TECHNICAL REPORT

In

Discharge Measurement

Using Different Methods at Arayat Station

In Pampanga River

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1. Acknowledgement

This fieldwork activity would not be possible without the help and guidance of the Staff of Training Centre and most especially the PRFFWC and HMD personnel, who assisted in the proper conduct of the four discharge measurements.

2. Introduction

Pampanga River (formerly known as Rio Grande de Pampanga - Great River of Pampanga) is the second largest river in the island of Luzon, next to Cagayan River and the third largest but most important river in the Philippines. It is located in the Central Luzon region and traverses the provinces of Pampanga, Bulacan, and Nueva Ecija.

Its headwaters are located at the Sierra Madre and runs a south and southwesterly course for about 260 kilometers until it drains into Manila Bay. The river's basin covers an area of 10,540 km², including the allied basin of Guagua River. The basin is drained through the Pampanga River and via the Labangan Channel into the Manila Bay.

Its main tributaries are Peñaranda and the Coronel-Santor Rivers on the eastern side of the basin and the Rio Chico River from the northwest side. The Angat River joins the Pampanga River at Calumpit, Bulacan via the Bagbag River. Mount Arayat (elevation: 1,026) stands in the middle of the basin. Southeast of Mount Arayat and the Pampanga River is the Candaba Swamp, covering an area of some 250 km². Absorbing most of the flood flows from the western slopes of a portion of the Sierra Madre and the overflowing of the Pampanga River via the Cabiao Floodway. This area is submerged during the rainy season but is relatively dry during summer.

Last October 11, 2013, The Philippines has suffered massive devastation caused by torrential rains and flooding as a consequence of Typhoon Santi. The data from the National Disaster Risk Reduction and Management Council (NDRRMC) shows that the typhoon has affected a total of 770 barangays in 26 municipalities, 9 cities, and 14 provinces. Cagayan Valley and Central Luzon are the worst hit by the typhoon which caused inundations. Some areas were also declared under state of calamity. The heavy and massive amounts of rainfall induced flooding and flooded the nearby areas. A mudslide also hit the RPSB3 Patrol Base in Mt. Arayat, Pampanga on October 12. A total of 115 barangays were flooded in Pampanga with seven of which are from the municipality of Arayat.

Moreover, prior knowledge on the status of river physiographic characteristics such as the river profiles, available river cross-sections, and all other data from existing rain gauge and water level stations is of paramount importance in order to efficiently and accurately simulate flooding events when there are impending weather systems that may threaten the river basin thereby inflicting destructive effects to human lives and properties. This information are vital in the issuance of flood advisories and bulletins for effective flood forecasting and warning which entails a great responsibility in ensuring safety of the people as well as reducing or minimizing the impacts if it is impossible to totally avoid these onslaughts.

The Philippines lies in the path of tropical cyclones. An annual average of twenty tropical cyclones enter the Philippine Area of Responsibility and out of this, seven to eight directly hit the country causing enormous water-related damages to human live and properties. According to the reports of the Office of Civil Defense, approximately 1,000 people every year are killed and/or missing due to floods brought about by cyclones.

3. Background

As part of the requirements for the Discharge Measurement component of the Stream Gauging Course, the author developed a fieldwork report entitled:

Discharge Measurement using Different Methods in the Arayat Station of Pampanga River

4. Objectives

The study conducted is guided with the general aim to fully understand and conduct an actual discharge measurement/stream gauging to implement the four indirect and direct methods of discharge measurement in the Arayat station of the Pampanga River.

a. Compare and contrast the four discharge measurement methods such as:
    - Method 1 (Float Method)
    - Method 2 (Slope-Area)
    - Method 3 (Acoustic Doppler Current Profiler)
    - Method 4 (Current Meter) – using Boat Method

b. Compilation and Manipulation of data gathered to compute for the discharge measurement and to arrive at a rating curve and rating curve equation

c. Analysis and Explanations of the results, specifically the effect of variations, discrepancy, contradictions and consistency of data.

5. Review of Related Studies

River cross-sectioning and post-flood surveys comprised the lot of field hydrological activities that were undertaken by the personnel of the Pampanga River Flood Forecasting and Warning Center (PRFFWC) within the Pampanga River Basin (PRB). Hydrographic works include river cross-sectioning, river velocity measurements, post-flood surveys and other hydrological related surveys and others. These activities are regular basic activities required in the improvement and the enhancement of flood forecasting and warning operations of the PRFFWC mainly for the development of flood forecasting models.

Based on the PRFFWC 2012 Annual Report, they did a joint river cross-sectioning of the major river systems within the PRB, particularly the main Pampanga River, in coordination with the Hydro-Meteorology Division as per Japan International Cooperation Agency-Technical Cooperation Project (JICA-TCP) on strengthening of Flood Forecasting and Warning System for Dam Operations (FFWSDO) within the months of April to July. They also did post-flood survey of the provinces of Pampanga, Bulacan and Cavite in connection with the flood event due to the Southwest Monsoon (Habagat) for the month of August.

In 2011, the PRFFWC conducted survey of Sta. Maria River Basin area for site selection of CCTV (closed-circuit television) set-up for monitoring river stage (qualitative) at selected sections along Sta. Maria River. The activity was in support of PDRRMO-Bulacan's expansion of its local flood warning system in the province February 24-25. Several post-flood surveys and investigation of various flooded areas affected during the enhanced SW monsoon over the basin was done on June 29 to July 01; flood event caused by Typhoons Pedring and Quiel on October 17 to 20; and San Miguel, Bulacan as a result of the event SLPA-ITCZ that affected the region on November 6-8.

6. Study Area: Arayat, Pampanga

Arayat is a first class municipality in the province of Pampanga, Philippines. According to the 2010 census, it has a population of 121,348 people. A large portion of Mount Arayat is located within this municipality.

The actual location of the river cross-sectioning is at Barangay San Agustin. Arayat with the San Agustin Bridge as the reference landmark taking into consideration the existence of the old benchmark and the new unmanned telemetered station located before the bridge.

Figure 1: A view of the upstream of Pampanga River in Arayat.

