TECHNICAL REPORT

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Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)

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Individual Technical Report

Introduction

Streamflow, or discharge, is defined as the volumetric rate of flow of water in an open channel, including any sediment or other solids that may be dissolved or mixed with it. Streamflow is usually expressed in dimensions of cubic metres per second (m^3/s). Streamflow cannot be measured directly, but must be computed from variables that can be measured directly, such as stream width, stream depth and flow velocity.

Anticipating floods before they occur allows for precautions to be taken and people to be warned so that they can be prepared in advance for flooding conditions. In order to make the most accurate flood forecasts, it is best to have a long time-series of historical data that relates stream flows to measure past rainfall events. It is also useful to know the volumetric capacity in catchment areas and ground-water levels.

As Hydrologist we should learn how to apply the principles learned inside the four corner of the training room. Application of these theories is through field activities. Hydrologist's Training Course (HTC) trainees experience of how to measure this data at Arayat Station in Pampanga River.

Main Objectives:

In this activity Discharge data is collected to evaluate discharge at Arayat Station in Pampanga River through the following methods;

- ✓ Current Meter
- ✓ By Float
- ✓ Slope-Area
- ✓ Acoustic Doppler Current Profiler

Site Description

Figure 1. **Pampanga River at Arayat Station**

The site being studied throughout the fieldwork is at the Arayat Station Pampanga River. Pampanga River (formerly known as Rio Grande de Pampanga) is the second largest river in the island of Luzon most important river in the Philippines. It is located in the Central Luzon region and traverses the provinces of Pampanga, Bulacan, and Nueva Ecija. It is in fact a wide-ranging river, a mud-covered and bushes occupied the banks shown in Fig.1.

METHODS IN DISCHARGE MEASUREMENT

1. **Current Meter**

A current meter is a precision instrument calibrated to measure the velocity of flowing water. The most common current meter used is the Price AA current meter which is also been used during the fieldwork. The Price AA current meter has a wheel of six metal cups that revolve around a vertical axis. An electronic signal is transmitted by the meter on each revolution allowing the revolutions to be counted and timed. Because the rate at which the cups revolve is directly related to the velocity of the water, the timed revolutions are used to determine the water velocity.

Measuring Discharge through the Current meter method is a dangerous job since you are in the bridge and automobiles are passing through every now and then. You should have an adequate amount of length of sounding reel for you to be able to measure the depth of the river. Making this method easier you should have to pay attention on what you are doing.

Figure 2. **Actual Setup of the Price AA Current Meter**

2. Float Method

Floats have limited use in stream gaging, but they can be used where the velocity is too low to obtain reliable measurements with the current meter, or where flood measurements are needed and the measuring structure has been destroyed or it is impossible to use a meter. Surface floats may be almost anything that floats, this activity uses Bamboo.

Two cross sections are selected along a reach of straight channel for a float measurement. The cross sections should be far enough apart so that the time the float takes to pass from one cross section to the other can be measured accurately.

Float measurements may sometimes be made through a reach extending from the upstream to the downstream side of a bridge. This kind of reach may be useful where velocity is very slow and velocity observations by current meter are not reliable.

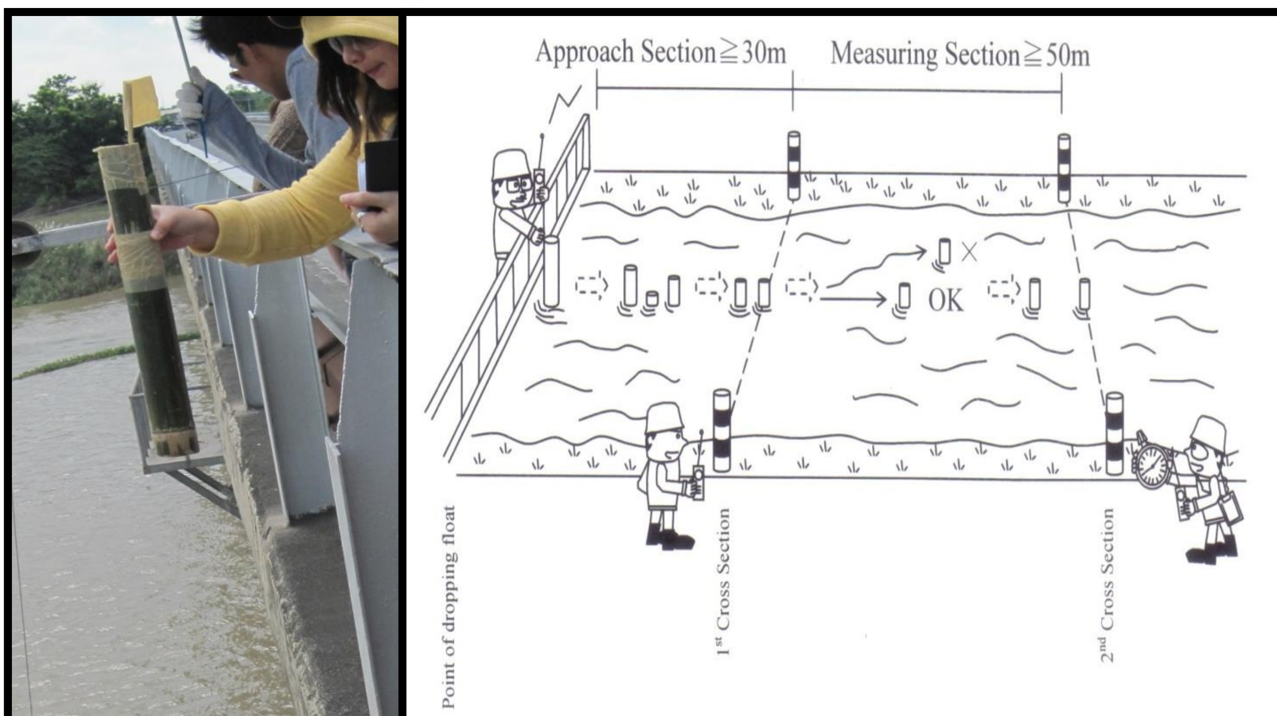


Figure 3. **Illustration for Float Method**

3. Slope-Area Method

Slope-Area Method is the most tedious and a time consuming among all the methods. In the slope-area method, discharge is computed on the basis of a uniform-flow equation involving channel characteristics, water-surface profiles and a roughness or retardation coefficient. The drop in water-surface profile for a uniform reach of channel represents energy losses caused by bed and bank roughness.

