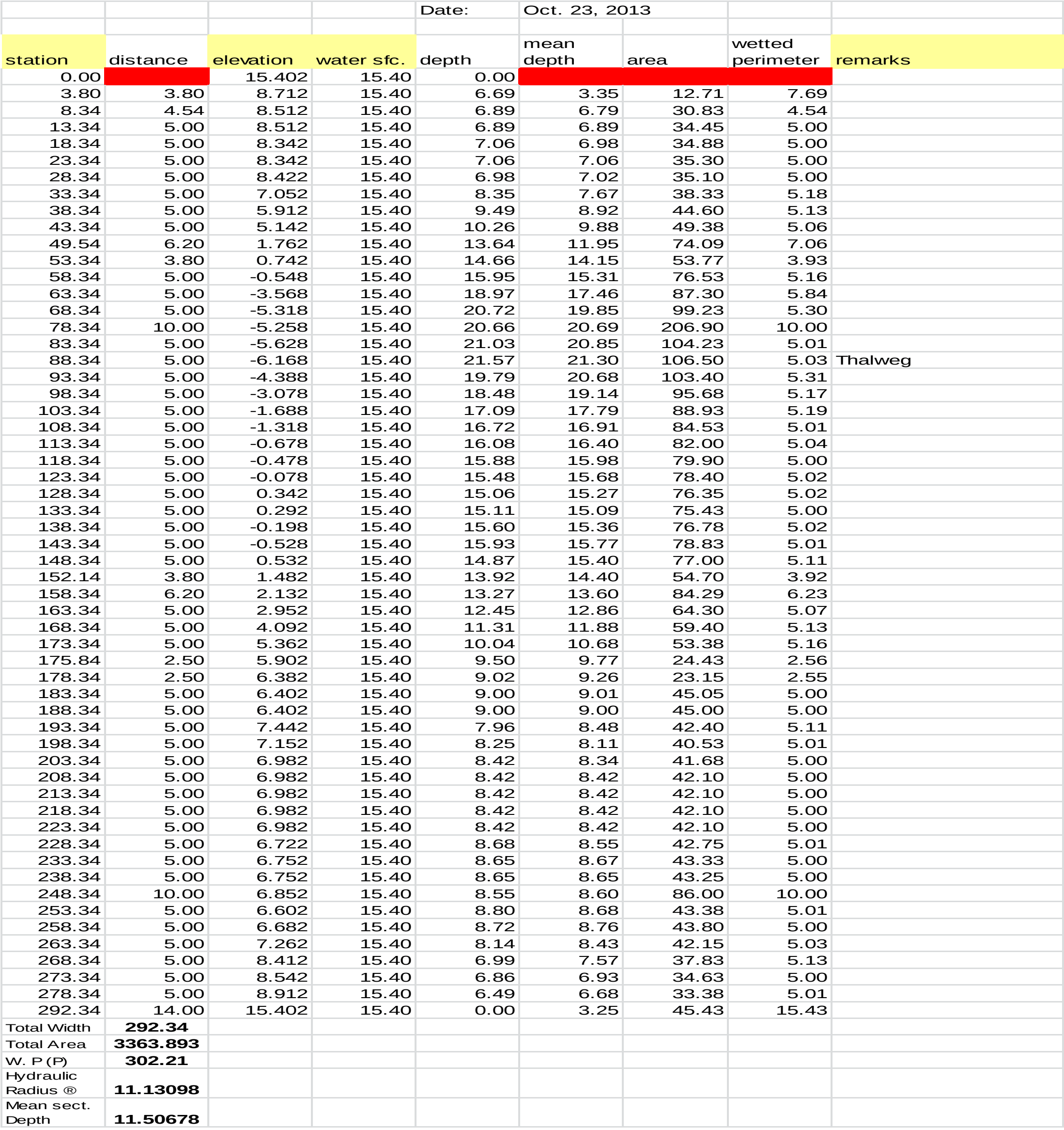
Station Interval	Depth (m)	Accumulated Horizontal Length (m)	Remarks
0	0.91	0	top of dike
3.8	7.6	3.8	Foot of dike
4.54	7.8	8.34	
5	7.8	13.34	
5	7.97	18.34	
5	7.97	23.34	
5	7.89	28.34	
5	9.26	33.34	
5	10.4	38.34	
5	11.17	43.34	
6.2	14.55	49.54	Left Water Edge
3.8	15.57	53.34	
5	16.86	58.34	
5	19.88	63.34	
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
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



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.