7. Methodology

During the ten-day fieldwork, four methods of discharge measurement were done in the downstream portion of the San Agustin Bridge in Arayat, Pampanga. Of the four methods, some were direct measurements such as the float, ADCP and current meter methods while slope area method is an indirect measurement. Details of each method were summarized in the following sections below.

7.1. Float Method

The float method is generally applied for floods which discharge observation by current meter and all other techniques is impractical to use. As the name of the method implies, floats are thrown down into the river and their travelling time in a certain cross section of the river is measured thus, the average velocity in the section can be estimated. This method is the easiest, most practical and cost-effective method for discharge measurements during high flow.

Floats are thrown from bridges but there are emergency cases when they are thrown from the river bank. Float materials used for this study are improvised using bamboo sections of about 1-meter length, filled with 3/4 –full sand with a flag marker for visibility. Travelling time of the float was determined using a stopwatch. The procedures are the following:

1. Use bamboo to serve as floats; they must be of the same length.
2. From the Left edge of the bridge (estimated edge in line with the left water edge), measure 5 points going to the right edge. Take note of the distances from each point.
3. Assign two persons to watch out for the float on the river, the first person should stand 50m from the section below the bridge, and the second, 100m from the first 50 m.
4. After all is set, drop the floats individually recording the time it reaches the first 50m as the starting time, and the time it reaches the 100m distance as the finishing time.
5. Each float undergoes at least 2 trials.
6. When these trials are already done, consider two cross sections, they must be straight to where the 2 watchers stand along the river.
7. Use a boat to take readings of depth through echo sounder, the cross sections in this case is divided into 8 verticals.
8. Also, use a range finder to measure horizontal distance from each vertical. These are done in each cross section from right to left bank and from left to right bank.

Figure 2: Dropping the bamboo float at the river

A requirement for this method is a straight section of the river with enough length consisting of approach section and measurement section. The approach section is from dropping point to the first cross section which requires at least 30-meter distance in order to enable a float to maintain its draft. The measurement section is from the first cross section to the second cross section in order to measure the travelling time of a float which requires at least 50 meters. However, in practice, the distance is determined by the maximum velocity multiplied by 10-15 seconds. In Japan, distances ranging from 50 to 100 meters are popular. Too long section causes error in measurement due to variation of stage for long travelling time.

Since discharge observation by float is conducted during high floods, it is difficult to measure water depth simultaneously thus, only water level is measured during discharge observation by float and cross section survey is conducted to estimate discharge area soon after the flood.

In the duration of the fieldwork activity, the two cross sections were measured by boat method using an echo sounder to record water depth and a range-finder to determine the distance of every vertical reckoned from the water edge. Water levels upon the start of observation and at the end were noted to be used to estimate the discharge area of each cross-section using the equation $Q_i = V_i \times A_i$.

7.2. Slope-Area Method

The slope-area method consists of using the slope of the water surface in a uniform reach of channel and the average cross-sectional area of that reach to give a rate of discharge. The discharge may be computed from the Manning formula:

$$\boldsymbol{Q = (1.486/n)\, A\, R_h^{2/3}\, S^{1/2}}$$

Where:

Q = discharge (m^3/s)

A = mean area of the channel cross section (m^2)

R_h = mean hydraulic radius of the channel (m)

σ = energy slope of the flow

n = a roughness factor depending on the character of the channel lining

A fairly straight reach of the channel should be chosen with length of equal or greater than 75 times the mean water depth and is a contracting area. If the reach is free of rapids, abrupt falls, or sudden contractions or expansions, then the water surface slope is the same as the energy slope.

Figure 3: Fairly straight river reach

Total station and prism are the tools to measure Vertical and horizontal distance including horizontal angle. We also use the echo sounder to measure the depth and the range finder to measure the horizontal distance across the river.

Using the total station, the benchmark (BM) in the old station at the left bank upstream of the Pampanga River was used. The known elevation of 9.114 meters was used to start with the measurements. In this study, a total of 36 Tie Points and 5 BM Back sights were measured taking off from the known elevation in the benchmark to the three cross sections for this method. The following equations were used to compute for the elevations of each TP and the Height of the Instrument. Several readings taken from the total station used were the Vertical Distance (VD), Horizontal Distance (HD) and Horizontal Angle (HA).

$$HI = BM + \text{Height of Prism Rod} - BS$$

$$\text{Unknown Elevation} = HI + FS - \text{Height of Prism Rod}$$

Where: HI = height of Instrument; BM = Benchmark Elevation; FS = Fore Sight (VD); BS = Back Sight (VD)

For the computation, a formulated excel suite provided by the PRFFWC for automatic discharge computation by slope-area method was provided.

7.3. Acoustic Doppler Current Profiler Method

In recent years, advances in technology have allowed the USGS to make discharge measurements by use of an Acoustic Doppler Current Profiler (ADCP). An ADCP uses the principles of the Doppler Effect to measure the velocity of water. The Doppler Effect is the phenomenon we experience when passed by a car or train that is sounding its horn. As the car or train passes, the sound of the horn seems to drop in frequency.

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.

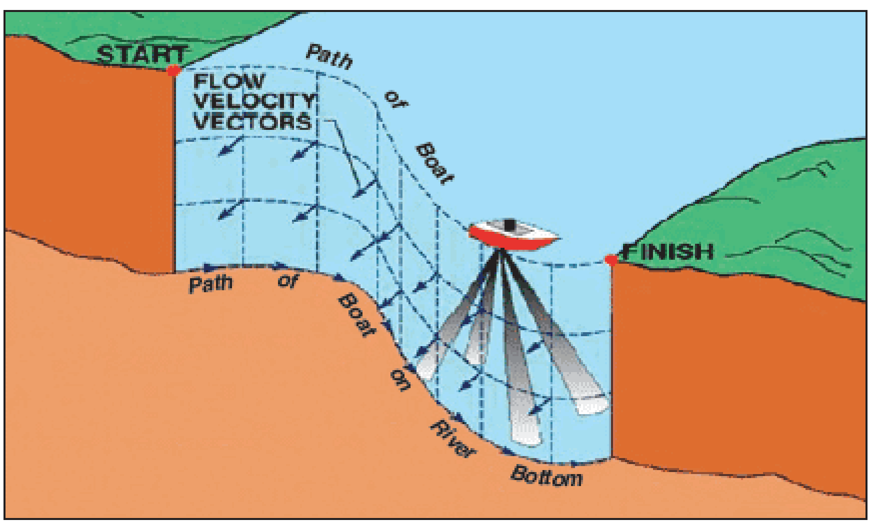

Figure 4: The ADCP Principle of discharge measurement

To make a discharge measurement, the ADCP is mounted onto a boat or into a small watercraft with its acoustic beams directed into the water from the water surface. The ADCP is then guided across the surface of the river to obtain measurements of velocity and depth across the channel. The river-bottom tracking capability of the ADCP acoustic beams or a Global Positioning System (GPS) is used to track the progress of the ADCP across the channel and provide channel-width measurements. Using the depth and width measurements for calculating the area and the velocity measurements, the discharge is computed by the ADCP using discharge = area x velocity, similar to the conventional current-meter method. Acoustic velocity meters have also been developed for making wading measurements.