Figure 4. **Actual Setup During of the Slope-Area Method**

4. Acoustic Doppler Current Profiler (ADCP)

The ADCP measures velocity magnitude and direction using the Doppler shift of acoustic energy reflected by material suspended in the water column, providing essentially a complete vertical profile of velocity. An ADCP uses the principles of the Doppler Effect to measure the velocity of water. The ADCP uses 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. Using the depth and width measurements for calculating the area and the velocity measurements, the discharge is computed by the ADCP using discharge = area � velocity, similar to the conventional current-meter method.

Acoustic Doppler Current Profiler (ADCP) is the easiest way of determining the discharge of the river. Setup the instrument, calibrate it and its ready to use. It is also the fastest and efficient way of giving you the results.

Figure 5. **Actual Setup of the Acoustic Doppler Current Profiler (ADCP)**

RESULTS AND DISCUSSION

A. Current Meter Method

The acquired data for current meter method includes the discharge (Q) table and a graph of depth versus distance that represents the river cross-section below San Agustin Bridge.

Discharge Measurement (Current Meter) for :					Arayat Station						River:	Pampanga			PRFFC
DM #:		Date:		October 17,2013			Team:					Group 1			FFB
Gage Height:		Start:	5.40	End:	5.28	Inst. # :					Wx:	fair			PAGASA
Observation Time:		Start:	1:35	End:	4:25	Calibration Eqtn.: V =		0.732	N+	0.013	note: just input negative value				hth/97
		Vertical dist. to water surface (m) =				10.50					for latter if eqtn. is minus.				
Total Area (m^2) =			873.66		Ave. Gage Height =			5.34			Sectional Width (m) =				115.0
Total Q (m^3/s) =			311.48		Ave. Vel. (m/s) =			0.357							
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	3.05	0	range out			80	61.2			0.970	x	x	x	
10	5	5.35		5.350	95	63	85	60	85	61	1.050	1.062	26.75	28.42	
15	5	5.08		5.080	95	61	95	60	100	61	1.172	1.178	25.40	29.91	
20	5	8.31		8.310	110	61	35	65	35	69	0.407	0.633	41.55	26.30	
25	7.5	21.63		21.630							x	x	162.23	x	
35	7.5	21.57		11.170							x	x	83.78	x	
40	5	21.94		14.550							x	x	72.75	x	
45	5	22.48		22.480							x	x	112.40	x	
50	5	9.15	17	8.526	75	60	70	61	65	60	0.853	0.860	42.63	36.66	
55	5	8.02	8	7.891	90	62	85	62	75	63	1.017	0.998	39.46	39.39	
60	5	5.8		5.800	90	61	80	60	75	62	0.989	0.992	29.00	28.78	
65	5	5.77	5	5.724	95	62	85	65	70	62	0.970	0.979	28.62	28.01	
70	5	5.7		5.700	95	63	85	63	70	62	1.001	0.989	28.50	28.20	
75	5	5.28		5.280	85	61	80	61	70	62	0.973	0.955	26.40	25.20	
80	5	4.95		4.950							x	x	24.75	x	
85	5	5.1		5.100							x	x	25.50	x	
90	5	4.9		4.900							x	x	24.50	x	
95	5	4.65		4.650							x	x	23.25	x	
100	5	4.57		4.570	80	60	70	62	70	62	0.839	0.877	22.85	20.04	
105	5	3.39		3.390	60	60	60	60	60	63	0.745	0.736	16.95	12.48	
110	5	3.28		3.280	40	68			45	62	x	0.494	16.40	8.10	

***Table 1*. Discharge (Q) Table using Current Meter Method**

Table 1 above made use of Microsoft Excel Suite that obtains an equivalent total discharge simply by completing all the following beige cells:

- Name of station and name of river
- Gage height at the beginning and end of the activity
- Calibration equation (general formula)
- Vertical distance to water surface in meters
- Distances from the initial point in meters
- Depths of each distance in meters
- Vertical angles ranging only from 4 to 36 degrees (otherwise, leave it blank)
- The number of revolutions within not less than 60 seconds, depending on the depth points used. For shallow points, only the 0.6 depth was filled. For deeper points, all the observation depths 0.2, 0.6, and 0.8 were filled up.
- Remarks or rating of the observation (optional)

Observe from Table 1 that not all sections have a recorded observation depth. This may be due to piers, water lilies, and turbulent flows that hindered in getting an accurate number of revolutions at a certain time. Next, filling up the beige cells will reveal the following data in white cells:

- Width of each subsection in meters
- A corrected vertical angle
- Computed velocity at one-point depths and mean velocity for three-point depths
- Area of each subsection in square meters
- Discharge of each subsection in cubic meters per second or cumecs
- Total area of the cross-section or simply the sum of all the subsections
- Total discharge of the cross-section or the sum of all the discharges
- Average of the computed and mean velocities

The recorded discharge from the Acoustic Doppler Current Profiler (ADCP) that day was around 250 to 280 cumecs. Arriving at 311.48-cumec discharge, which is way larger compared to the expected value, may be due to insufficient data along the piers and other obstructions below a subsection.