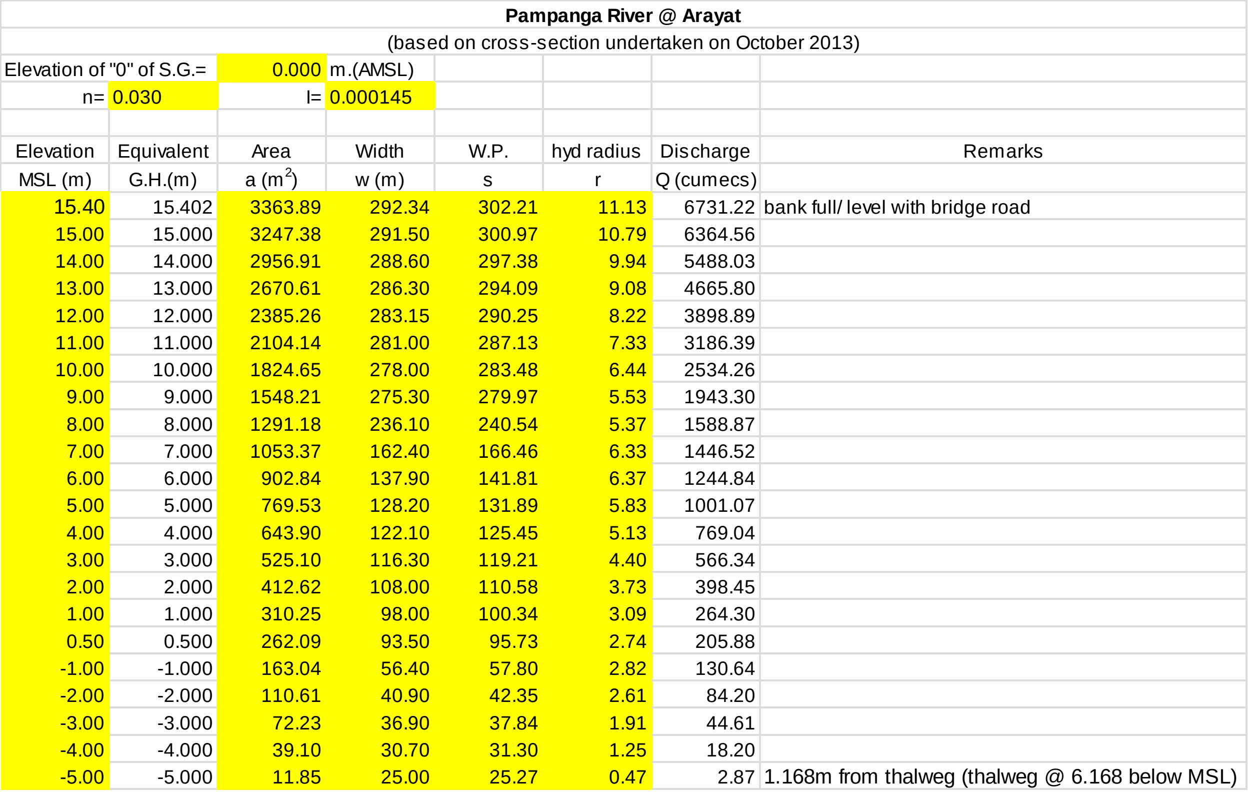
The resulting data are the entered on a cross section excel suite that computes for width, area, wetted perimeter and hydraulic radius for a given water surface elevation. Note that in this survey, the bridge was assumed to be straight with no piers obstructing the river.

4.2 Discharge estimation



				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)

