Technical Report in

Stream Gauging Field Work

Arayat Station, Pampanga

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18 November 2013

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1. Introduction

Stream gauging is a technique used to measure the Discharge, or the volume of water moving through a channel per unit time of a stream. Discharge measurement is usually expressed in cubic meter per second (m^3/s) and denotes with a letter "Q", also computed through the values of width, depth and velocity.

As prerequisite in the subject of Stream Gauging, the Discharge Measurement in Hydrological Training Course conducted by Philippines Atmospheric, Geophysical and Astronomical Services and Administration (PAGASA), a field work was done in Pampanga, for 10 days (October 15 to 24, 2013).

As the Philippines is the most exposed country in the world to tropical cyclones due to its location facing the Pacific Ocean where most of the cyclones were formed, flooding is most likely to occur in any part of the country. One of the flooded areas in the Philippines is Pampanga and just recently, October 12 to 13 of the same year, the area was affected by the Typhoon named SANTI (international name SARI) that caused flooding to most part of the province and nearby areas.

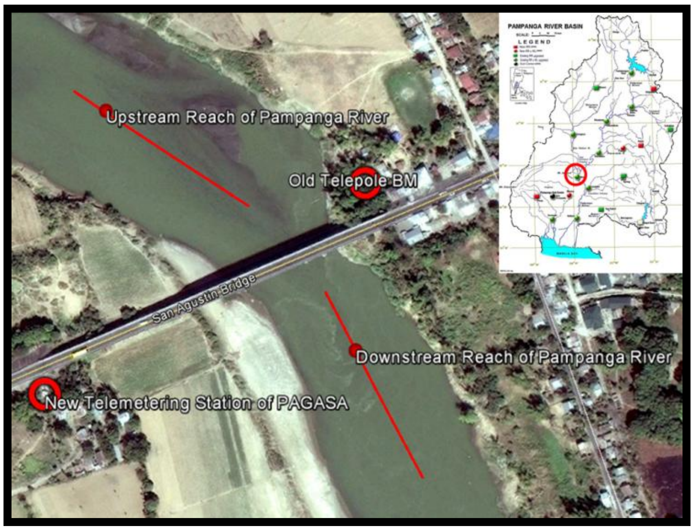
One of the areas affected was Arayat, Pampanga and this is where the field activity was conducted. The said area was surveyed and using different method, the Discharge was measured.

2. Objectives

The general purpose of the field work activities the discharge of Pampanga River along Arayat Station of Pampanga River Basin. As SANTI affected the said area just recently, identification of flood marks and flood extent was also important to be able to measure the maximum discharge. Accomplishing those task needed to use different method as well as to understand each procedure and identify its good points and limitations. For future reference, the rating curve, equation and table is also computed and updated.

3. Site Description

The area of study was located at Barrio San Agustin, Arayat, Pampanga around 77km away or about 1 to 2 hours of travel from Manila and with coordinates of 15°10'5.88" North and 120°46'55.99" South. The Arayat Station having rain and water level gauges is one of the stations monitored and maintained by Pampanga River Basin and Flood Forecasting and Warning Center (PRFFWC).



Arayat Station, Pampanga

Based on the 2009 survey of PRFFWC personnel, the Arayat station has an estimated elevation of 9 meters and Staff Gauge (S.G.) "0" gage elevation of 0.077 meter based on the Mean Sea Level (MSL) with an old telepole benchmark (BM) having an elevation of 9.11meters.

Old Arayat Station along the Pampanga River at relative high flows

The total length of Pampanga River is about 260 kilometer and Arayat Station lies on the Main middle of the said river. The old telemetering station and telepole benchmark could be found on the left river banks, while, on the other hand, the new telemetering station was found on the right bank of Pampanga River.

(Left) is the old Arayat Station and (Right) is the new Arayat station along the Pampanga River at relative low flows

The Pampanga River is relatively at low to medium flow when the survey was conducted this 17 to 18 and 21 to 22 of October 2013. The Pampanga River is fairly wide and was surrounded by vegetation and trees in both banks, with a combination of silt and clay as the type of soil, while, the riverbed is composed of silt, clay, gravel, sand and pebbles.

Downstream reach of Pampanga River in Arayat Station

4. Measurement of Discharge

Since the discharge could not be measured directly but only derived from the variables measurable by the available different approach or method was used in discharge measurement.

The following are the schedule during the field work activities: (a) Day 1 – October 17, 2013, Slope-area method; (b) Day 2 – October 18, 2013, Discharge measurement using Acoustic Doppler Current Profiler (ADCP); (c) Day 3 – October 21, 2013, Current Meter method; and (d) day 4 – October 22, 2013, Float method.

4.1. Slope-Area Method

Slope-area method is a type of indirect method of computing discharge during flood events but can only be done after the event is finish under a fairly good weather.

In order to conduct a slope-area discharge measurement, the following criteria was observed:

- The reach must be fairly straight and contracting.
- 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.
- The fall of the reach must be greater than 0.15 meters.

4.1.1. Procedure

Everything was setup, the total station oriented to North, along with it was the prism for an easy target. Located at the upstream left bank region near San Agustin Bridge was a benchmark used as the basis of the measurement having an elevation of 9.114 Above Mean Sea Level (AMSL). The benchmark was run across the right bank 53 kilometers downstream of San Agustin Bridge, as the first stream cross section which uses a tape measure to measure the distance. Having an interval of 150 kilometers in each stream cross section, the second stream cross section was 203 kilometers while the third cross section was 353 kilometers away from the bridge, estimating the distance using a range-finder.

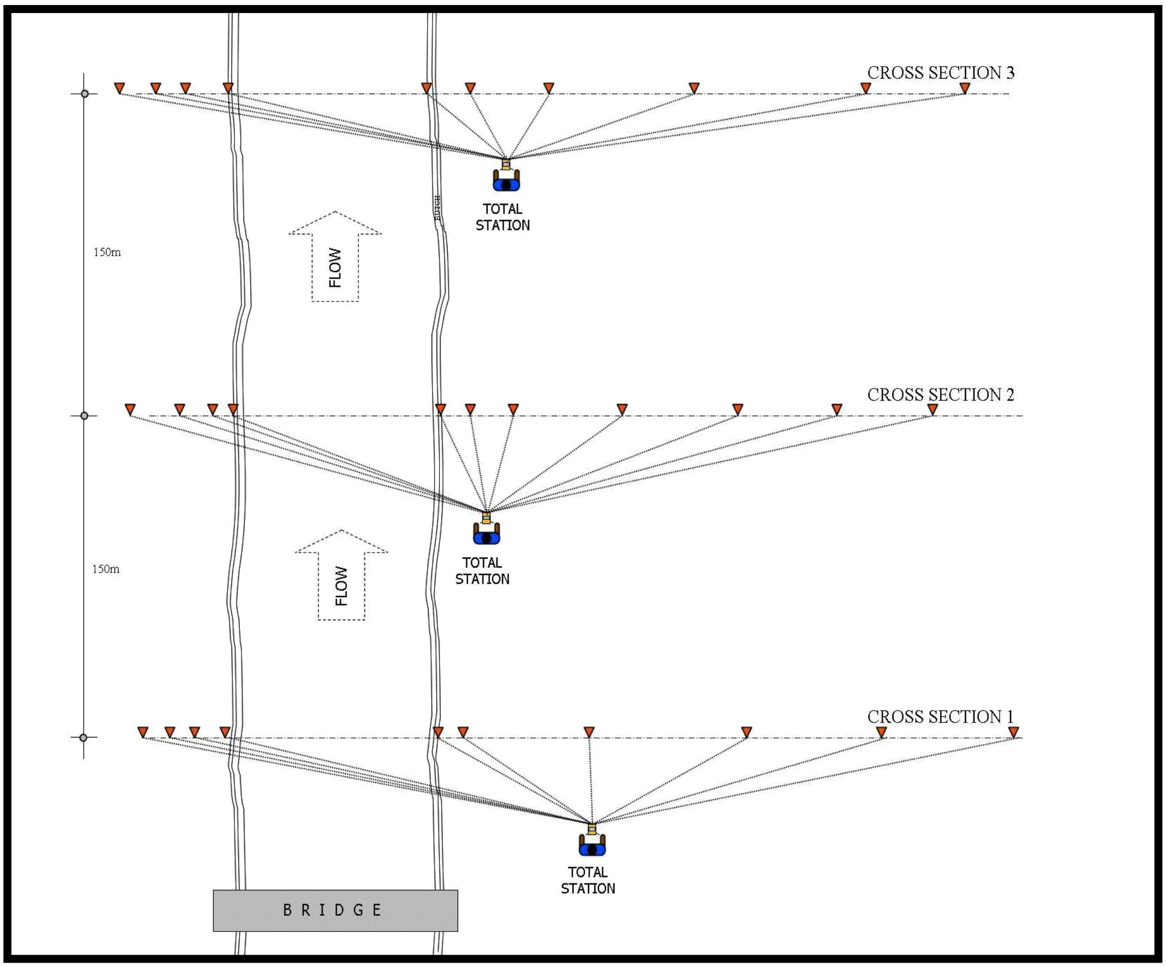


Illustration of the slope area method done in the survey

For every stream cross section, points were established and measured from the flood extent of the right bank going to the flood extent of the left bank. At each point, using the total station and prism, the Horizontal Distance (HD), Horizontal Angle (HA) and Vertical Distance (VD) was measured, but starting from the Right Water Edge going to the Left water Edge echo sounder and range-finder was used to measure the HD and VD assuming that the transect was fairly straight. Due to some difficulty, in the first cross section, a ladderized method was used to measure HD and VD from left water edge to the flood extent of the left bank.

The following tables below are the summary of the 3 stream cross section done in the survey, left bank going to the right bank:

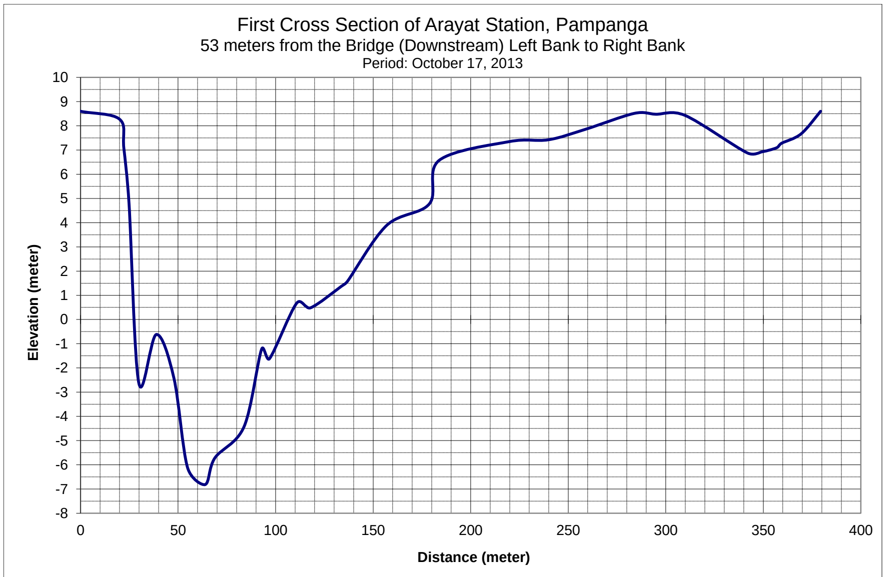
FIRST CROSS-SECTION				
POINT	DISTANCE			ELEVATION
	ACTUAL	CORRECTED	ACCUMULATED CORRECTED	
P1	0	0	0	8.6
P2	20	20.00	20	8.272
P3	2.2	2.20	22.2	7.072
P4	2.66	2.66	24.86	4.782
P5	5	5.00	29.86	-2.618
P6	9	9.00	38.86	-0.618
P7	9	9.00	47.86	-2.418
P8	7	7.00	54.86	-6.118
P9	9	9.00	63.86	-6.818
P10	5	5.00	68.86	-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