The World Meteorological Organization (WMO) guide to stream gauging using ADCP suggests four transects to be measured at certain distances. For this study, a total of eight transects were measured at varying distances estimated from each transect.

7.4. Current Meter Method

The most common method used by the USGS for measuring discharge is the mechanical current-meter method. In this method, the stream channel cross section is divided into numerous vertical subsections. In each subsection, the area is obtained by measuring the width and depth of the subsection, and the water velocity is determined using a current meter. The discharge in each subsection is computed by multiplying the subsection area by the measured velocity. The total discharge is then computed by summing the discharge of each subsection.

Numerous types of equipment and methods are used by USGS personnel to make current-meter measurements because of the wide range of stream conditions throughout the United States. Subsection width is generally measured using a cable, steel tape, or similar piece of equipment. Subsection depth is measured using a wading rod, if conditions permit, or by suspending a sounding weight from a calibrated cable and reel system off a bridge, cableway, or boat or through a hole drilled in ice.

Figure 5: Current meter method by boat

For this study, current meter measurements were taken using the boat method. The Price AA current meter was used with a sounding reel loaded in the boat. Since the water level is significantly low compared from the high flow during the first day of fieldwork, a one point method was used – which is 0.6 from the water surface. Several verticals were measured guided with a tagline to ensure a relatively straight cross section. The calibration equation to be used will be:

$$V = 0.702N + 0.013$$

7.5. Rating Curve

If a measurement of the flow is made by the current-meter method on different occasions when the river is flowing at different depths, these measurements can be used to draw a graph of amount of flow against depth of flow. The depth of flow of a stream or river is called stage, and when a curve has been obtained for discharge against stage, the gauging station is described as being rated. Subsequent estimates of flow can be obtained by measuring the stage at a permanent gauging post, and reading off the flow from the rating curve. If the cross-section of the stream changes through erosion or deposition, a new rating curve has to be drawn up. To plot the rating curve, it is necessary to take measurements at many different stages of flow, including infrequently occurring flood flows. Clearly this can take a long time, particularly if access to the site is difficult, so it is preferable to use some type of weir or flume which does not need to be individually calibrated, and these are discussed in later sections.

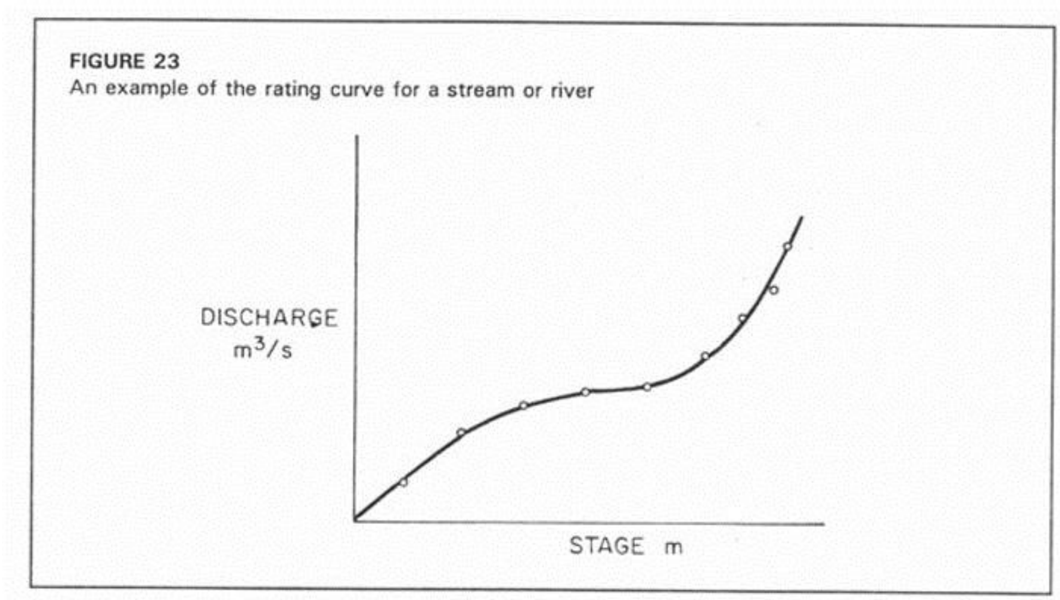

Figure 6: Example of Rating curve

8. Results and Discussion

Results of the study from the four different discharge measurement methods were summarized in the following tables below.

Table 1: Summary of measurements for the Float Method.