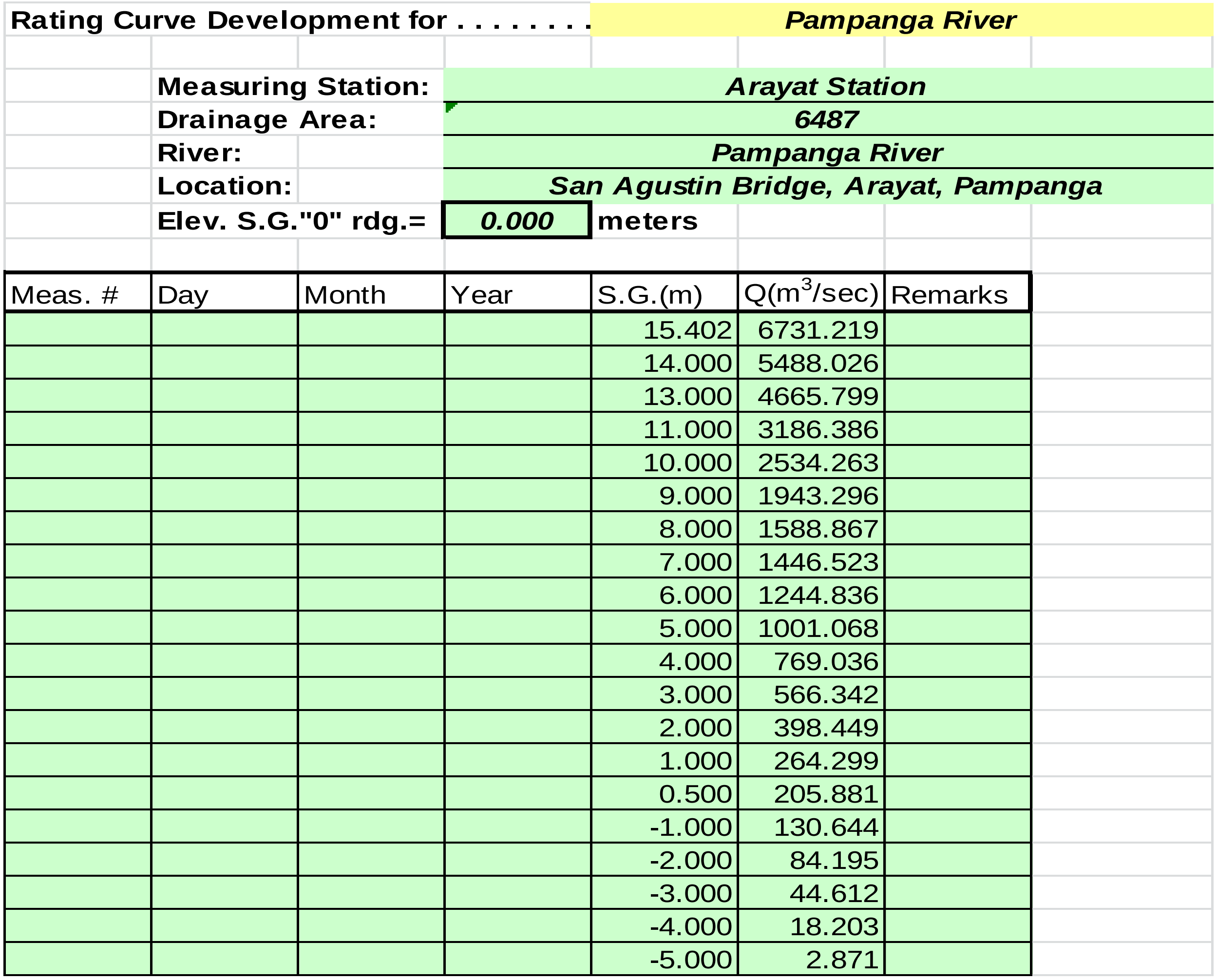
Elevation of "0" of S.G.= 0.000 m.(AMSL)

n= 0.030 I= 0.000145

Elevation MSL (m)	Equivalent G.H.(m)	Area a (m^2)	Width w (m)	W.P. s	hyd radius r	Discharge Q (cumecs)	Remarks
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 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.