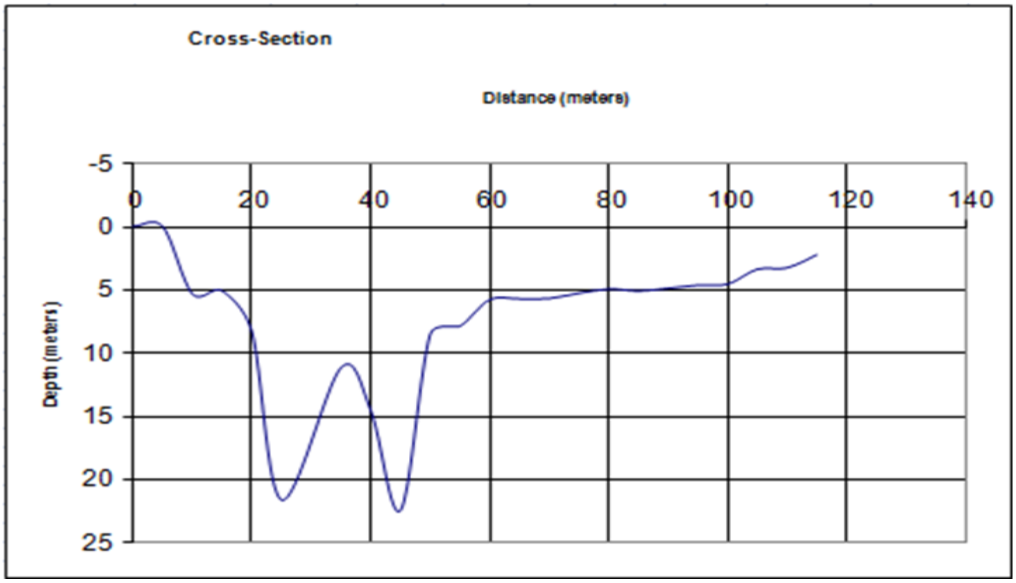


Figure 6. **Pampanga River Cross-section Derived from Distance-Depth Relation**

Figure 6 reveals the cross-section of Pampanga River below San Agustin Bridge using the distance and depth acquired from the Q table. The curve shows how the cross-section has its deepest points near the left water edge and shallower on the right half of the river.

B. Float Method

The acquired data for float method includes two manually computed tables for the physical parameters of each cross-section, their cross-sections based on distance versus elevation, and the equivalent discharge table for the two transects.

station	distance	elevation	water sfc.	depth	mean depth	area	wetted perimeter
0.00		4.73	4.73	0.00			
24.00	24.00	2.33	4.73	2.40	1.20	28.80	24.12
39.00	15.00	1.93	4.73	2.80	2.60	39.00	15.01
40.00	1.00	1.73	4.73	3.00	2.90	2.90	1.02
58.00	18.00	-0.07	4.73	4.80	3.90	70.20	18.09
79.00	21.00	-4.97	4.73	9.70	7.25	152.25	21.56
91.00	12.00	-5.57	4.73	10.30	10.00	120.00	12.01
105.00	14.00	-6.47	4.73	11.20	10.75	150.50	14.03
110.00	5.00	-6.67	4.73	11.40	11.30	56.50	5.00
128.00	18.00	-5.07	4.73	9.80	10.60	190.78	18.07
142.00	14.00	-3.47	4.73	8.20	9.00	125.97	14.09
146.00	4.00	2.43	4.73	2.30	5.25	20.99	7.13
149.00	3.00	4.73	4.73	0	4.73	x	x
Total Width	**149**						
Total Area	**957.896**						
W. P (P)	**150.1368**						
Hydraulic Radius ®	**6.380154**						
Mean sect. Depth	**6.428832**						

***Table 2a*. Physical Parameters for the First Cross-section using Float Method**

***Figure 2a.* Equivalent First Cross-section using Distance and Elevation**

station	distance	elevation	water sfc.	depth	mean depth	area	wetted perimeter
0.00		4.73	4.73	0.00			
25.00	25.00	2.73	4.73	2.00	1.00	25.00	25.08
43.00	18.00	1.83	4.73	2.90	2.45	44.10	18.02
47.00	4.00	1.83	4.73	2.90	2.90	11.60	4.00
55.00	8.00	0.63	4.73	4.10	3.50	28.00	8.09
65.00	10.00	0.23	4.73	4.50	4.30	43.00	10.01
78.00	13.00	-0.57	4.73	5.30	4.90	63.70	13.02
84.00	6.00	-0.77	4.73	5.50	5.40	32.40	6.00
100.00	16.00	-1.37	4.73	6.10	5.80	92.80	16.01
105.00	5.00	-1.57	4.73	6.30	6.20	31.00	5.00
118.00	13.00	-2.07	4.73	6.80	6.55	85.12	13.01
126.00	8.00	-1.87	4.73	6.60	6.70	53.58	8.00
138.00	12.00	-1.57	4.73	6.30	6.45	77.38	12.00
145.00	7.00	-2.07	4.73	6.80	6.55	45.84	7.02
165.00	20.00	1.43	4.73	3.30	5.05	100.96	20.30
172.00	7.00	3.73	4.73	1.00	2.15	15.04	7.37
174.00	2.00	4.73	4.73	0	4.73	x	x

Total Width	**174**						
Total Area	**749.511**						
W. P (P)	**172.9488**						
Hydraulic Radius ®	**4.333715**						
Mean sect. Depth	**4.307534**						