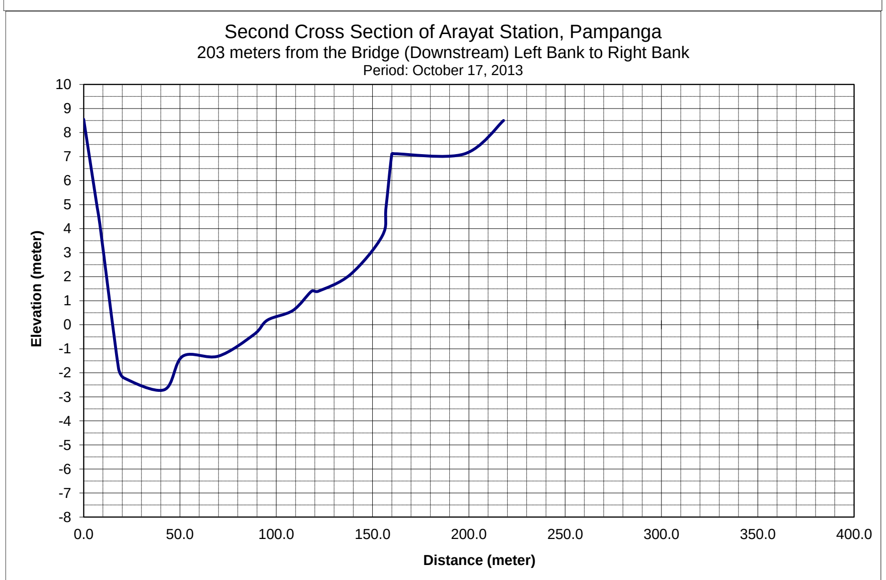
FIRST CROSS-SECTION				
POINT	DISTANCE			ELEVATION
	ACTUAL	CORRECTED	ACCUMULATED CORRECTED	
P28	7.5	7.50	349.36	6.928
P29	7.5	7.50	356.86	7.094
P30	2.5	2.50	359.36	7.279
P31	10	10.00	369.36	7.667
P32	10	10.00	379.36	8.6

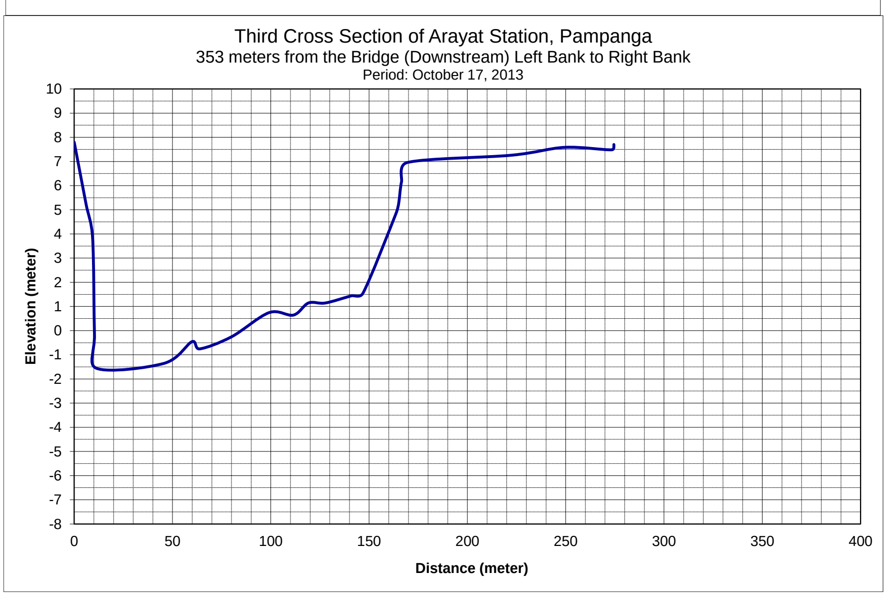
SECOND CROSS-SECTION				
POINT	DISTANCE			ELEVATION
	ACTUAL	CORRECTED	ACCUMULATED CORRECTED	
P1	0	0	0.0	8.552
P2	7.00	7.00	7.0	4.895
P3	1.41	1.41	8.4	4.185
P4	9.67	9.67	18.1	-1.805
P5	2.64	2.64	20.7	-2.205
P6	21.10	21.10	41.8	-2.705
P7	9.67	9.67	51.5	-1.305
P8	18.46	18.46	70.0	-1.305
P9	18.46	18.46	88.4	-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

Shown in the next page are the graphs, illustrating the 3 stream cross section done in the survey running from left bank going to the right bank where values for elevation was referenced to Mean Sea Level (MSL):


First Cross Section of Arayat Station, Pampanga
53 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


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

4.1.2. Issues and difficulties

Listed below are the issues and difficulties in doing a slope-area method:

- **Identification of flood marks and extent** – Flood marks could easily be found, especially the flood event just happened recently, but the problem is locating the flood extent considering that the right bank of the river is relatively flat that results to interviewing the locals to gather the needed information. The flood extent was located but measuring it was quite difficult for it is a resident area, accessibility issues and the area was too muddy to walk through.
- **Tedious and time consuming** – The whole activity was tiresome and time consuming, requiring at least 3 stream cross sections and the equipments was not easy to carry and to transfer from one place to another. Survey the river more than 300 meters, looking for the flood marks and finding a way to make the measurements possible considering a lot of obstructions and the property is not public.
- **Instability of the boat used during the river survey** – Measuring the prism riding on a boat was quite hard for the boat was unstable and the rod man cannot maintain balance for a very long time due to the current. Also maintaining a straight stream cross section was quite impossible considering that there was no tagline used at the time because the tagline available wasn't enough to reach the other bank assuming that the stream cross section was fairly straight.
- **Equipment issues** – In the middle of the survey, problem will arise in the equipment running out if battery that you have to improvise. Also the problem in the accuracy of such device that you will not notice not unless you plot everything in the paper.
- **Terrain** – The flood happened just happened recently so it is expected that the soil is still soft that adds difficulty in accessing the place and doing the measurement. It is also difficult to transfer from one place to another and find a stable footing.

- **General accessibility issues** – The banks are mostly with mud, trees and vegetation that makes it impossible to measure everything in a straight line and another factor that it is a residential area that requires permission to the owner before you could access everything that needs to be measured and located.

4.1.3. Results and Findings

After that the corrections were made in the measurement during the survey, everything was encoded in the Slope Area excel suite that was provided by Mr. Hilton T. Hernando. Below are the results of the survey:

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:

			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

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

Rem:

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

Q_{1-2-3} = 3983.73 cumecs

Discharge

The roughness coefficient (n) used was 0.40 due to the trees, reeds and bushes in both banks when the flood event happened. The estimated discharge during the passage of Typhoon SANTI was 3983..73 cubic meters per second.

Slope-Area Cross-Section Computation

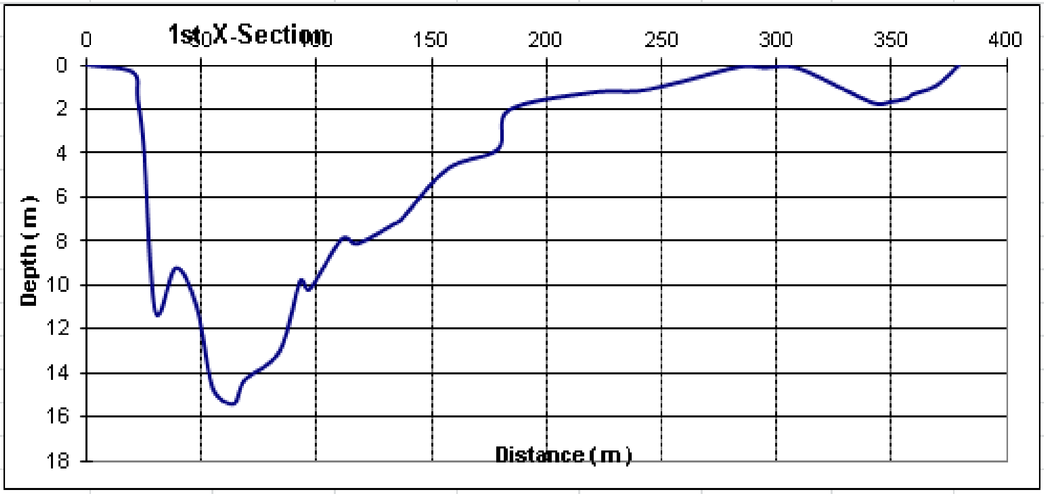
Station:	***Arayat***			Survey Date:		***17-Oct-13***	
River:	***Pampanga***				Gage Ht.=	***5.31***	meters
Cross-Section number ONE (1)							
Station	**Distance**	**Elevation**	**Water Sfc. elev.**	**Depth**	**Mean Depth**	**Area**	**Wetted Perimeter**
0		8.6	8.6	0			
20	20	8.272	8.6	0.328	0.164	3.28	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**				

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**				

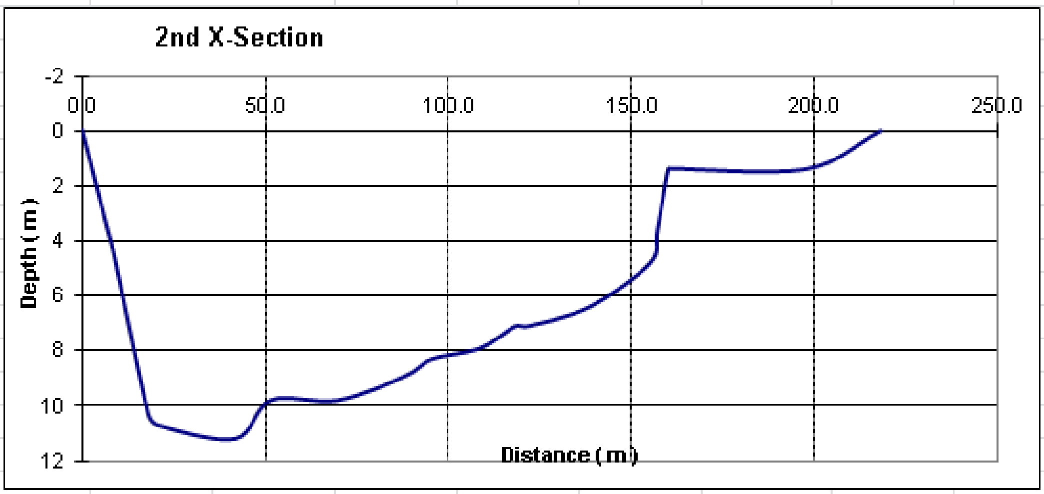
Slope-Area Cross-Section Computation							
Station:	*Arayat*			Survey Date:		*17-Oct-13*	
River:	*Pampanga*				Gage ht.=	*5.31*	meters
Cross-Section number THREE (3)							
Station	**Distance**	**Elevation**	**Water Sfc. elev.**	**Depth**	**Mean Depth**	**Area**	**Wetted Perimeter**
0.0		7.797	7.7	-0.097			
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