Station	Time (s)	Distance (m)	Velocity (m/s)	Cross Section 1			Cross Section 2		
				HD (m)	Depth (m)	Q (cms)	HD (m)	Depth (m)	Q (cms)
0				0.0			0.0		
1	129	100	0.775	61.0	4.3	136.67	63.0	4.9	159.53
2	106	100	0.943	82.0	6.4	102.64	84.0	6.0	127.36
3	75	100	1.333	95.0	9.2	202.40	108.0	7.0	182.00
4	100	100	1.000	115.0	11.6	208.80	123.0	7.6	117.80
5	125	100	0.800	131.0	7.2	112.32	139.0	6.9	126.96
6				154.0			169.0		
Total						**762.83**			**713.65**
Average						**738.24**			

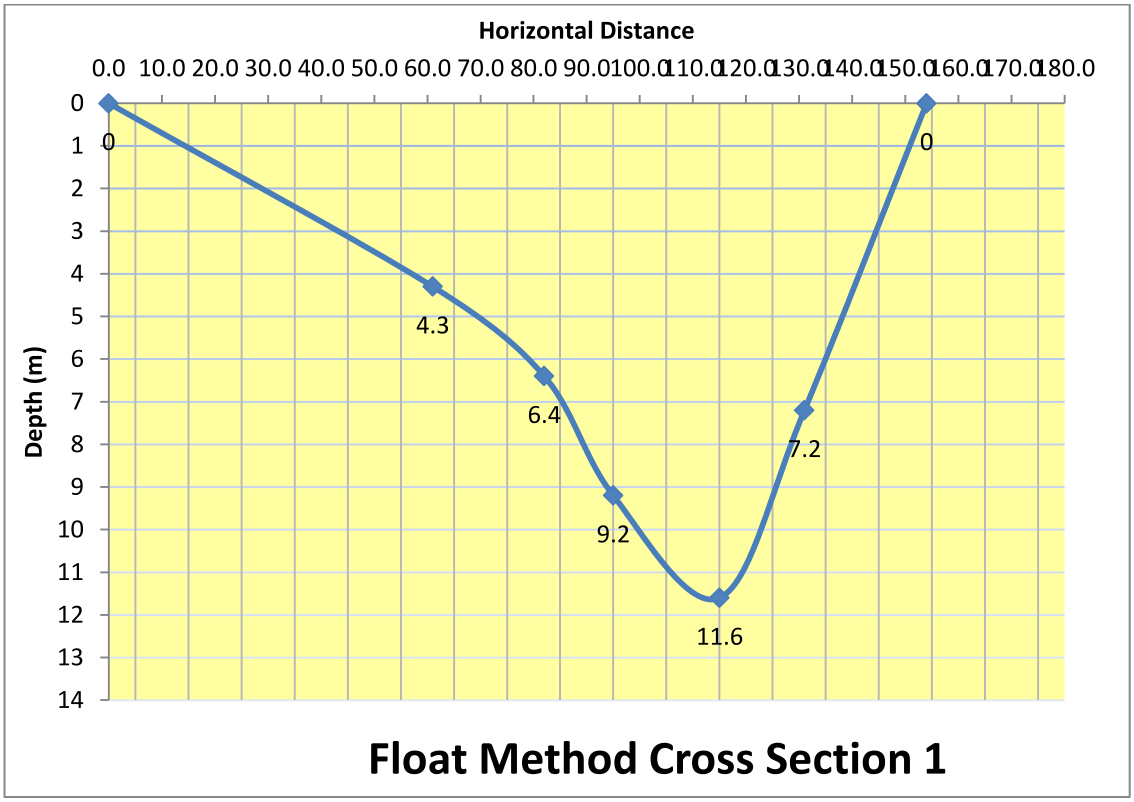

Figure 7: Float Cross Section 1 Profile

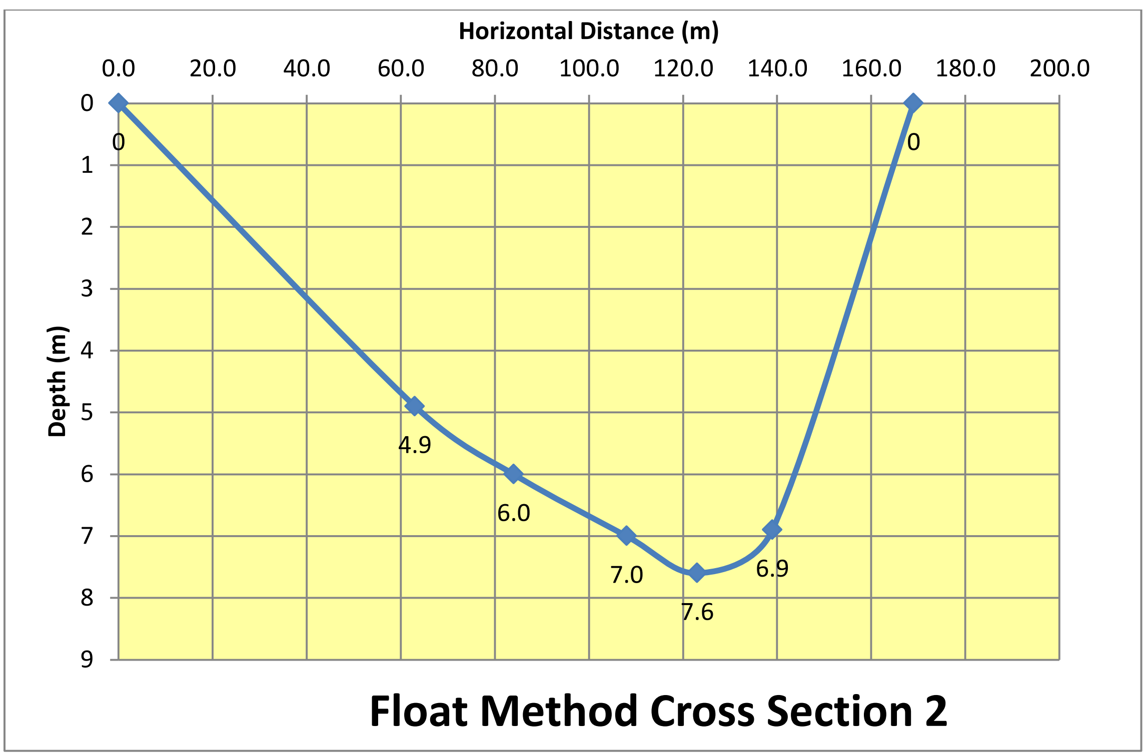

Figure 8. Float Cross Section 2 Profile

Table 2: Summary of measurements for the Slope-Area Method.