***Table 2b*. Physical Parameters for the Second Cross-section using Float Method**

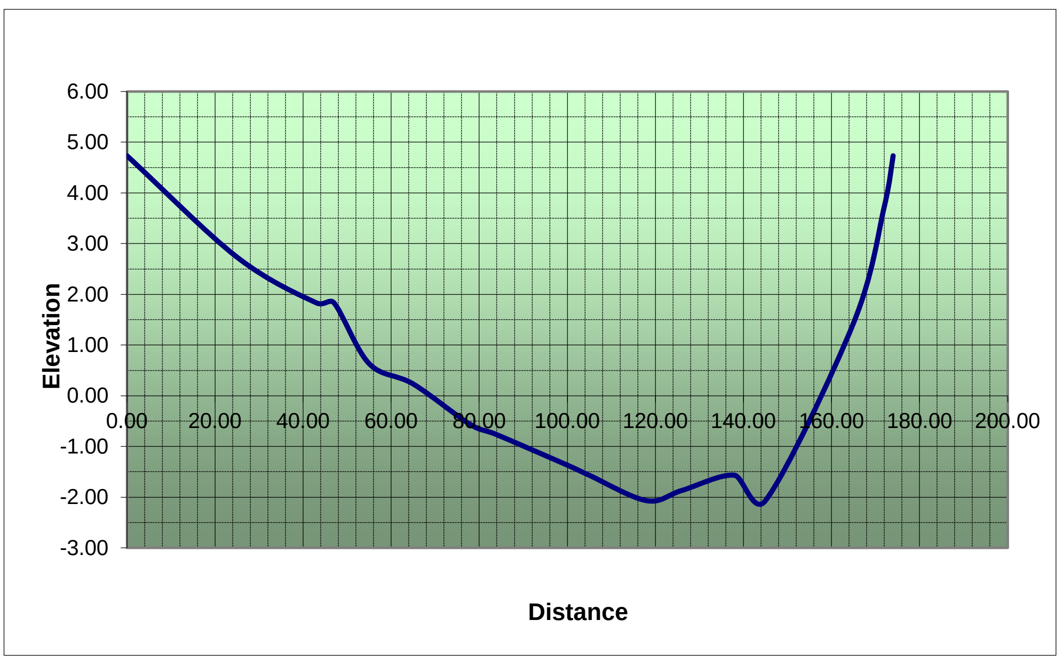


***Figure 2b*. Equivalent Second Cross-section using Distance and Elevation**

Station	Traveling time									
	1st trial	2nd trial	Ave Time (sec)	Velocity	Correction Coef	Corrected Vel	1st Section	2nd Section	Ave Area	Divided Q
1	FAIL	1:36:59	96.00	1.04	0.92	0.959	54.71	62.35	58.53	56.11
2	01:37:37	1:51:30	104.00	0.96	0.92	0.885	268.75	319.80	294.28	260.31
3	1:34:11	FAIL	93.00	1.08	0.92	0.989	691.25	510.00	600.63	594.18
4	1:37:35	1:38:36	97.50	1.03	0.92	0.944	1181.25	800.10	990.68	934.79
5	2:17:50	2:12:27	134.55	0.74	0.92	0.684	1093.13	574.20	833.66	570.24
									Total Q=	2415.63

Float method shows a similar, but simpler approach compared to the slope-area method. Microsoft Excel Suite may be used (Tables 2a and 2b) in determining the total width, area, wetted perimeter, hydraulic radius, mean depth, and a graphic representation of the cross-sections (Figures 2a and 2b).

However, the discharge (Q) table is the most important among the given data since it shows in detail the time it took for one float to travel from one cross-section to another. From this, the mean velocity of the two trials can be obtained. A FAIL on one trial shall be disregarded so the average time will be the other trial itself. Table 2c was manually computed, revealing a total average discharge of 2415.63 cumecs. This is roughly 7 to 8 times higher compared to the discharge measurement using current meter method.

C. Slope-Area Method

Data for the slope-area method includes three tables for the physical parameters of the three cross-sections, graphic representation of such parameters, and a summary table for determining the equivalent discharge of Pampanga River.

Slope-Area Cross-Section Computation							
Station:	***Arayat***			Survey Date:	***Oct.21, 2013***		
River:	***Pampanga***				Gage Ht.=	***3.16***	meters
Cross-Section number ONE (1)							hth/ 97
Station	**Distance**	**Elevation**	**Water Sfc. elev.**	**Depth**	**Mean Depth**	**Area**	**Wetted Perimeter**
0		8.451	5.546	-2.905			
134.1687	134.1687	6.55	5.546	-1.004	-1.9545	-262.233	134.1822
143.8222	9.6535	3.997	5.546	1.549	0.2725	2.630579	9.985383
154.2193	10.3971	0.05	5.546	5.496	3.5225	36.62378	11.12108
167.8637	13.6444	0.006	5.546	5.54	5.518	75.2898	13.64447
185.8268	17.9631	-0.029	5.546	5.575	5.5575	99.82993	17.96313
206.3107	20.4839	-0.069	5.546	5.615	5.595	114.6074	20.48394
227.8004	21.4897	-0.099	5.546	5.645	5.63	120.987	21.48972
244.9382	17.1378	-0.149	5.546	5.695	5.67	97.17133	17.13787
271.3575	26.4193	-0.054	5.546	5.6	5.6475	149.203	26.41947
279.6424	8.2849	5.299	5.546	0.247	2.9235	24.22091	9.863781
284.2909	4.6485	5.546	5.546	0	0.1235	0.57409	4.655058

Total Width =	**284.29**	**meters**	**Hydraulic Radius(r) =**	**1.60**	**meters**
Total Area =	**458.91**	**meters^2**	**Mean Section Depth =**	**1.61421**	**meters**
Wetted Perimeter(P) =	**286.946**	**meters**			