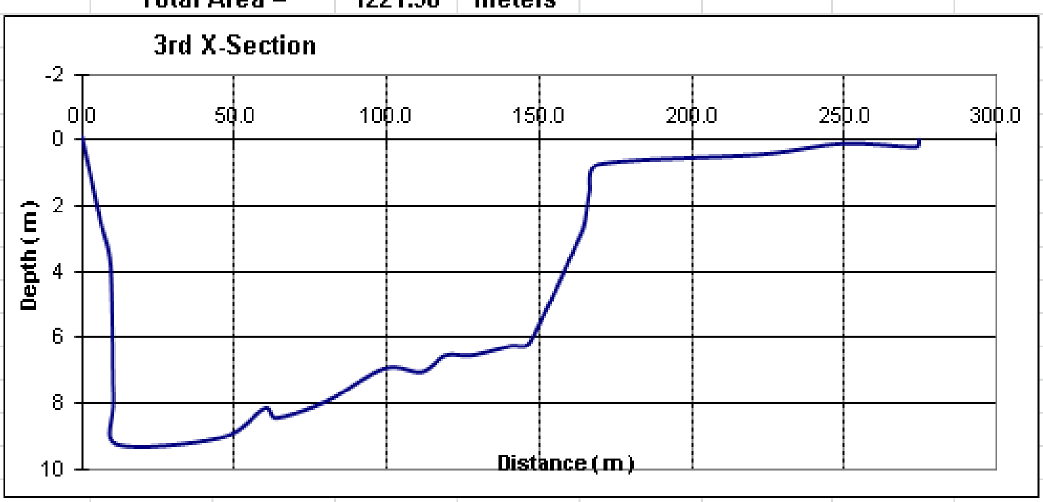
Total Area = 1623.42 meters^2



Total Area = 1355.39 meters^2



Total Area = 1221.98 meters^2



The slope-area gives you an idea of how much the discharge during the flood event but cannot guarantee accuracy due to the following reasons:

- **Technical error**, the range-finder was not accurate, for it assumes everything straight and does not give you an angle measurement and not unless every observation is plotted corrections could not be made.
- Looking at the river with our naked eye, the downstream reach of the river is fairly straight but looking into the data and plotting everything in the paper, the stream cross section was not actually straight for the 3 cross sections it bends and gets narrow in the second cross section.
- **Some tools was not available or insufficient** to help during the survey, like the tag line to maintain a fairly straight traverse in the river as well as the spare prism to be used at the other side of the bank.
- **Due to some accessibility problem**, the measurement was not always done along the cross section established. Adjustment and correction were made to the observed data to make the cross section fairly straight. And although calculations were applied, it would only be an assumption to what was happened in the field.
- **Identifying the flood marks and extents is subjective** and some areas could not be clearly identified due to obstructions and could only rely on to what does the resident remembers.
- **Choosing the roughness coefficient to use is also subjective** that such analysis to the site could be wrong.

But basically slope-area method could give you a picture of what happened during the flood event and a good basis in establishing a critical level that could actually affect the areas with a purpose of early warning for the people to prevent casualty of the floods in the area.

4.2. ADCP (Acoustic Doppler Current Profiler) Method

Due to the advancement of technology, they had developed an Acoustic Doppler Current Profiler that could measure both the water current or velocity and depth of a river in a point using sound waves. The equipment was built to help people measure the discharge with ease and avoiding hard labour in computations.

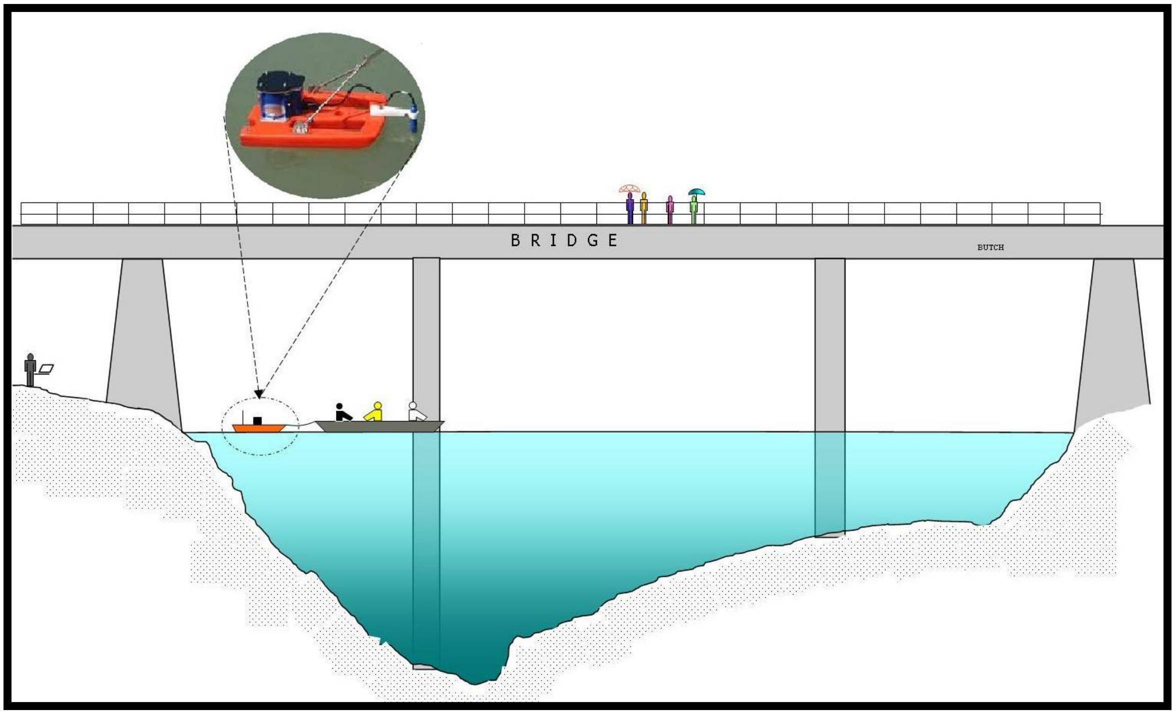


Illustration of the ADCP method done in the survey

4.2.1. Procedure

The measurement was done 50 meters from the bridge in the downstream. To start with ADCP Method, the equipment was assembled by mounting the sensors and transmitter on a meter long, yellow-colored plastic vessel while the software was initialized in the computer where the data will be received. Connect both the computer and the equipment, after the connection has been established, set the unit and time then proceed to SYSTEM PASS, if the system passed, the site information will be stated and the calibration started, holding the equipment you will do the yaw, pitch and roll until the software tells passed calibration. Measurement starts when the calibration is done.

The equipment was mounted to a boat that allows them to traverse from one bank to the other side, it is important that the operator of the computer and the person riding the boat will have a constant communication. The distance from the initial point to the water edge will be measured either in the left or right bank of the river, also the gauge height should be noted in order for the software to start. When all is set and it started to move in a normal speed it will start to measure 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.

When the equipment reaches the other side of the river, you are required to measure the end point to the water edge then end the EDGE input the distance measured and end TRANSECT.

The average transect in every stream cross section is 4 but depending on the results, one can add another transect.

4.2.2. Issues and Difficulties

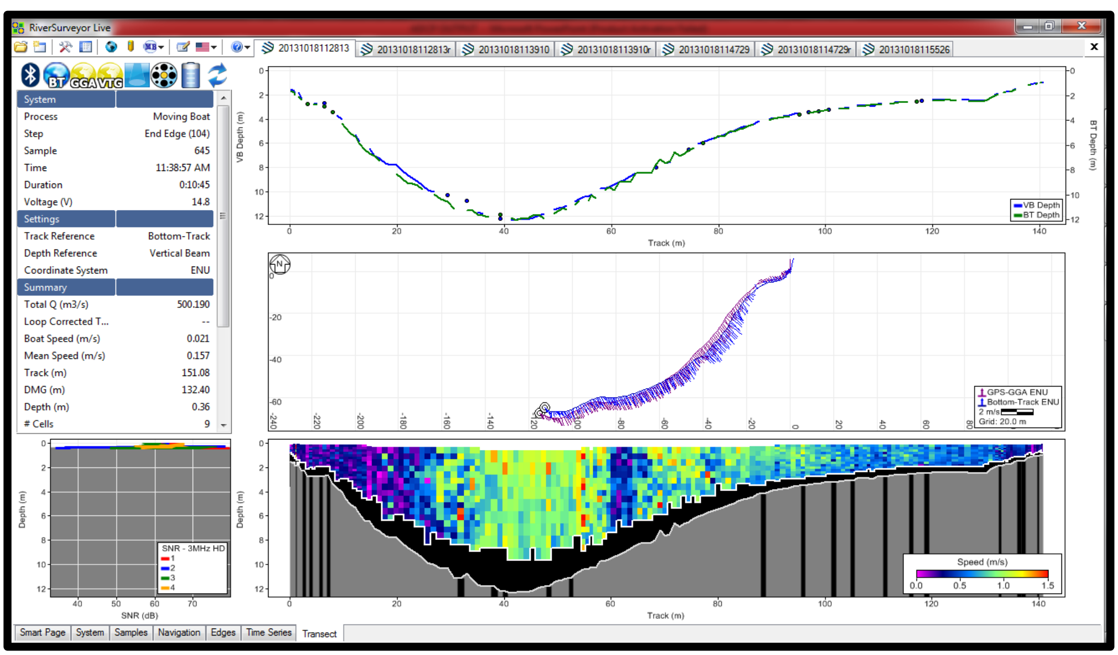
- **ADCP is actually less time consuming** in computing discharge and gives results as soon as possible that you could actually decide if there is a need for another transect

- **Calibrating was not easy task to do** for the equipment was quite heavy and big that is making it impossible for a small guy to actually calibrate it to yaw, pitch an roll that could take some times.
- It could measures a water column up to 1000m long
- Turbulent water, lilies and other water obstruction could actually lead to different calculations
- And unlike to human, the equipment itself cannot adjust to some circumstances that needs immediate response
- Constant communication with the computer operator and the one holding the ADCP is very important and that delayed actions could lead to equipments miscalculations

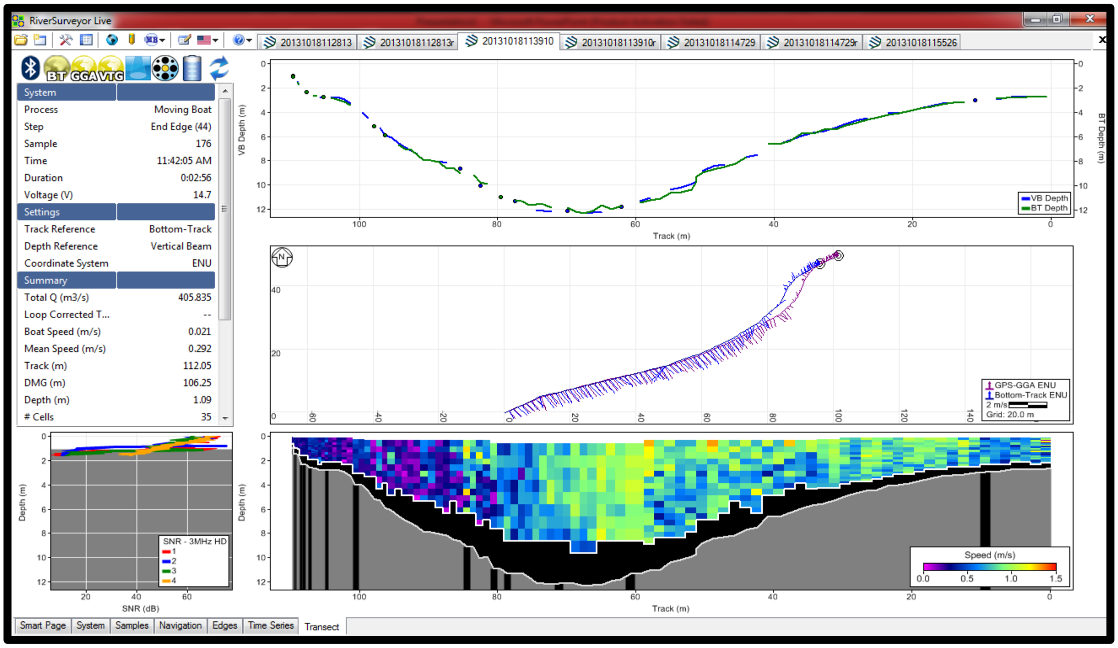
4.2.3. Results and Findings

Below are the results obtained in the survey, having 4 transect a gauge height reading of 4.65 meters.