Station	VD (m)	HA (deg-min-sec)	HD (m)	Elevation (m)	Remarks
BS1	0.776	24° 34' 00"	8.642	9.538	
TP1	-0.792	225° 45' 20"	209.487	7.546	
BS2	-0.586	119° 20' 20"	37.278	9.332	
TP2	0.142	233° 09' 20"	104.74	8.274	HWM1 RB
TP3	-0.526	248° 45' 20"	35.468	7.606	
TP4	0.326	247° 59' 00"	11.93	8.458	
TP5	0.197	107° 14' 00"	19.707	8.329	
TP6	-0.889	84° 18' 40"	50.677	7.243	
BS3	0.68	293° 30' 90"	7.821	8.066	
TP8	-1.735	78° 04' 20"	103.399	5.131	
TP9	-3.018	77° 58' 00"	109.198	3.848	RB WE1
TP10	0.713	79° 50' 40"	284.873	7.579	HWM1 LB
TP7	-1.018	82° 34' 00"	77.728	5.848	
TP11	0.906	79° 51' 20"	212.274	7.772	
TP12	-0.743	80° 06' 40"	201.579	6.123	
TP13	-3.057	80° 22' 40"	199.509	3.809	LB WE1
BS4	0.263	350° 48' 00"	108.521	8.483	
TP14	-1.12	80° 14' 20"	96.287	3.763	RB WE2
TP15	-0.996	69° 56' 00"	93.386	6.287	
TP16	-3.421	72° 10' 20"	243.28	3.862	LB WE2
TP17	1.092	72° 37' 20"	250.296	8.375	
TP18	-0.746	70° 34' 40"	87.386	6.537	
TP19	0.539	73° 21' 00"	302.738	7.822	HWM2 LB
TP20	-0.663	69° 50' 40"	67.002	6.62	
TP21	0.083	61° 13' 00"	26.601	7.366	
TP22	-0.041	20° 11' 40"	8.162	7.242	
TP23	1.039	290° 51' 20"	16.994	8.322	
TP24	0.973	255° 05' 20"	38.451	8.256	HWM2 RB
BS5	0	351° 28' 20"	277.511	8.746	
TP25	-0.867	91° 02' 00"	100.313	4.279	RB WE3
TP26	-3.41	91° 21' 40"	249.356	4.136	LB WE3
TP27	-1.507	90° 42' 00"	97.097	6.039	
TP28	0.788	87° 36' 20"	290.393	7.534	HWM3 LB
TP29	-1.098	91° 01' 20"	257.446	6.448	
TP30	-0.845	92° 00' 00"	93.696	6.701	
TP31	-0.379	100° 18' 20"	53.608	7.167	
TP32	0.1	122° 52' 40"	9.815	7.646	
TP33	-0.018	238° 39' 40"	15.247	7.528	
TP34	0.94	256° 58' 40"	19.332	8.486	
TP35	0.96	267° 08' 40"	45.271	8.506	
TP36	0.683	267° 33' 20"	94.086	8.229	HWM3 RB

Table 3: Slope-Area Summary Sheet (3- Section)

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:	
Gauge Height:		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	146.00	2056.71	7.579	8.274	7.9265	14.087	0.03	13.84	398751.9	1.5E+10	1	0.099	tranquil
2	172.00	1525.85	7.822	8.256	8.039	8.871	0.03	8.83	218797.6	4.5E+09	1	0.168	tranquil
3	180.00	1676.52	7.534	8.229	7.8815	9.314	0.03	9.24	247827.2	5.4E+09	1	0.149	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	100	-0.1125	0	contracting	1.822469	poor	1791.280	x	x
2-3	200	0.1575	0.5	expanding	0.882863	good	1601.182	9334.831	5.830
1-2-3	300	0.045	0	contracting	1.608991	poor	1753.026	**2389.701**	1.363

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	x	0.068878	0.125144	-0.05627	-0.16877	-0.00169	x	295374.2	x
2-3	9334.831	0.125144	0.103661	0.021483	0.168241	0.000841	0.029004	232860.5	6753.786

Rem:

$Q_{1\text{-}2\text{-}3}$ = 2389.70 **cumecs**

Discharge

Station:	*Arayat*				**Date:**	*18-10-13*	
River:	*Pampanga River*				**Gage Ht.**	**0.00**	**meters**
	Total Area =		**2056.71**	**meters²**			