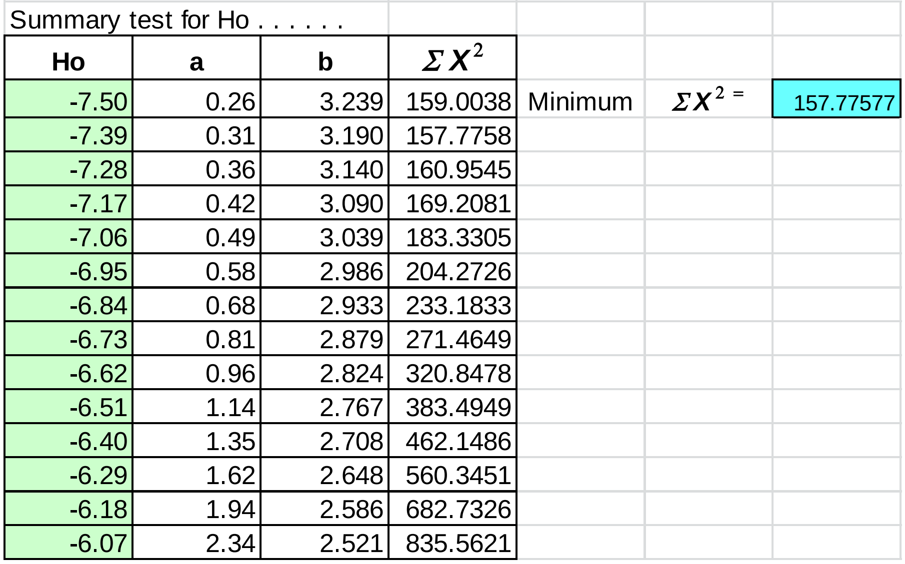


Rating Curve Development for . . . . ***Pampanga River***

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	

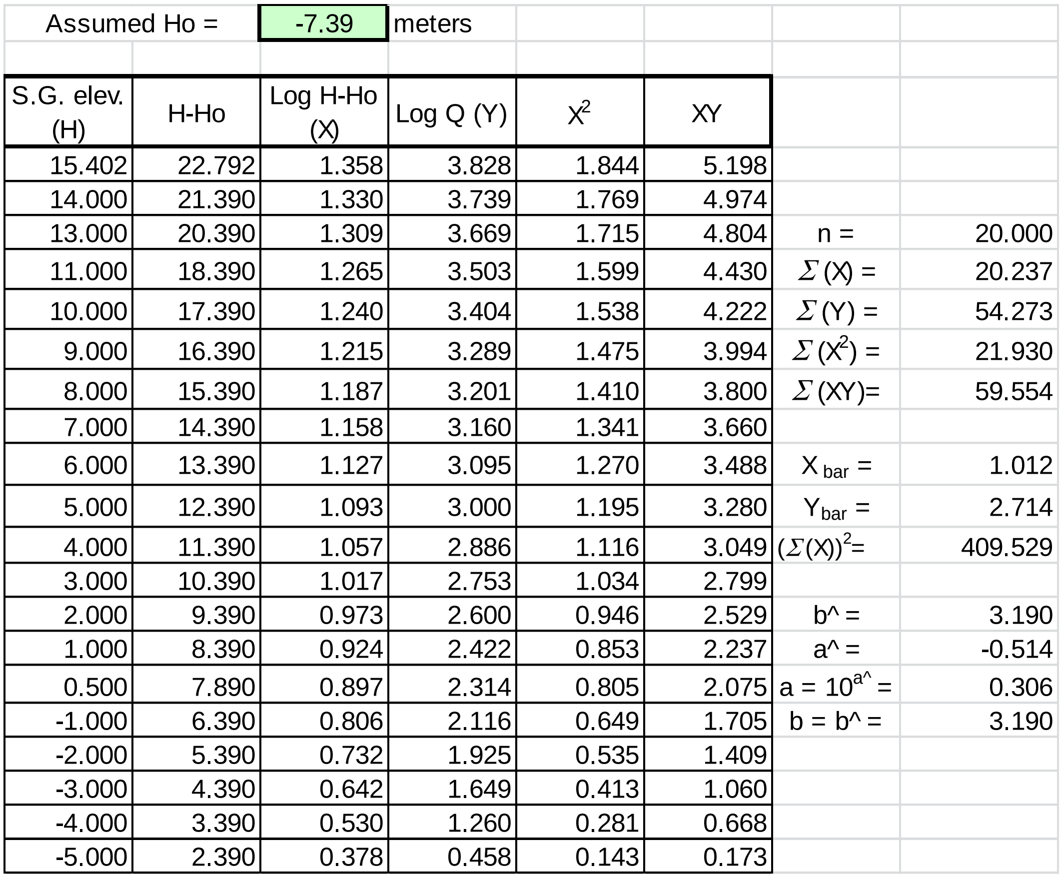
After the H-Q Values are entered, the value for Ho (elevation of zero flow) would have to be determined by trial and error on the "rat" tab of the same excel suite:



Summary test for Ho . . . . . .