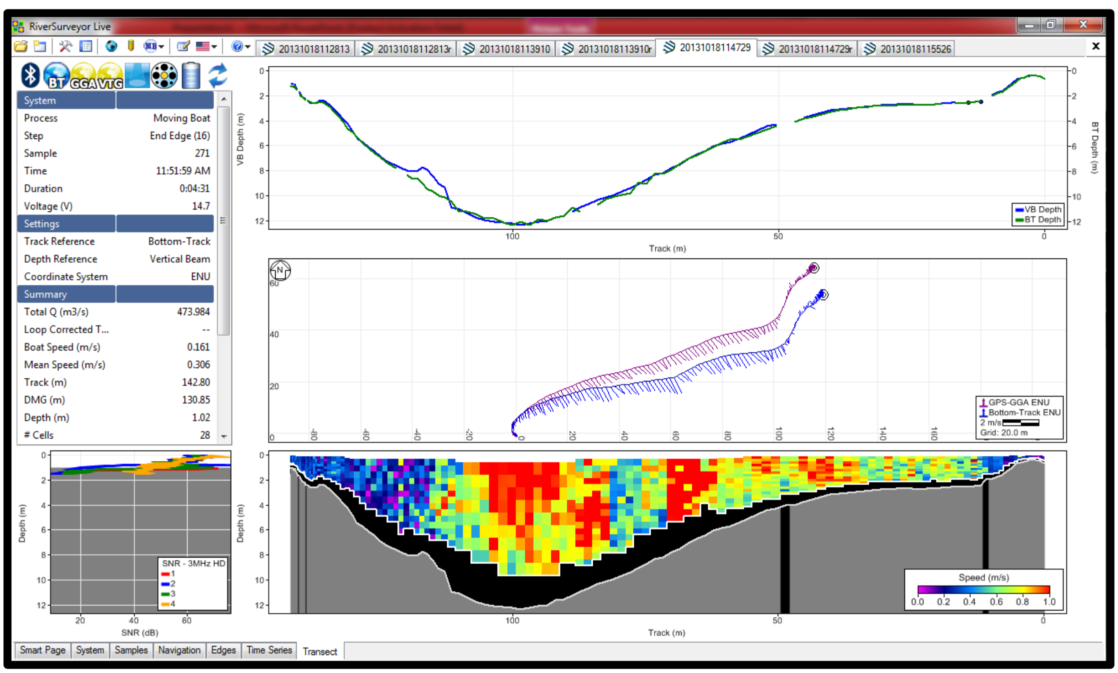
Transect 1 at 11:28 in the morning having a discharge of 500.190 cubic meters per second.



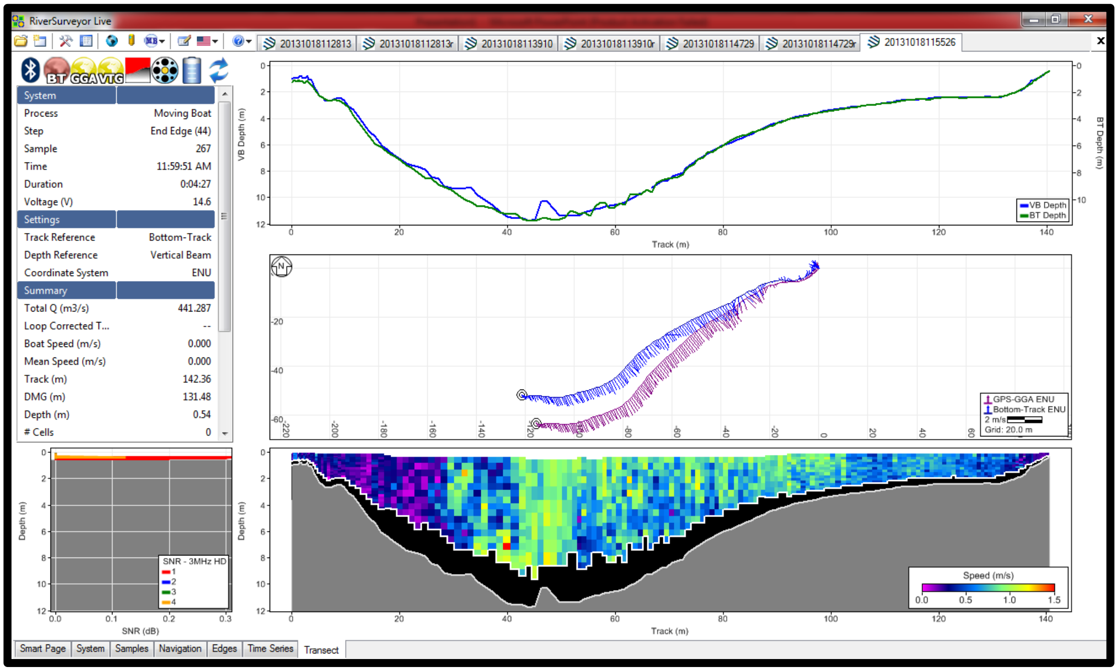
Transect 2 at 11:39 in the morning having a discharge of 405.835 cubic meters per second.



Transect 3 at 11:47 in the morning having a discharge of 473.984 cubic meters per second.



Transect 4 at 11:55 in the morning having a discharge of 441.287 cubic meters per second.



Looking at the data, there is an issue of inaccuracy in the first transect due to invalid bottom tracking that leads to ensemble in estimating the gaps, and miscommunications lead some error in the second transect, the movement of the ADCP should be synchronized with the computer while the third transect had a problem with the obstruction leads to miscalculation of the equipment. So basically, the best result among the four transect was the fourth transect or the final transect. Now, looking at the results the following was observed:

- The blackened areas means that velocity was too slow to measure but this things could be fix by adjusting the frequency “ping” that the ADCP uses, less frequency travels far than using a high frequency but the data that will be gathered is less accurate and setting to a very high frequency can discharge the battery easily.
- The ADCP made some calculations to make the transect in stream cross section fairly straight that spare us from doing manual calculations and corrections in the data.

- The first graph shows the Vertical Beam (VB) and Bottom Tracking (BT) that enables us to actually see if there are missing values or gaps.
- The second graph basically shows us the traverse made by the equipment that was oriented to North.
- The last graph was to graphically show the transect made by the equipment with some corrections were made to missing data and the meander of the equipment.
- The right panel shows the calculated Discharge of the equipment as well as the Velocity of the flow.
- The benefit of the ADCP, it gives velocity and depth in small scale that could lessen the problem with gaps

Basically the equipment is still subject to validation through our conventional current meter method and working with this two values, a more accurate and reliable measurements could be obtained.

4.3. Current Meter Method

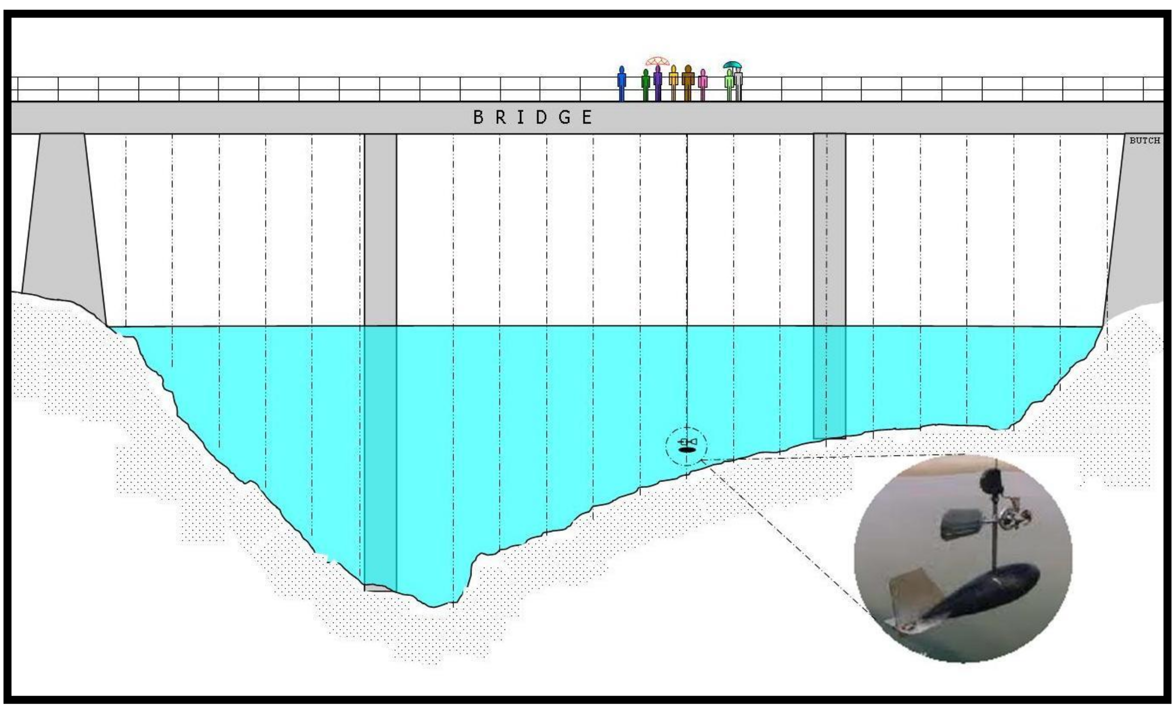


Illustration of the Current Meter method done in the survey

As the name implies, the general purpose of the current meter method was to measure the current of flow in a river cross section in each point, the other variable measures was the vertical depth and out of this variables, the total discharge was computed following the equation:

$$Q = \sum_{i=1}^{n} a_i v_i$$

Where Q = total discharge, in cubic metres per second (m^3/s), a_i = cross-section area, in square metres (m^2), for the ith segment of the n segments into which the cross section is divided, and v_i = the corresponding mean velocity, in metres per second (m/s) of the flow normal to the ith segment, or vertical.