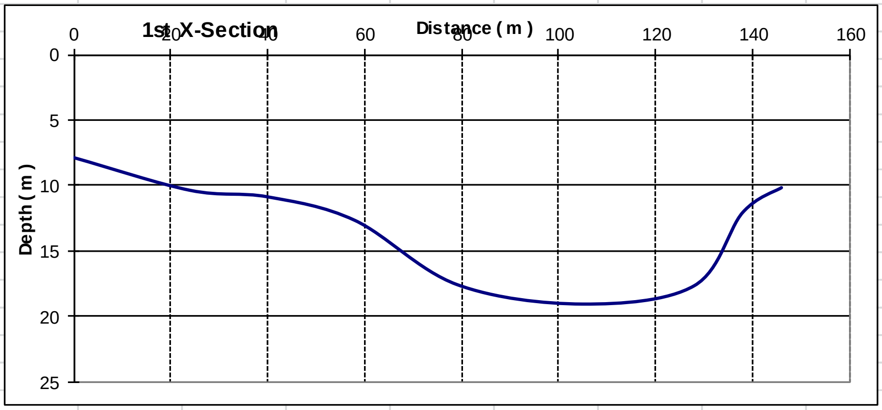

Figure 11: 1st Cross Section

	Total Area =		**1525.85**	**meters²**

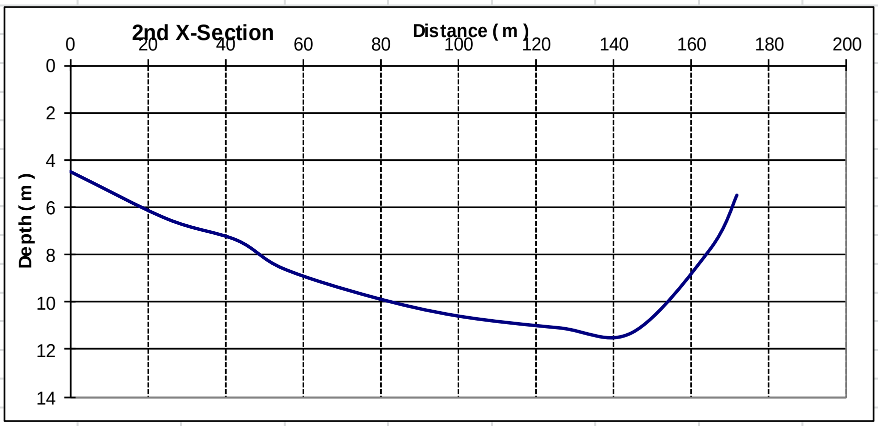

Figure 12: 2nd Cross Section

	Total Area =		**1676.52**	**meters²**

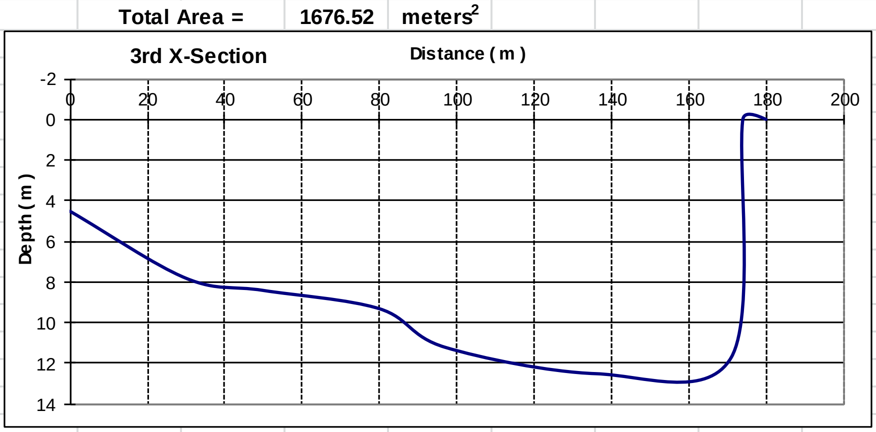

Figure 13: 3rd Cross Section

Table 4: Summary of measurements for the ADCP.

Transect	Discharge (Q in cms)
1	292.871
2	292.668
3	304.15
4	334.503
5	250.691
6	238.568
7	296.384
8	301.213
Average	**288.881**

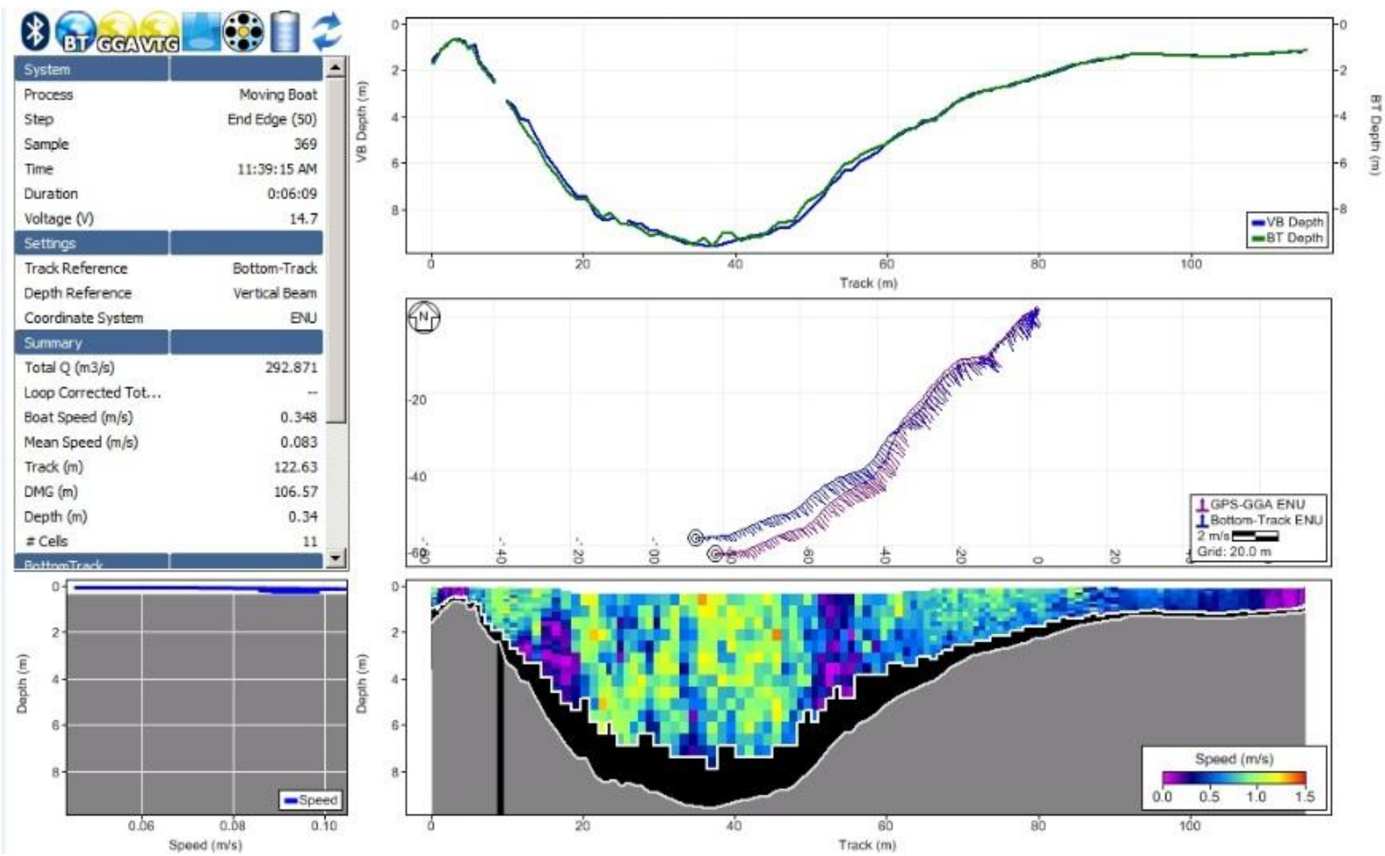

Figure 9: ADCP Transects

The ADCP has several salient points which make discharge measurement fast and easy. In the past, measuring the current depth profile required the use of long strings of current meters but this is no longer needed as ADCP measures small scale currents. Unlike previous technology, ADCPs measure the absolute speed of the water, not just how fast one water mass is moving in relation to another. It measures a water column up to 1000m long.