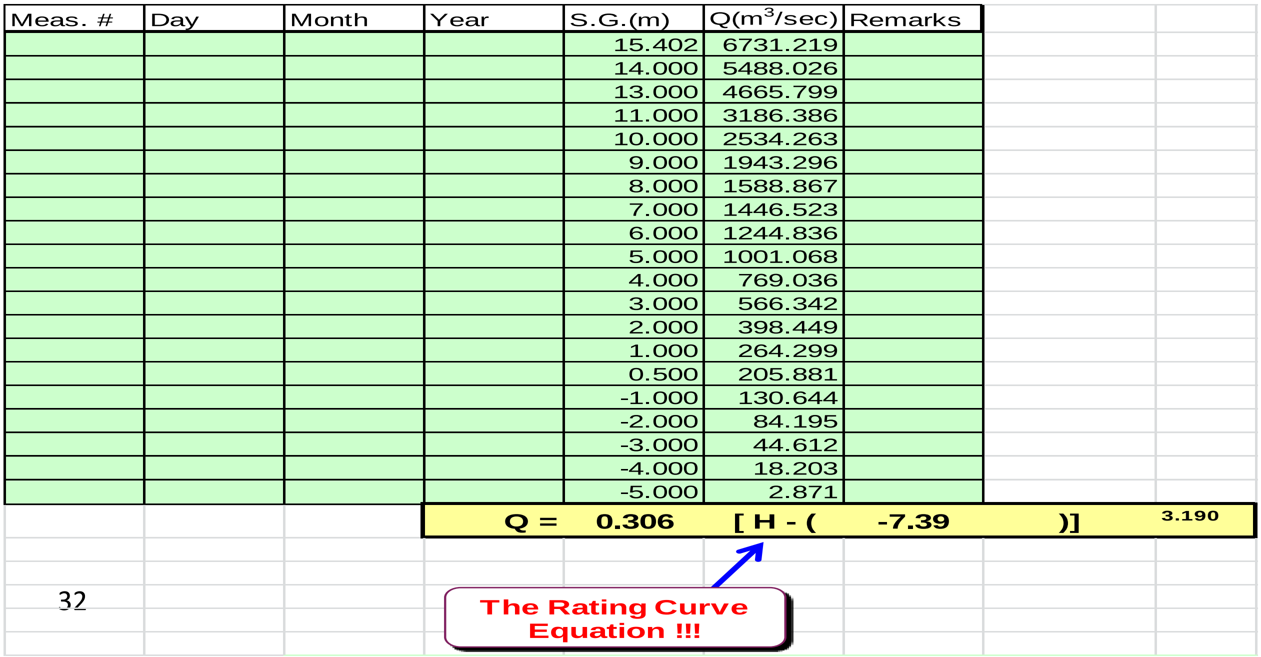
Ho	a	b	ΣX^2			
-7.50	0.26	3.239	159.0038	Minimum	$\Sigma X^2 =$	157.77577
-7.39	0.31	3.190	157.7758			
-7.28	0.36	3.140	160.9545			
-7.17	0.42	3.090	169.2081			
-7.06	0.49	3.039	183.3305			
-6.95	0.58	2.986	204.2726			
-6.84	0.68	2.933	233.1833			
-6.73	0.81	2.879	271.4649			
-6.62	0.96	2.824	320.8478			
-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	$\Sigma(X) =$	20.237
10.000	17.390	1.240	3.404	1.538	4.222	$\Sigma(Y) =$	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	$\Sigma(XY)=$	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	