4.3.1. Procedure

The method was performed in the bridge measuring the distance of the Left Bank water edge going to the right bank water edge. Following the requirements that the Discharge of each vertical section should not exceed the 10 percent of the Total Discharge, the stream cross section was sub-divided into 24 segments having a 5 meters interval near the edges while 3 meters interval is it reaches the deeper portions. A large interval was used to make adjustment when pier, lilies or ripples is present.

For every segment, the vertical depth from the water surface to bottom was measured using an echo sounder. The Price AA current meter was setup together with the sounding reel (20 meters long), Columbus for weight and the beeper, the test spin for a current meter was 2 minutes while the beeper is set to 5 revolutions per beep. In determining the vertical depth through the scale of sounding reel, 1 complete revolution equals to 3 meters. A stopwatch was used to measure the revolution in around 60 to 65 seconds.

Base on the vertical depth obtained using the echo sounder, the determination of methods of observation was determined, if the depth exceeds 1 meter, the 2-point method will be used, the reading in 20% and 80% of the depth, while less than a meter of depth the 6 tenth method will be used, reading in 60% of the depth.

To measure the velocity and depth, the current meter was positioned at each segments established earlier, the current meter was then lowered so as to align it from the railing to the road, the current meter then was set to “0”, after which, the current meter was lowered again up to the water surface to measure the vertical distance from the road to the surface of the water. The current meter was set to “0” again and lowered to 20% and 80% of the vertical depth, counting the beeps in every 60 to 65 seconds at each vertical point. The angle is also measured so as to check if the angle of displacement is still acceptable of not, it should only range to 4 to 36, if it exceeds 36, additional weight is a must.

The steps were repeated at each segment so as to measure the revolution per 60 to 65 seconds, angular displacement and the vertical depth.

4.3.2. Issues and Difficulties

Some are the issues and difficulties encountered in the survey:

- **The length of the sounding is limited to 20 meters** that it cannot measures the vertical depth greater than the said limitation.

- **Tedious work and time consuming**, as you need to repeat the steps in every segment of the stream cross section
- **The equipment is prone to obstruction** that might cause error in the counting of beeps
- **The current meter did not pass the spin test** of 2 minutes that will lead to miscalculations
- Working on top of the bridge under the direct heat of the sun could lead to some dizziness and sun burn
- **The equipment was heavy** that makes it difficult to maintain it perpendicular to the bridge.

4.3.3. Results and Findings

The following data shown below were obtained during the survey:

POINT	Water surface to bottom	80 % or 0.80			20 % or 0.20			Gage Ht	Time
		Angle	Beep	Second	Angle	Beep	Second		
0									
5	2.2	10	12	61.57	6	18	62.57	3.16	11:15
10	3.6	12	12	63.94	13	18	60.71	3.16	11:25
15	6	17	5	61.33	12	10	61.48	3.16	11:31
18	7.7	28	16	60.62	18	18	62.17	3.16	11:40
21	7.6	23	17	64.44	29	17	62.05	3.16	11:48
25	PIER								
26.7	PIER								
33	8.4	28	9	65.35	15	16	60.82	3.12	12:02
36	8.7	16	12	61.62	26	16	61.92	3.12	12:10
39	9.3	25	12	62.39	23	17	63.71	3.12	12:16
42	8.8	25	13	61.63	19	16	64.51	3.12	12:24
45	8.1	3	10	65.27	24	16	63.45	3.12	12:30
48	6.6	4	14	64.52	15	15	64.55	3.12	13:08
51	6	5	12	65.6	8	15	61.17	3.12	13:19
54	5.3	14	12	63.98	3	15	64.23	3.12	13:27
57	4.6	23	12	64.26	2	16	63.35	3.12	13:32
60	3.5	4	12	62.32	1	16	63.55	3.12	13:39
65	3.6	3	11	61.06	2	15	61.99	3.12	13:44
70	3.3	2	10	63.29	1	15	62.48	3.12	13:49
75	2.7	3	11	63.57	4	15	64.57	3.12	13:54
80	2.5	2	11	64.65	4	15	65.2	3.11	14:02
85	2.4	2	11	65	4	14	61.5	3.11	14:09
94.8	PIER								
96.5	PIER								
100	2.7	4	6	63.84	4	10	61.87	3.11	14:17
105	1.2	4	4	88.39	3	5	62.54	3.11	14:26
110	0.9	-	-	-	-	-	-	3.11	14:38
115	0.27	-	-	-	-	-	-	3.11	14:42
117.5	-	-	-	-	-	-	-		

The beep was multiplied by 5 to get the revolution per the seconds indicated, after the computation the data was then encoded in the excel suite that Mr. Hilton provided, getting the velocity formula V=0.702N+0.013, below are the results of such computation:

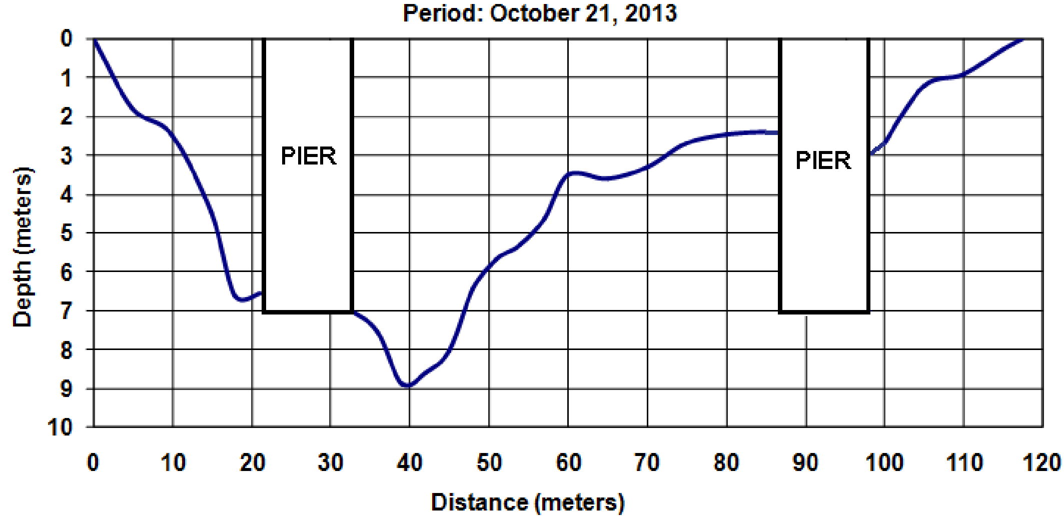
Discharge Measurement (Current Meter) for :		ARAYAT STATION		River:	PAMPANGA RIVER		PRFFC
DM #:	03	Date:	October 21, 2013	Team:	Group 3		FFB
Gage Height: Start:	3.16	End:	3.11	Inst. # :	1	Wx: Fair	PAGASA
Observation Time: Start:	11:15	End:	14:42	Calibration Eqtn.: V =	0.702 N+ 0.013	note: just input 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	

The Discharge measured is 293.42 cubic meters per second with a Mean Gage Height of 3.12 meters. Although this is the conventional method, still the results are reliable, too bad that the current meter failed the spin test of 2 minutes. The output of the current meter works well with ADCP. Plus the benefit of using the conventional current meter method is that, human, can make adjustments when the water is turbulent, the pier is present and lilies. The results from the current meter usually used to validate the outputs of ADCP.

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	

Cross Section of Pampanga River at Arayat Station, Pampanga
along the Bridge (Downstream) Left Bank to Right Bank
Period: October 21, 2013



4.4. Float Method

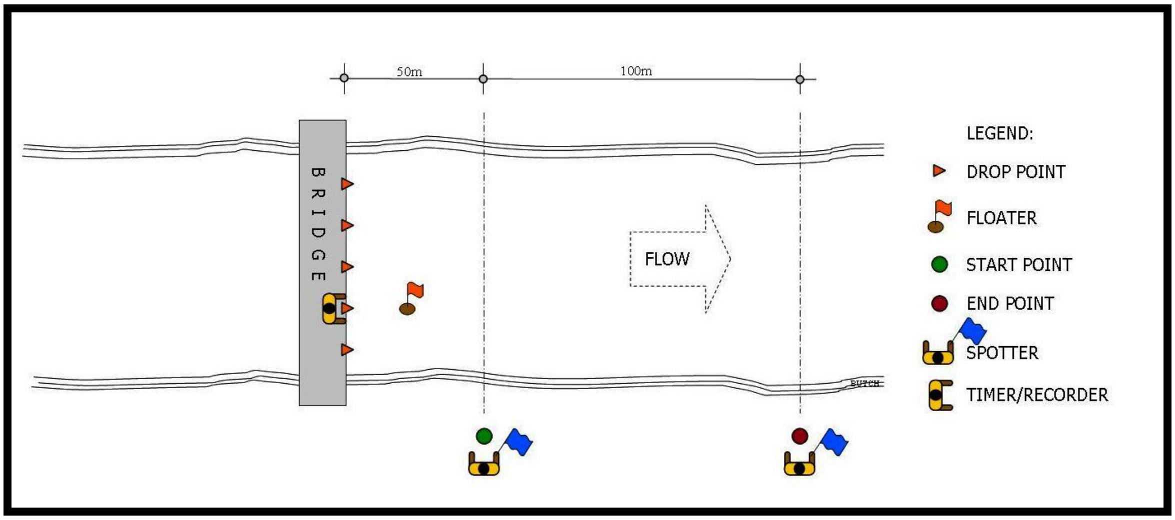


Illustration of the Current Meter method done in the survey

The simplest and cheapest way of measuring the Discharge by actually using floats. The floats were thrown in the river and measure their travelling time in a certain section of the river.

4.4.1. Procedure

The stream cross section was sub-divided into five points having a large interval near the edges and small gaps as it gets deeper. With the 10 floats available, 2 was to use in each point. The floats must be thrown at the top of the bridge facing downstream. Minimum person for this method is 3, the first man will be the one to throw the float in the river, the other 2 will be standing in either left or right bank to signal when the float passes in their stream cross section. The first cross section should to at least 30 meters away from the bridge to allow the float to rise and become stable. From the first cross section a distance of 50 to 100 meters was established going to the second cross section, too long section causes error in measurement due to variation of stage for long travelling time. It is important that the 3 persons will have a constant communication with each other. During the survey a bamboo float was used around 1 foot, filled with sand up to its 75 % with a flag marker that can easily be seen even from afar. When the measurement started, the three persons will then timed the travel time of the float as the results were obtained three values should be average taking a consideration that a value does not differ too much from the other or it will be an error.