However, it also presents disadvantages such as a.) High frequency pings yield more precise data, but low frequency pings travel farther in the water. So scientists must make a compromise between the distance that the profiler can measure and the precision of the measurements; b.) ADCPs set to "ping" rapidly also run out of batteries rapidly; c.) If the water is very clear, as in the tropics, the pings may not hit enough particles to produce reliable data; d.) Bubbles in turbulent water or schools of swimming marine life can cause the instrument to miscalculate the current; and e.) Users must take precautions to keep barnacles and algae from growing on the transducers.

Table 5: Summary of measurements for the current meter method.

Station	Distance from Left Water Edge (m)	Water Surface Depth (m)	0.6 Depth (m)	Velocity	
				No. of Revolutions	Time (sec)
1	1	NA	NA	Unable	60
2	6	1	0.4	Unable	60
3	9	2.1	0.84	Unable	60
4	12	3.17	1.268	Unable	60
5	16	4.7	1.88	1	60
6	21	6	2.4	6	61
7	26	6.8	2.72	10	61
8	31	8.1	3.24	10	61
9	36	8.6	3.44	13	62
10	41	8.11	3.244	8	63
11	46	8.05	3.22	5	65
12	51	7.4	2.96	9	75
13	56	6.5	2.6	5	30
14	61	5.42	2.168	1	45
15	66	3.62	1.448	7	66
16	71	2.75	1.1	Unable	60
17	76	1.8	0.72	Unable	75
18	81	0.9	0.36	NA	NA
19	86	0.35	0.14	NA	NA
20	98.3	NA	NA	NA	NA

Table 6: Summary of measurements for the Rating Curve

Pampanga River @ Arayat							
(based on cross-section undertaken on October 2013)							
Elevation of "0" of S.G.=		0.082	m.(AMSL)				
n=	0.030	I=	0.00015				
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	15.320	3363.89	292.34	302.21	11.13	6846.29	
15.00	14.918	3247.38	291.50	300.97	10.79	6473.36	
14.00	13.918	2956.91	288.60	297.38	9.94	5581.85	
13.00	12.918	2670.61	286.30	294.09	9.08	4745.56	
12.00	11.918	2385.26	283.15	290.25	8.22	3965.54	
11.00	10.918	2104.14	281.00	287.13	7.33	3240.86	
10.00	9.918	1824.65	278.00	283.48	6.44	2577.59	
9.00	8.918	1548.21	275.30	279.97	5.53	1976.52	
8.00	7.918	1291.18	236.10	240.54	5.37	1616.03	
7.00	6.918	1053.37	162.40	166.46	6.33	1471.25	
6.00	5.918	902.84	137.90	141.81	6.37	1266.12	
5.00	4.918	769.53	128.20	131.89	5.83	1018.18	
4.00	3.918	643.90	122.10	125.45	5.13	782.18	
3.00	2.918	525.10	116.30	119.21	4.40	576.02	
2.00	1.918	412.62	108.00	110.58	3.73	405.26	
1.00	0.918	310.25	98.00	100.34	3.09	268.82	
0.50	0.418	262.09	93.50	95.73	2.74	209.40	
-1.00	-1.082	163.04	56.40	57.80	2.82	132.88	
-2.00	-2.082	110.61	40.90	42.35	2.61	85.63	
-3.00	-3.082	72.23	36.90	37.84	1.91	45.37	
-4.00	-4.082	39.10	30.70	31.30	1.25	18.51	
-5.00	-5.082	11.85	25.00	25.27	0.47	2.92	
	-0.082					0.00	
	-0.082					0.00	
	-0.082					0.00	
	-0.082					0.00	
	-0.082					0.00	