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

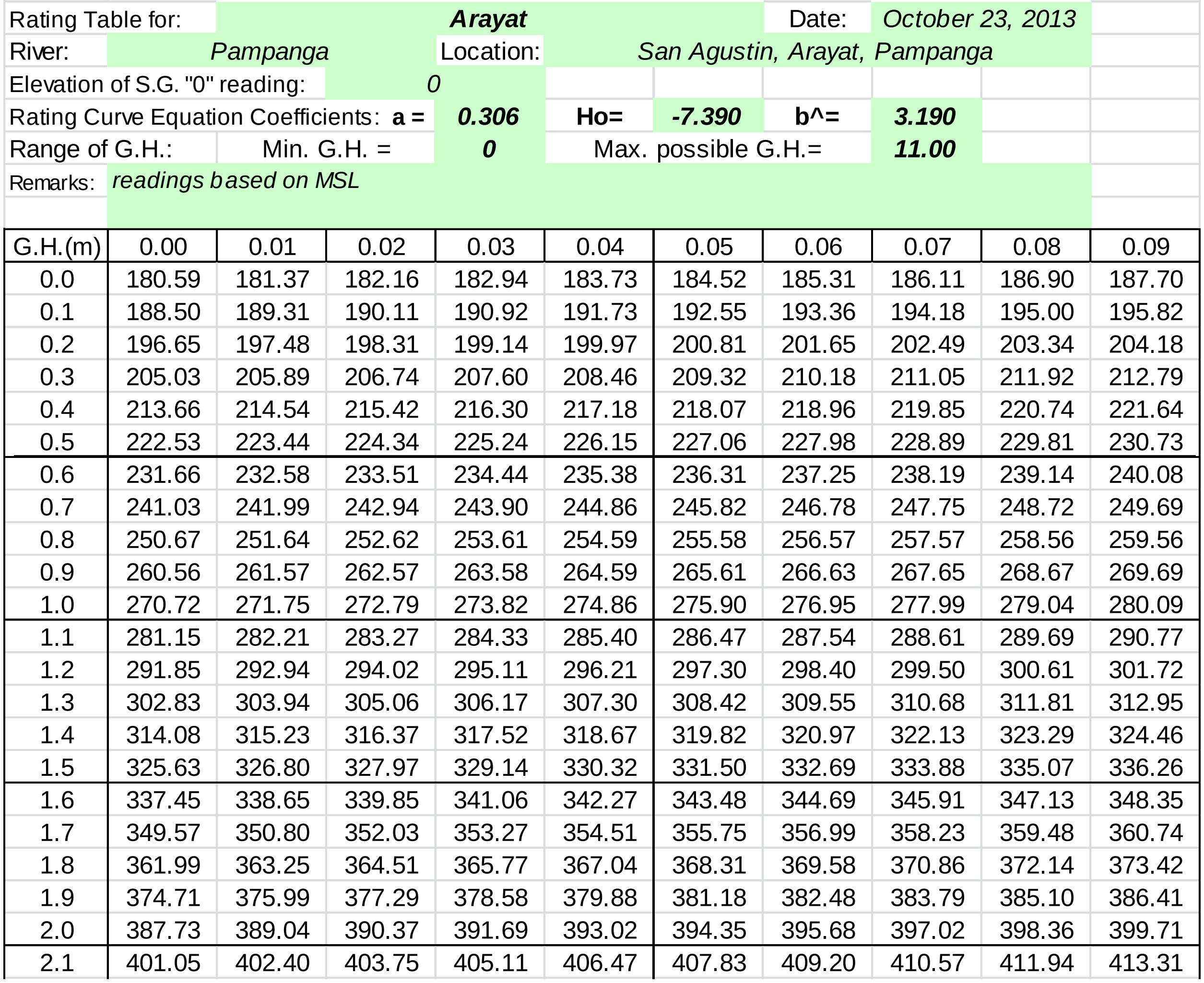
The Rating Curve Equation !!!

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:

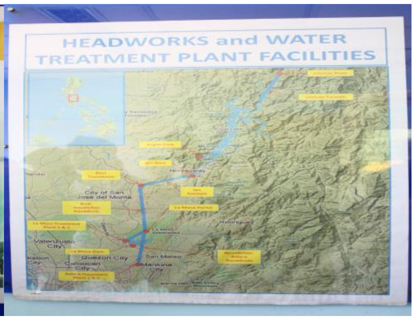
1. The H-Q values used in the formulation of the rating equation are in themselves only estimates computed based on manning's equation. The error may have been magnified when the rating curve equation and the rating table are computed.
2. The bridge was assumed to be straight. In reality, the bridge's 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

FIELD VISIT

- **Field Visit in La Mesa Dam**

  (October 15, 2013 Tuesday)



During our visit in La Mesa Dam which is located in Quezon City. I have learned that it is part of the Angat-Ipo-La Mesa water system, which supplies most of the water supply of Metro Manila. The La Mes a Dam is an earth dam whose reservoir can hold up to 50.5 million cubic meters occupying an area of 27 square kilometers.

I also learned that the dam doesn't have any control gates or spillways but merely an overflow dam, and at the time that the dam reaches its 80.15 m spill level the flood water just flows freely to Metro Manila and contributres to flooding in some areas.