After the velocity was measured, the next step was to measure the Discharge of each section, taking into consideration that the gage height changes through time. The same procedure was in the slope-area, only here, it does not include the flood extent but only the measurement from left water edge to right water edge. *(See 4.1.1. for the procedure)*

4.4.2. Issues and Difficulties

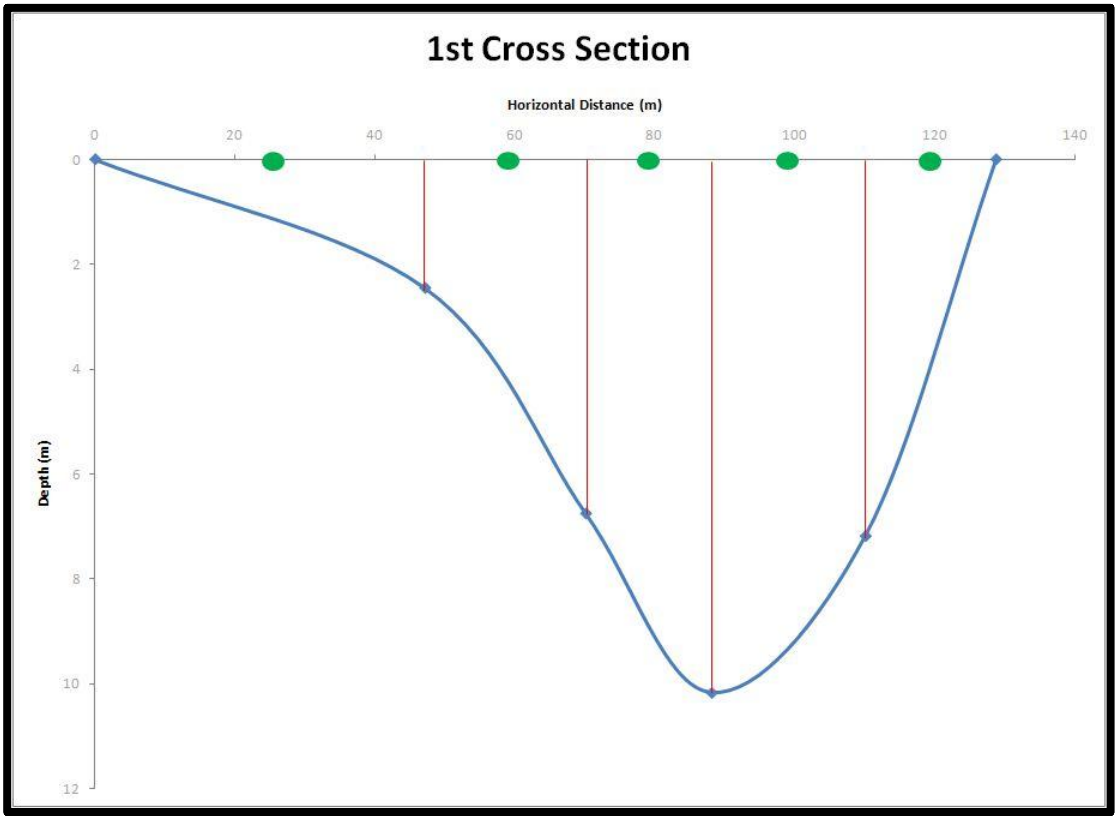
The following are the issues and difficulties found during the survey:

- **Miscommunication**, it will lead to different start time, stop time and duration
- **Presence of debris and lilies**, that actually stops the float from flowing
- **The flow is relatively low,** that it takes time before the float could actually move especially near the edges
- **Strong winds,** the wind was too strong that it actually drags the float that slows it down and goes to other segment.
- **Problem with the float,** the float was either too heavy or the flag was removed that the float fails.

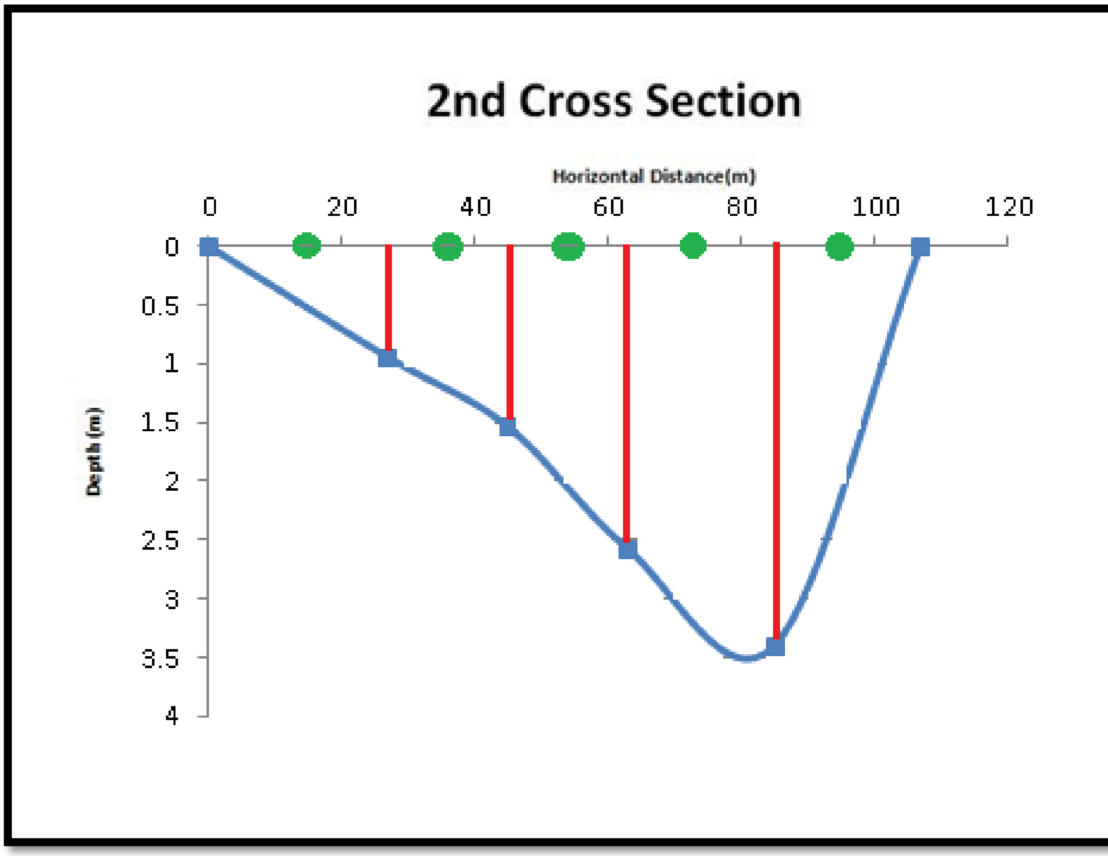
4.4.3. Results and Findings

The following are the results obtained in the survey:

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



As the areas at each vertical cross section were obtained, the discharge can then be calculated while the velocity can be calculated to the distance traversed divided by the time elapsed. The correction coefficient of 0.92 was then applied to arrive at the average velocity. Below are the computations obtained using the excel suite that Mr. Hilton provided:

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 was 240.62 cubic meters per second at 2.78 gage height.

Using the float method at a relatively low flow could lead to the outcomes inaccuracy, for a lot of difficulties arises *(see 4.4.2).* Additional factor was, too long section causes error in measurement due to variation of stage for long travelling time.

The most inexpensive and simplest way of measuring discharge, and could be done during high flow or flood events but the cross section could be done after the flood event is finish.

4.5. Direct Method using Manning's Equation

As one of the objectives in Discharge measurement was to establish a rating curve, equations and tables that could actually shows discharge at various elevations.

4.5.1. Procedure

Using the data obtained by the group of Mr. Benison, the summary of data was below:

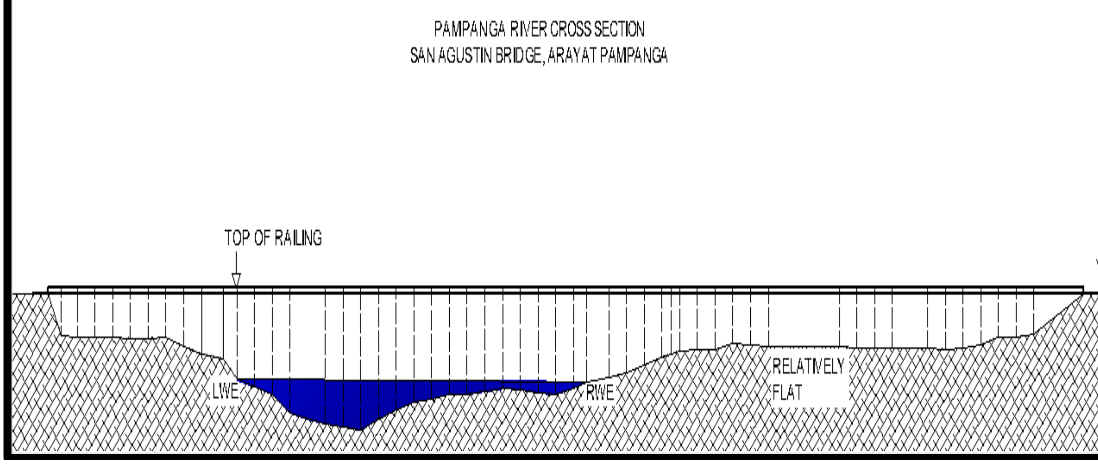
PAMPANGA RIVER BED PROFILING

Arayat, Pampanga

Start Time:	1342 HH	**Bridge Measurements:**	
End Time	1405 HH	**Heigth of Railing to Curb:**	0.75 m
Date:	Oct. 23, 2013	**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	Station Interval	Depth (m)	Accumulated Horizontal Length (m)	Remarks
0	0.91	0	top of dike	6.2	14.18	158.34	
3.8	7.6	3.8	Foot of dike	5	13.36	163.34	
4.54	7.8	8.34		5	12.22	168.34	
5	7.8	13.34		5	10.95	173.34	
5	7.97	18.34		2.5	10.41	175.84	
5	7.97	23.34		2.5	9.93	178.34	
5	7.89	28.34		5	9.91	183.34	
5	9.26	33.34		5	9.91	188.34	
5	10.4	38.34		5	8.87	193.34	
5	11.17	43.34		5	9.16	198.34	
6.2	14.55	49.54	Left Water Edge	5	9.33	203.34	
3.8	15.57	53.34		5	9.33	208.34	
5	16.86	58.34		5	9.33	213.34	
5	19.88	63.34		5	9.33	218.34	
5	21.63	68.34		5	9.33	223.34	
10	21.57	78.34	Edge of Pier	5	9.59	228.34	
5	21.94	83.34		5	9.56	233.34	
5	22.48	88.34		5	9.56	238.34	
5	20.7	93.34		10	9.46	248.34	
5	19.39	98.34		5	9.71	253.34	
5	18	103.34		5	9.63	258.34	
5	17.63	108.34		5	9.05	263.34	
5	16.99	113.34		5	7.9	268.34	
5	16.79	118.34		5	7.77	273.34	
5	16.39	123.34		5	7.4	278.34	Foot of dike
5	15.97	128.34		14	0.91	292.34	top of dike
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				



The data was obtained through sounding rope measured from the railing of the bridge up to the bottom of the river. From the measurement of the Ms. Vivian's group, the bridge curb was measured 15.562 meters above mean sea level (AMSL), adding the height of the railing to the curb measured 0.75 meters, the height of the railing would be 16.312 meters AMSL. Getting the difference of the height of railing to the depth obtained by the group of Benison, the elevation AMSL would be calculated.