***Table 3a*. Physical Parameters of the 1st Cross-section Using Slope-Area Method**

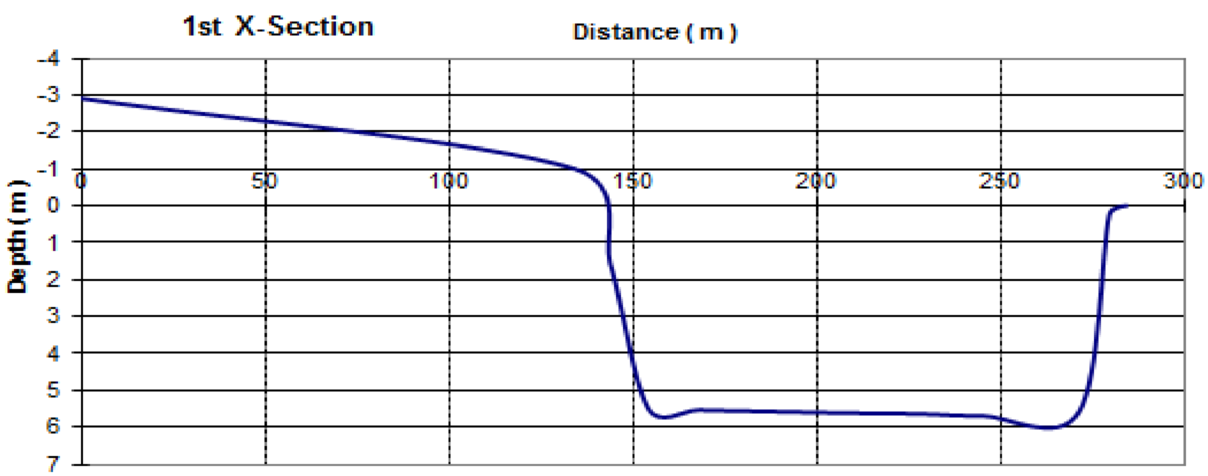


***Figure 3a*. Graphic Representation of the 1st Cross-section Using Distance-Depth Relation**

Slope-Area Cross-Section Computation							
Station:	*Arayat*			Survey Date:		*Oct.21, 2013*	
River:	*Pampanga*				Gage ht.=	*3.16*	meters
Cross-Section number TWO (2)							hth/ 97
Station	**Distance**	**Elevation**	**Water Sfc. elev.**	**Depth**	**Mean Depth**	**Area**	**Wetted Perimeter**
0		5.061	5.061	0			
166.1196	166.1196	4.018	5.061	1.043	0.5215	86.63137	166.1229
176.4954	10.3758	-0.003	5.061	5.064	3.0535	31.68251	11.1277
193.3365	16.8411	-0.029	5.061	5.09	5.077	85.50226	16.84112
209.3011	15.9646	-0.064	5.061	5.125	5.1075	81.53919	15.96464
227.7976	18.4965	-0.057	5.061	5.118	5.1215	94.72982	18.4965
247.5566	19.759	-0.103	5.061	5.164	5.141	101.581	19.75905
271.4966	23.94	-0.149	5.061	5.21	5.187	124.1768	23.94004
293.6271	22.1305	-0.179	5.061	5.24	5.225	115.6319	22.13052
314.3919	20.7648	-0.28	5.061	5.341	5.2905	109.8562	20.76505
321.6627	7.2708	4.653	5.061	0.408	2.8745	20.89991	8.786297
323.2061	1.5434	5.659	5.061	-0.598	-0.095	-0.14662	1.842314

Total Width =	**323.21**	**meters**	**Hydraulic Radius(r) =**	**2.62**	**meters**
Total Area =	**852.08**	**meters^2**	**Mean Section Depth =**	**2.63635**	**meters**
Wetted Perimeter(P) =	**325.776**	**meters**			

Table 3b. **Physical Parameters of the 2nd Cross-section Using Slope-Area Method**

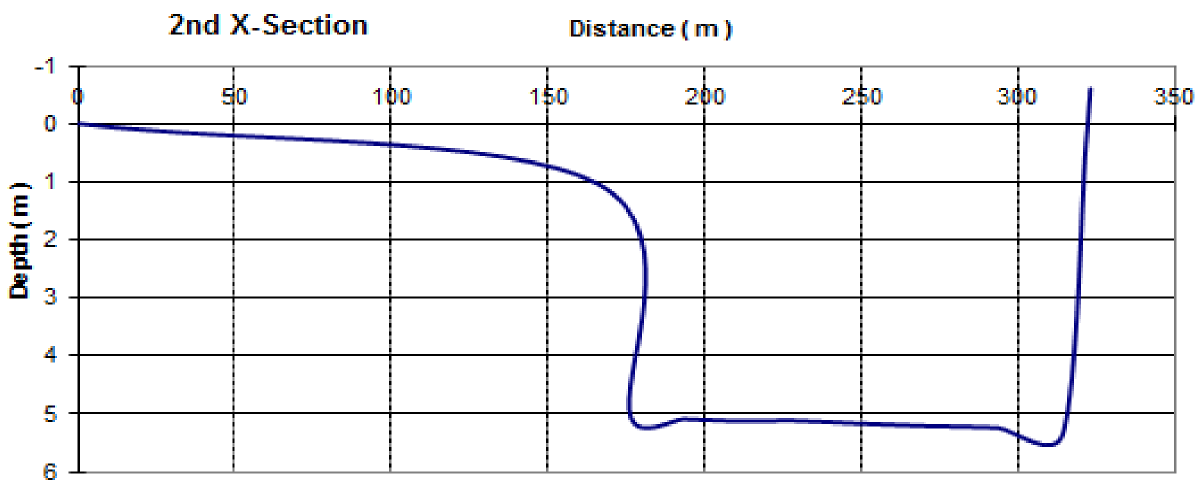


Figure 3b. **Graphic Representation of the 2nd Cross-section Using Distance-Depth Relation**

Slope-Area Cross-Section Computation							
Station:	*Arayat*		Survey Date:		*Oct.21, 2013*		
River:	*Pampanga*			Gage ht.=	*3.16*	meters	
Cross-Section number THREE (3)							hth/ 97
Station	**Distance**	**Elevation**	**Water Sfc. elev.**	**Depth**	**Mean Depth**	**Area**	**Wetted Perimeter**
0		4.967	4.967	0			
100.0491	100.0491	3.318	4.967	1.649	0.8245	82.49048	100.0627
125.3529	25.3038	-0.483	4.967	5.45	3.5495	89.81584	25.58769
138.9185	13.5656	-0.5	4.967	5.467	5.4585	74.04783	13.56561
155.9567	17.0382	-0.549	4.967	5.516	5.4915	93.56528	17.03827
178.0093	22.0526	-0.596	4.967	5.563	5.5395	122.1604	22.05265
201.759	23.7497	-0.671	4.967	5.638	5.6005	133.0102	23.74982
226.1464	24.3874	-0.715	4.967	5.682	5.66	138.0327	24.38744
248.0367	21.8903	-0.766	4.967	5.733	5.7075	124.9389	21.89036
265.2483	17.2116	-0.76	4.967	5.727	5.73	98.62247	17.2116
279.5832	14.3349	4.55	4.967	0.417	3.072	44.03681	15.28677
287.2792	7.696	4.793	4.967	0.174	0.2955	2.274168	7.699835

Total Width =	**287.28**	**meters**	**Hydraulic Radius(r) =**	**3.48**	**meters**
Total Area =	**1003.00**	**meters^2**	**Mean Section Depth =**	**3.49136**	**meters**
Wetted Perimeter(P) =	**288.533**	**meters**			

Table 3c. **Physical Parameters of the 3rd Cross-section Using Slope-Area Method**

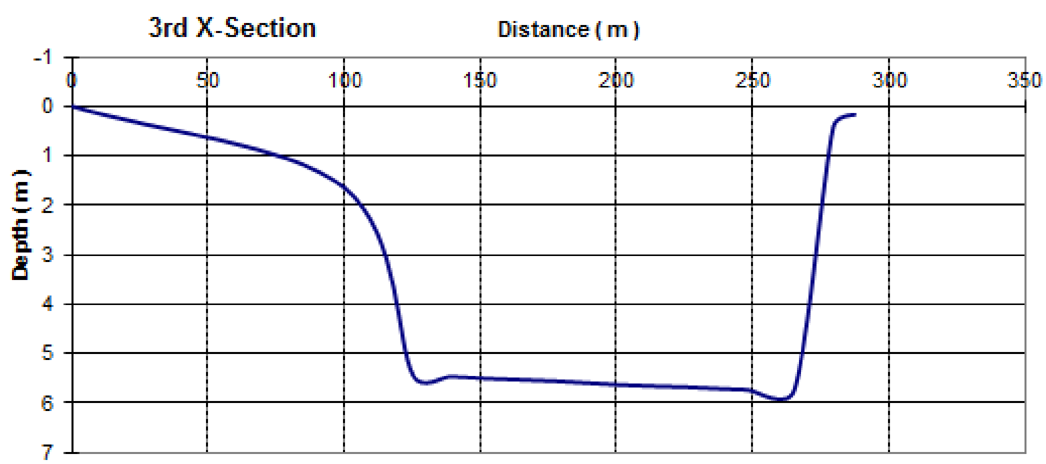


Figure 3c. **Graphic Representation of the 3rd Cross-section Using Distance-Depth Relation**