The primary purpose of the dam is to collect water for drinking and other practical purposes and not as a flood control necessity. The water collected from the three intakes in the reservoir is treated on-site by the Maynilad Water Services, and at the Balara Treatment Plant further south by the Manila Water. Both water companies are private concessionaires awarded by the Metropolitan Waterworks and Sewerage System. And a vital link to the water requirements of 12 million residents of Metro Manila considering that 1.5 million liters of water pass through this reservoir everyday. It is also the last forest of its size in the metropolis.

Field Visit in Pantabangan Dam (October 19, 2013 Saturday)

During our visit at Pantabangan Dam, I have learned that it is an earth-fill embankment dam on the Pampanga River located in Pantabangan, Nueva Ecija. The multi-purpose dam provides water for irrigation and hydroelectric power generation while its reservoir, Pantabangan Lake, affords flood control. The reservoir is considered one of the largest in Southeast Asia and also one of the cleanest in the Philippines. It is composed of three sections: the main dam, a saddle dam, and an auxiliary dam located with the spillway.

The dam sits at the head of a 853 km^2 catchment area and its reservoir has a surface area of 69.62 km^2 and elevation of 230m when at its maximum level. The reservoir's life is estimated at 107 years due to silt from denudation. The dam was design to withstand an intensity 10 earthquake. The water level at the Pantabangan Dam is use to irrigate over 100,000 hectares of agricultural lands, and it hydroelectric power house located at the base of the main dam has the capacity of 100 MW power generation. The dams spilling level is at 221m. I also learned that during the dams entire operation, only 3 times had it released water to the downstream due to the fact that it has a larger catchment area for storing sufficient water level.

- **Field Visit in Cong Dadong Dam**

(October 21, 2013 Monday**)**

After our fieldwork we went to Cong Dadong Dam. I have learned that this dam's mean purpose is for irrigation only. The dam forms part of the Pampanga Delta Development Project-Irrigation Component (PDDP-IC). Taking its source from the Pampanga River and is expected to provide year-round irrigation to 10,270 hectares of farmland involving 7,900 farmers in the seven towns of Pampanga primarily Sta. Ana, Mexico, San Luis, Candaba, San Simon, Apalit and Arayat. Its critical level is 7 meters. It has 3 gates, the first gates acts a spillway were most of the water flow, while the other 2 gates had double doors to separates the debris and water lilies from the water.

I have learned also that it is considered as the largest irrigation and diversion type of dam in Southeast Asia.

- **Municipal Disaster Risk Reduction and Management Council** Calumpit Bulacan (October 23, 2013)

We went to Bulacan to visit the Municipal Disaster Risk Reduction and Management Council of Calumpit, Bulacan. I have learned that Calumpit was one of Best Municipal Disaster Risk Reduction and Management Council in the Philippines, as we went there I noticed that the municipality is very much equipped with necessary tools, rescue vehicles, and monitoring equipment to reduce risk and be prepared for incoming disasters. This is due to the fact that Calumpit is a flood prone area, and during rainy season especially during typhoons and SouthWest monsoon, it is the most flood part of Bulacan. In terms of flood forecasting and monitoring, they have created a computer based monitoring system that enables them to be aware of existing typhoons: where its path, water level in river and tide level in Manila Bay. With this monitoring they are able to create and establish plans, conducts drills to lessen or be prepared when disaster like flood and earthquake comes through not only in their municipality but also in nearby municipality. I also learned that the Local government, private sectors and common citizens are helping each other to survive incoming disasters. It is so amazing how the people help each other.

- **Field Visit in Angat Dam** (October 24, 2013)

On our last day of fieldwork, we visited Angat Dam. I learned that it was a part of the Angat-Ipo-La Mesa water system. The dikes of Angat Dam are rock and earth-filled, and based on studies, it is more adaptable and flexible to earthquakes compared to concrete dike and get stronger through the years. The multi-purpose dam provides water for irrigation, hydroelectric power, water supply and flood control function. It has a total storage capacity of 850 million cubic meters. Angat dam has a normal high water level of 210 meters with a spilling level of . Angat has three gates opening a total of 1.5 meters to gradually release water that had accumulated due to incessant rains during typhoons.

I also learned that Angat”s 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. Its powerhouse generates at least 146 megawatts to the Luzon power grid, while serving as a major flood control in Bulacan.I also learned that Angat dam releases water at an average of once per year, especially during rainy season due to the fact that Angat Dam has a lesser storage water capacity with a big watershed.