The computed values were now encoded to the excel suite that Mr. Hilton provided, see results below:

				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 elevation profile of the whole cross-section enclosed with the water surface equivalent to the maximum elevation it will calculate the width, total area, wetted perimeter, and hydraulic radius when the water reaches the bridge railing was then computed and copied to another excel suite. The process was then repeated for every 1 whole number interval in the elevation, the summary is shown 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)

After the process was made, the gage height and discharge values above are paste in another excel file to obtain the rating equation, below shows the process:

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		

On the rat worksheet, the value for H_o (elevation of zero flow) should be determined using a trial and error as shown below:

Summary test for Ho						
Ho	a	b	ΣX^2			
-7.50	0.26	3.239	159.0038	Minimum	ΣX^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			

As seen above the H_o, with the lowest value of chi square was -7.39 meter and was encoded in the previous sheet to obtain the rating equation as shown below:

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 = $10^{a\text{^}}$ =	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		

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 equation obtained in assumed H_o of -7.39 meter is:

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

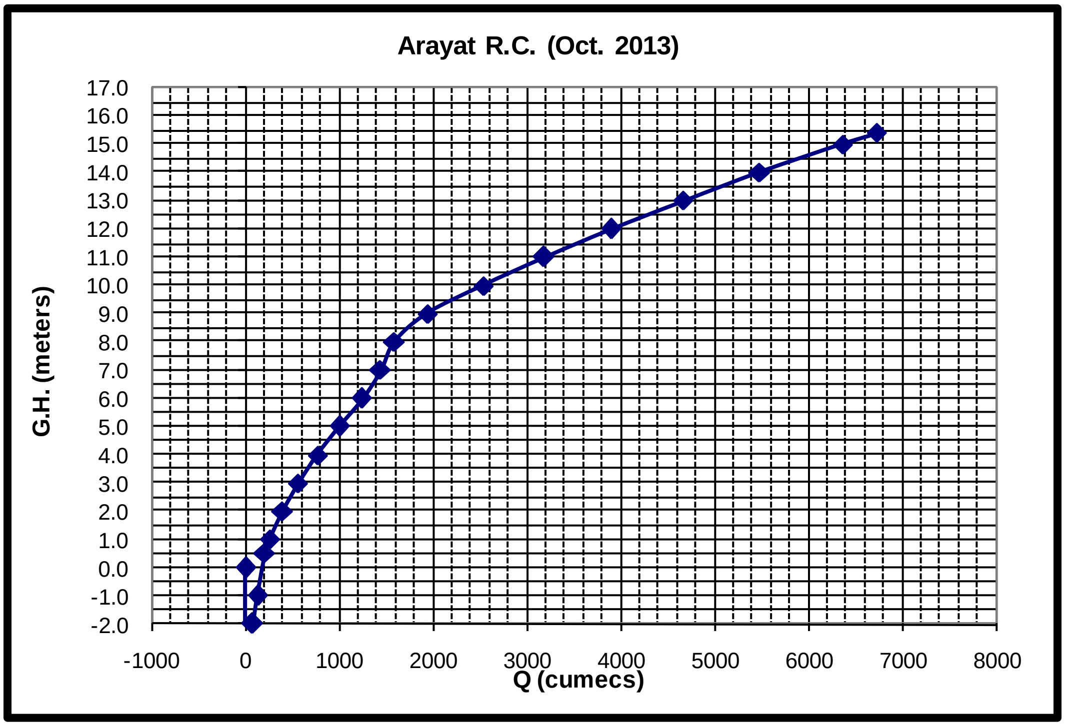
To obtained the rating table the values in the rating equation is encoded into another excel suite, as shown below, the a, H_o and b^ is encoded to arrive at the rating table:

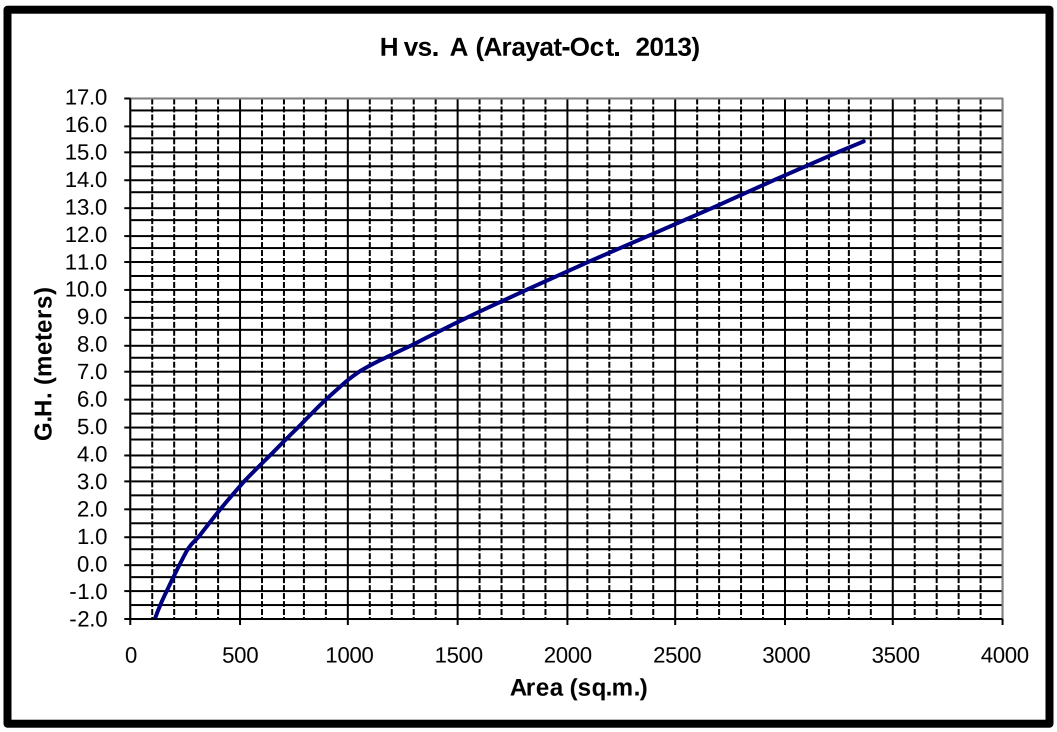
Rating Table for:				*Arayat*			Date:	*October 23, 2013*		
River:	*Pampanga*			Location:	*San Agustin, Arayat, Pampanga*					
Elevation of S.G. "0" reading:			*0*							
Rating Curve Equation Coefficients: a =				***0.306***	**Ho=**	***-7.390***	**b^=**	***3.190***		
Range of G.H.:		Min. G.H. =		***0***	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

4.5.2. Issues and Difficulties

- Everything in the process varies with the roughness coefficient, a .001 change in value will have 3% change in the Discharge.
- The process relies on the field observation that any mistake in the field will affect the whole output
- Most of the variables were subjective that could lead to the output's accuracy
- The data obtained was based on ideal condition that affects its reliability

4.5.3. Results and Findings



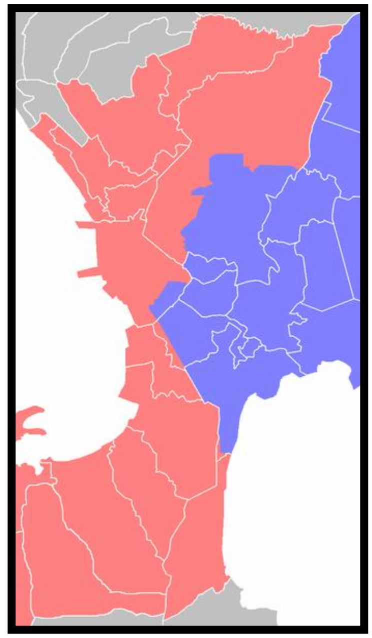


The some of the results were shown in the ***section 4.5.1*** when the procedure was drawn. Shown above, as the Gage Height increases the area increases as well as the Discharge.

The rating table obtained in the process was actually very helpful to the Hydrologist, that for a given level, the measurement of Discharge was actually computed. But the difficulty was every now and then the rating curve, equation and table should be updated for any changes occur in the area. This will help the Hydrologist establishing the critical level of the area that could mean an advance warning to the people.

5. Site visited

5.1. La Mesa Dam



La Mesa Dam is located at Quezon City and part of the Angat-Ipo-La Mesa water system which supplies most of the water supply of Metro Manila. La Mesa is an earth dam whose reservoir can hold up to 50.5 million cubic meters occupying an area of 27 square kilometres.

Metropolitan Waterworks and Sewerage System (MWSS), the government agency in charge of water supply divided Manila and its surrounding areas into two private concessionaires: (Red) The 60 percent of the water collected in the reservoir is treated on-site by Maynilad Water Services supplying most part of Metro Manila while (Blue) the 40 percent goes to Balara Treament Plant further south by the Manila Water supplying the eastern side of Metro Manila

La Mesa Dam was built in 1929 with an impounding purpose and has no spill gates and only overflow of water occurs. The critical water level of La Mesa Dam is needed to forecast the flooding would likely to occur in the area downstream mostly part of Metro Manila. As the water overflows, they could estimate the discharge and warn people of the possible outcome.

5.2. Pantabangan Dam

Pantabangan Dam is an earth-fill embankment dam on the Pampanga River built in 1971 and is constructed at Pantabangan, Nueva Ecija. It is a multi-purpose dam which provides water for irrigation and hydroelectric power generation while its reservoir, Pantabangan Lake, affords flood control. Its reservoir is considered as one of the largest in the Southeast Asia and one of the cleanest in the Philippines.

Due to its flood control capability, it can control the spilling water that allows them to prepare for an incoming volume of water. With the help of PAGASA and other agencies, they established early warning system that enables them to warn people in the area when the critical water level is reach.

(Left) spillway gates and (Right) Water Reservoir of Pantabangan Dam

5.3. Cong “kuya” Dadong Dam

Dam named after former President Diodado Macapagal and was located at Arayat, Pampanga. The main purpose of the dam was to supply water for Irrigation of the following munipicipality of Pampanga: Apalit, Arayat, Candaba, Mexico, San Luis, San Simon and Sta. Ana.

(Left) Cong Dadong Dam and (Right) its spillway gates

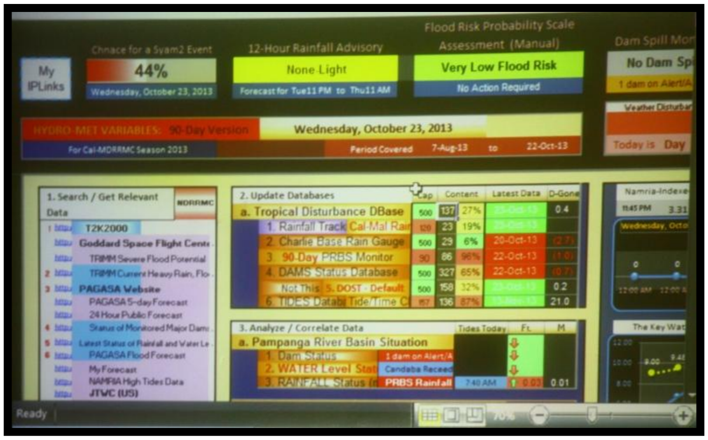
The Dam enables them to divert the flow of water to intended receiver and can block the water during high flow of Pampanga River but at a certain level only.

5.4. MDRRMC of Calumpit, Bulacan

Above is the front of Municipal Hall of Calumpit, Bulacan

Municipal Disaster Risk Reduction Management Council (MDRRMC) was formed

due to the continuous flood problem in Bulacan especially in Calumpit, they designed an excel form that will show them if their area is on its critical level or approaching the critical level, which enables them to have an early warning to the people in their vicinity.

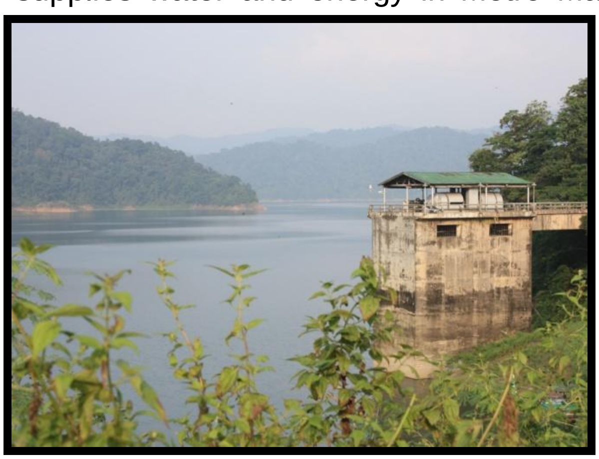


They use color to represent the level of water and its corresponding meaning. They also conduct seminar of flood awareness to their people and assigned a response team if ever emergency will happen.