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 Station*	River:	*Pampanga River*
Flood Date:		Drainage Area:	
Gauge Height:	*3.16*	Meas. #:	

X - Section Properties:

hth/ 97

X-Sect.	Width	Area	Highwater Marks Left Bank	Right Bank	Average Water Sfc.	d_m (mean depth)	n	r	K	K^3/A^2	α	F	State of Flow
1	284.29	458.91	8.451	5.546	6.9985	1.614	0.035	1.60	17959.04	2.8E+07	1	1.885	rapid
2	323.21	852.08	5.061	5.659	5.36	2.636	0.035	2.62	46364.11	1.4E+08	1	0.794	tranquil
3	287.28	1003.00	4.967	4.793	4.88	3.491	0.035	3.48	66034.39	2.9E+08	1	0.586	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	155.157	1.6385	0.5	expanding	0.387348	poor	655.495	4040.949	6.165
2-3	270.726	0.48	0.5	expanding	0.702121	good	927.540	2470.455	2.663
1-2-3	425.883	2.1185	0.5	expanding	0.271965	poor	771.328	**3440.336**	4.460

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

Discharge Computation:(comparison)

Reach	Assumed Q	h_v U/S	D/S	Δh_v	h_f	$S=h_f/L$	$S^{1/2}$	K_w	**Computed Q**
1-2	4040.949	2.867476	0.831726	2.035749	2.656375	0.017121	0.130846	28855.76	3775.648
2-3	2470.455	0.831726	0.600272	0.231454	0.595727	0.0022	0.046909	55331.96	2595.582

Q_{1-2-3} = 3440.34 cumecs

Discharge

Rem:

Table 3d. **Summary Sheet of the Three Cross-sections Using Slope-Area Method**

Before the fieldwork, typhoon Santi causes flooding in the area (Arayat Station, Pampanga River). During the activity highest flood mark has been recognized and using the Excel Suite the discharge measurement resulted to 3440.34 cumecs.

D. ADCP Method

The River Surveyor® software illustrates in detail the river cross-section as well as its discharge in the shortest amount of time. This software program made by SonTek is Windows-based and operates in real time.

As mentioned, three trials were made across the same river cross-section, some 50 meters downstream from the bridge. A cross from one edge to the other edge is equivalent to one trial thus, one set of data. Captions were taken from the computer as follows:

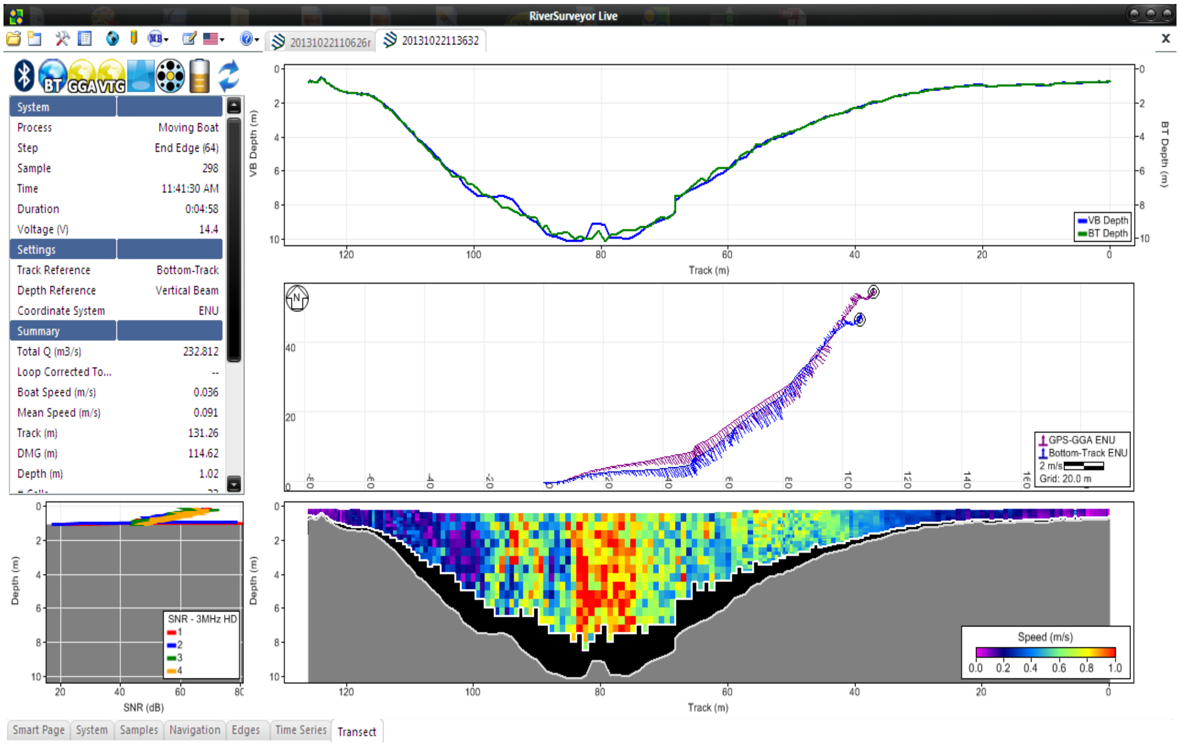


***Figure 4a*. Cross-section and Discharge from *RiverSurveyor* using ADCP Method (1st trial)**

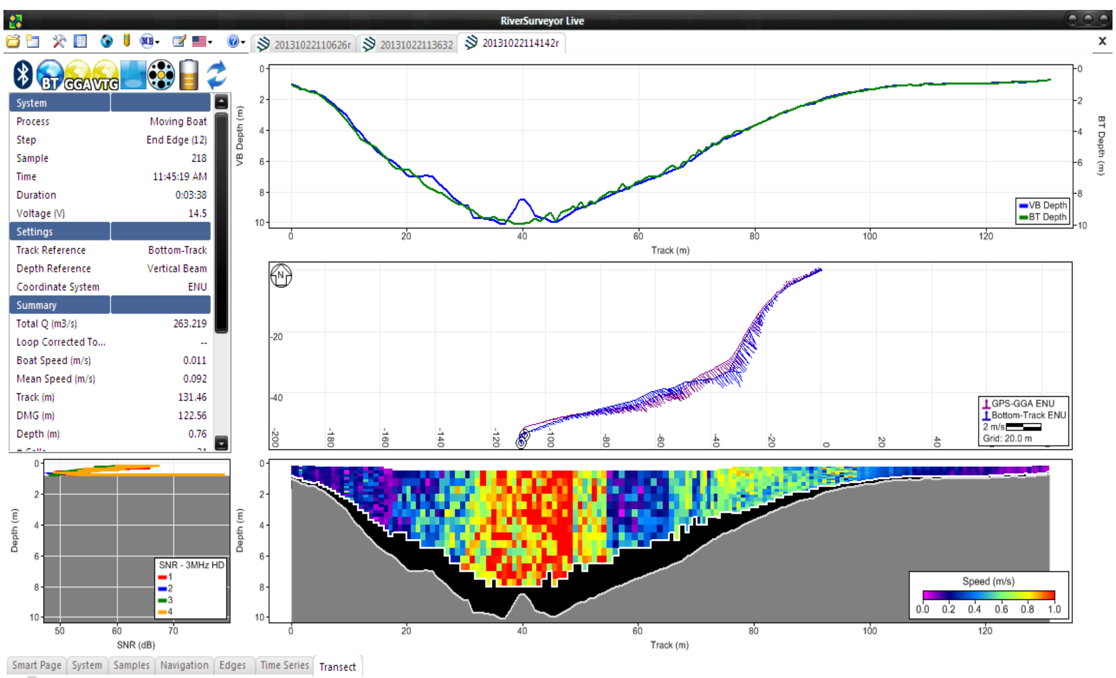


***Figure 4b*. Cross-section and Discharge from *RiverSurveyor* using ADCP Method (2nd trial)**

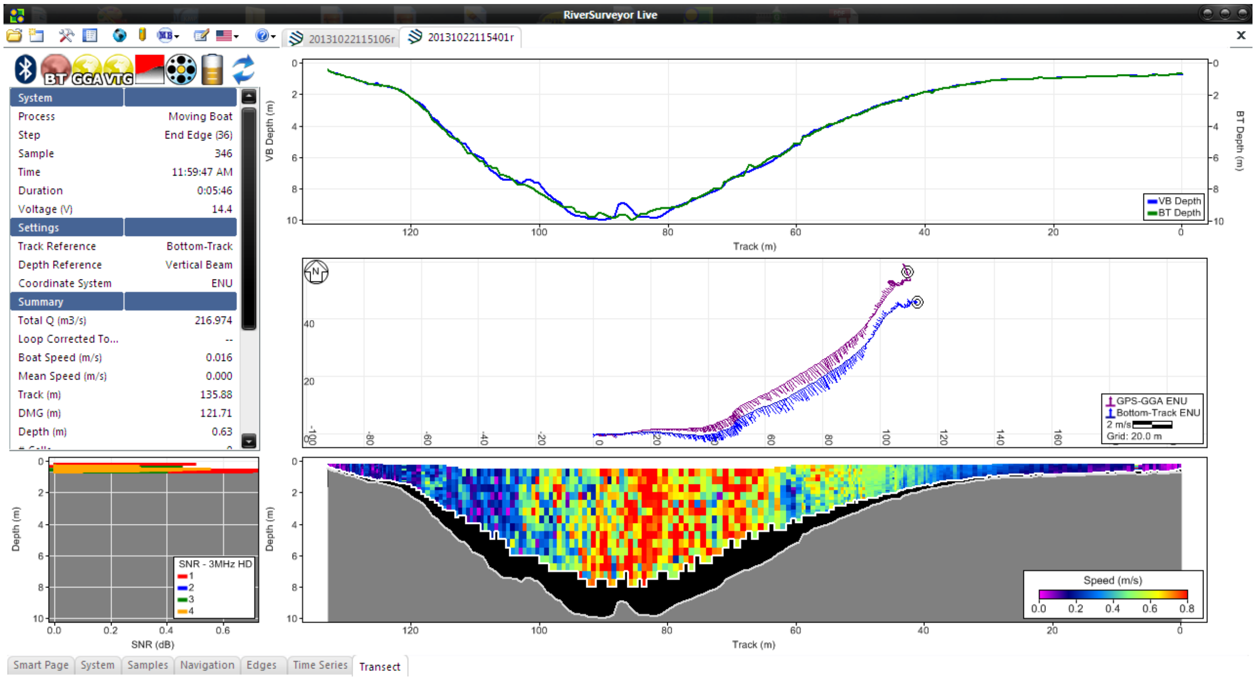


***Figure 4c*. Cross-section and Discharge from *RiverSurveyor* using ADCP Method (3rd trial)**

The RiverSurveyor® screen shows the System, Settings, and Summary on the left part and the vessel track and river cross-section on the right. Based on the similarity of the obtained cross-sections (lowest graph on the right), it can be said that the profile of the stream bed is accurate. The colored sections represent water and its velocity, where the red pixels represent flows of up to 0.8 meters per second. The black areas touching the stream bed is also noticeable. These are waters of the river with velocities that could not be determined by the ADCP. Nonetheless, an equivalent discharge for each trial was obtained.

Based on the three trials, with discharges equal to 232.812, 263.219, and 216.974 cumecs respectively, the average discharge is equal to 237.668 cumecs. This is a low discharge compared to the previous methods done due to a sudden drop in the water level of the river during that day.

Development of a Rating Curve, Equation and Table

Part of discharge measurement is to establish a rating curve defined by a graph of discharge versus stage for a given point on a stream, usually at gauging stations, where the stream discharge is measured across the stream channel with a flow meter. 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.

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.