PAGASA helps MDRRMC in making everything possible, the data from PAGASA is very important and MDRRMC helps PAGASA in warning the people.

5.5. Angat Dam

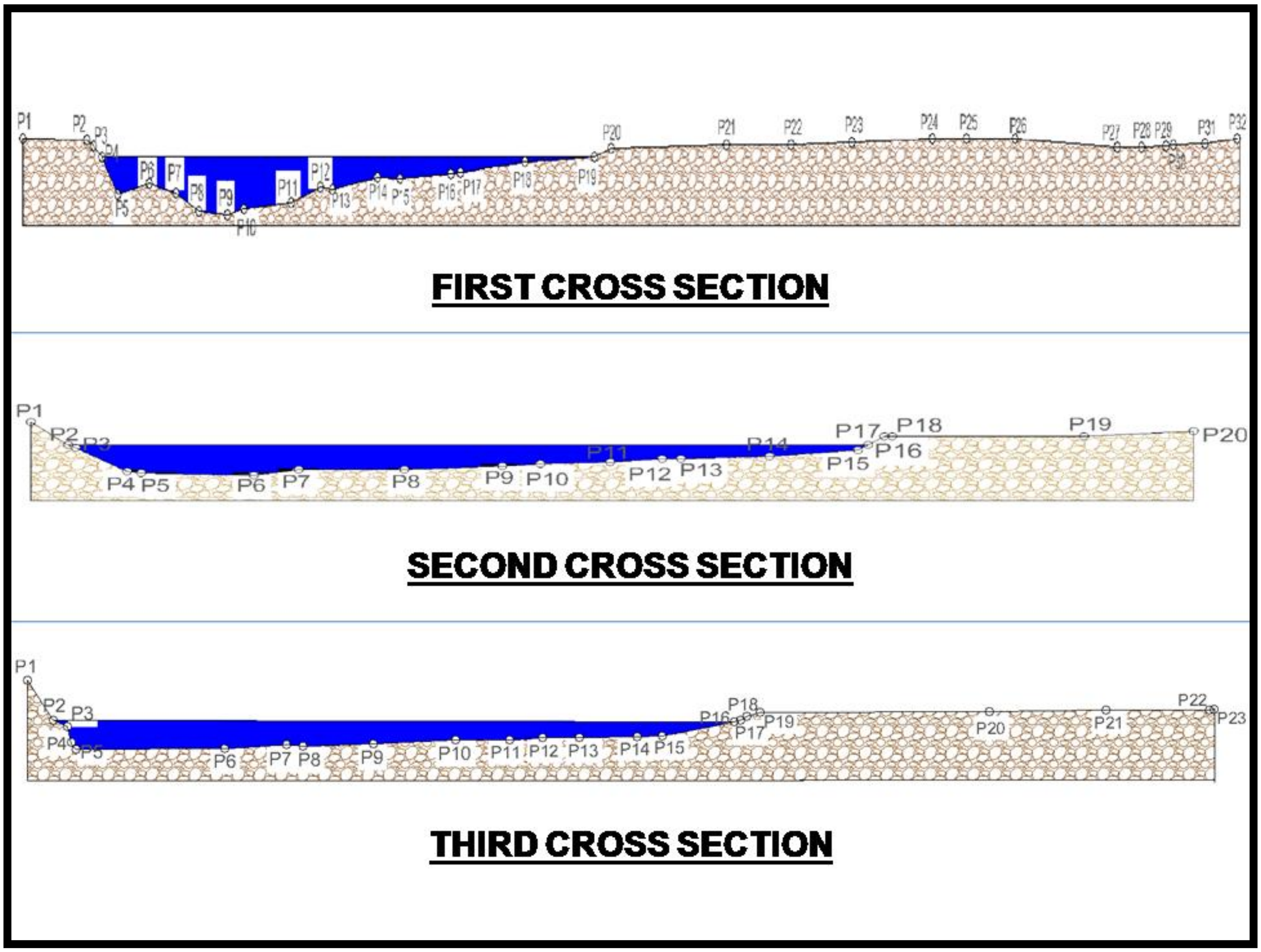
Angat Dam a concrete water reservoir embankment hydroelectric dam that supplies water and energy in Metro Manila and its nearby areas. The dam is

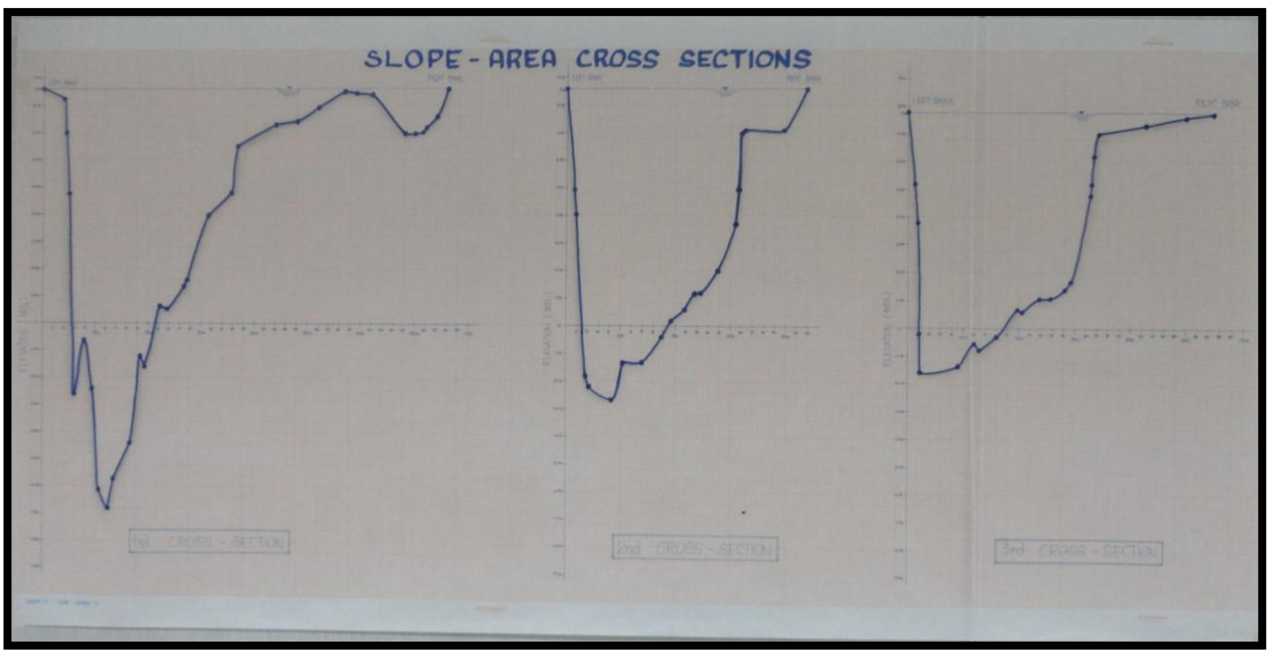


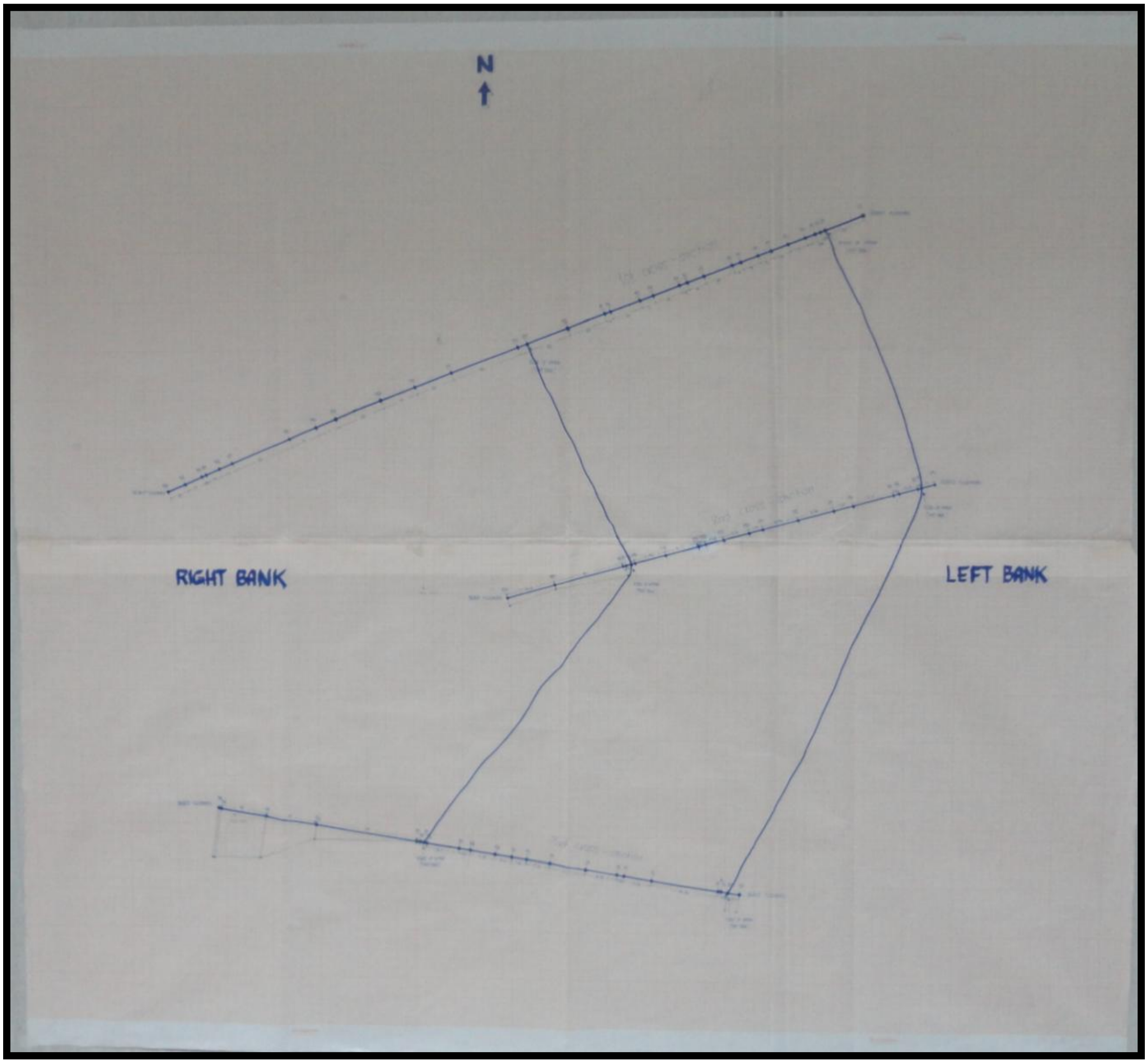
located at Barangay Tibagan, Bustos, Bulacan and was part of Angat-Ipo-La Mesa Water System.

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.

6. Appendices



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