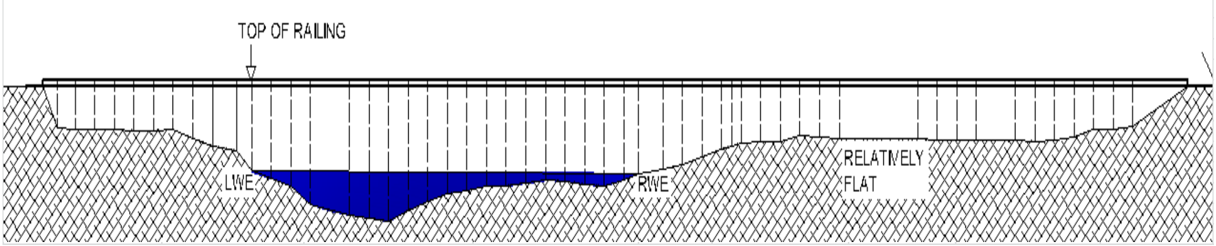
Cross section survey

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			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					

PAMPANGA RIVER CROSS SECTION
SAN AGUSTIN BRIDGE, ARAYAT PAMPANGA



The survey did by our group 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**.**

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	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)

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	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		

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:

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

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

Other considerations

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

1. The H-Q values used in the formulation of the rating equation are in themselves only estimates computed based on manning's equation. The error may have been magnified when the rating curve equation and the rating table are computed.

2. The bridge was assumed to be straight. In reality, the bridge's elevation varies in certain sections.

3. The bridge was assumed to have no piers when it fact, it does. Piers affect water velocity surrounding its perimeter, and consequently, also affect discharge to a certain degree. Only the elevation of the river bed without the pier was considered.

4. The roughness coefficient used may have been inaccurate.

5. There might have been an error in evaluating the Ho. Since this was done by trial and error, other values for Ho that were not tried might have given closer results.

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

FIELD VISITS

I. La Mesa Dam

The La Mesa Watershed and Eco-Park consists of the La Mesa Dam and an ecological nature reserve site in Quezon City. It is part of the Angat-Ipo-La Mesa water system, which supplies most of the water supply of Metro Manila. The La Mesa Dam is an earth dam whose reservoir can hold up to 50.5 million cubic meters and occupying an area of 27 square kilometres.

Figure 9. **The La Mesa Dam**

II. Pantabangan Dam

Pantabangan Dam is an earth-fill embankment dam on the Pampanga River located in Pantabangan in Nueva Ecija province of the Philippines. 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.

The dam is a 107 m tall and 1,615 m long embankment-type with 9,174,658 m^3 of homogeneous earth-fill and an impervious core. The crest of the dam is 12 m wide while the widest part of its base is 535 m. The dam's crest sits at an elevation of 232 m and is composed of three sections: the main dam, a saddle dam, and an auxiliary dam located with the spillway. The design discharge of the spillway is 4,200 m^3/s. The dam's reservoir has a gross capacity of 2,996,000,000 m^3 and 2,083,000,000 m^3 of that volume is active for irrigation and power. The dam sits at the head of 853 km^2 catchment area and its reservoir has a surface area of 69.62 km^2 and elevation of 230 m 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.

Figure 7. **Pantabangan Dam**

III. Angat Dam

Angat Dam is a concrete water reservoir embankment hydroelectric dam that supplies the Manila metropolitan area water. It was a part of the Angat-Ipo-La Mesa water system. The reservoir supplies about 90 percent of raw water requirements for Metro Manila through the facilities of the Metropolitan Waterworks and Sewerage System and it irrigates the farmland in the provinces of Bulacan and Pampanga.

***Figure 8*. Angat Dam**

IV. CONG DADONG DAM

Cong Dadong Dam is used essentially for Irrigation purposes only. Farmers' beneficiaries will avail of the new irrigation service during the dry season that extends up to April, including those in the southern Nueva Ecija town of Cabiao and San Antonio which had earlier opposed the project. The Cong Dadong Dam is programmed to irrigate by way of gravity. It is located kilometres upstream of the studied area in Arayat Station, Pampanga River.

Figure 10. **The Cong Dadong Dam**

V. MDRRMC in Calumpit, Bulacan

Municipal Disaster Risk Reduction Management Centre (MDRRMC) at Calumpit Bulacan shows what their objectives are and it is to minimize risks, dangers, damages in disaster prone areas since according to them they are flood loving people, To equip personnel and volunteers with up-to-date trainings on disaster preparedness, To ensure efficient and effective monitoring & response to disaster, To stir community awareness on disaster preparedness and control. Its management improvised their own facilities in order to forecast bad weather condition, to be updated on the water level of their rivers which is also a big help in giving warnings before disaster is going to happen.

Figure 11. **Actual Picture of Trainees in Calumpit Bulacan**

Relating Field Visits to HTC

Flood controls, such as dams, can be built and maintained over time to try and reduce the occurrence and severity of floods as well. Stop at Dams like Pantabangan Dam, Angat Dam, La Mesa Dam and Cong Dadong Dam is relatively electrifying. Visiting this kind of structures for us future Hydrologist is certainly an enormous advantage for us to know its uses, particularly in controlling flood. It is also a Hydrologist undertaking to communicate in every dam personnel particularly in the major dams in the Philippines. We also need to know its individual capacity and its spilling level since it is one of the causes of flooding in the low lying areas inside the basin.

Visiting one of the Municipal Disaster Risk Reduction Management Center (MDRRMC) in the Philippines permits us to distinguish what are their uses and their capabilities to respond when catastrophe comes along.

CONCLUSION

Determining discharge through different approaches is actually tedious but at the same time it is exciting. The stress-free method is over and done with the Acoustic Doppler Current Meter (ADCP) since you are a bit occupy yourself with the instrument and it provides you the outcomes right after investigation. ADCP is also the most accurate and effective technique in computing discharges. Technology really makes Hydrologists life easier, before ADCP is being discovered surveyors used to determine the discharge through Slope-Area Method which is extremely tedious among all the approaches. Safety is a primary consideration when measuring discharge from bridges using current meter. High-speed traffic can present a major safety hazard; in fact, it is no longer permissible to make discharge measurements from some National route bridges without special permission.

A discharge measurement using different methods gives different values. This is likely due to the nature of accuracy of each method and differences in water levels each day. Since a different group uses different methods each day.

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