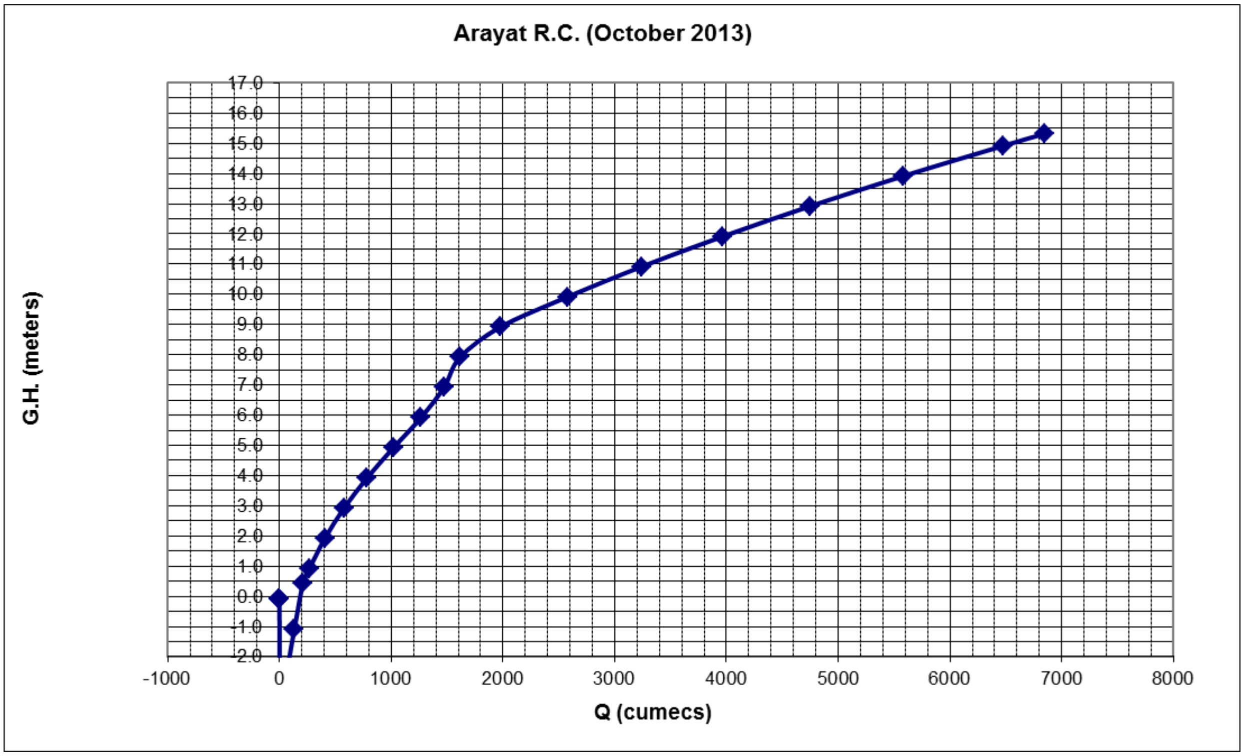

Figure 10: Rating Curve of Arayat Station

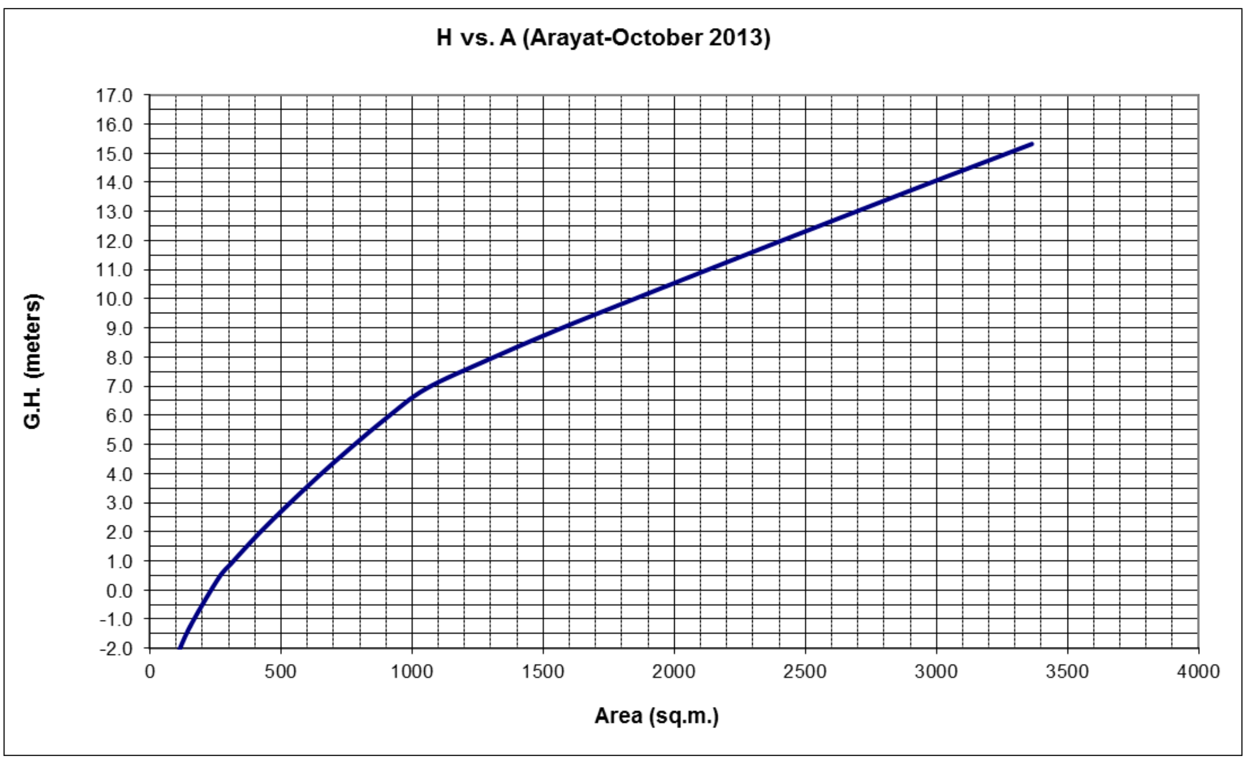

Figure 10: Graph of G.H. vs. Area

Table 6: Rating Table of Arayat

Rating Table for:			***Arayat***			Date:			
River:		*Pampanga*		Location:		*San Agustin, Arayat, Pampanga*			
Elevation of S.G. "0" reading:			*0*						
Rating Curve Equation Coefficients:		**a =**	***0.026***	**Ho=**	***-10.100***	**b^=**	***3.851***		
Range of G.H.:		Min. G.H. =	***0.082***	Max. possible G.H.=			***11.08***		
Remarks:	*readings based on staff gage and not in MSL*								

G.H.(m)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.1	197.76	198.51	199.26	200.01	200.77	201.53	202.29	203.05	203.81	204.58
0.2	205.35	206.12	206.89	207.66	208.44	209.22	210.00	210.78	211.57	212.35
0.3	213.14	213.93	214.73	215.52	216.32	217.12	217.93	218.73	219.54	220.35
0.4	221.16	221.97	222.79	223.61	224.43	225.25	226.07	226.90	227.73	228.56
0.5	229.39	230.23	231.07	231.91	232.75	233.60	234.44	235.29	236.15	237.00
0.6	237.86	238.71	239.58	240.44	241.30	242.17	243.04	243.91	244.79	245.67
0.7	246.55	247.43	248.31	249.20	250.09	250.98	251.87	252.77	253.67	254.57
0.8	255.47	256.37	257.28	258.19	259.10	260.02	260.94	261.86	262.78	263.70
0.9	264.63	265.56	266.49	267.42	268.36	269.30	270.24	271.18	272.13	273.08
1.0	274.03	274.98	275.94	276.90	277.86	278.82	279.79	280.76	281.73	282.70
1.1	283.68	284.65	285.63	286.62	287.60	288.59	289.58	290.58	291.57	292.57
1.2	293.57	294.57	295.58	296.59	297.60	298.61	299.63	300.65	301.67	302.69
1.3	303.72	304.75	305.78	306.81	307.85	308.89	309.93	310.97	312.02	313.07
1.4	314.12	315.18	316.24	317.30	318.36	319.42	320.49	321.56	322.64	323.71
1.5	324.79	325.87	326.96	328.04	329.13	330.22	331.32	332.42	333.52	334.62
1.6	335.72	336.83	337.94	339.06	340.17	341.29	342.41	343.54	344.66	345.79
1.7	346.93	348.06	349.20	350.34	351.48	352.63	353.78	354.93	356.09	357.24
1.8	358.40	359.57	360.73	361.90	363.07	364.25	365.42	366.60	367.79	368.97
1.9	370.16	371.35	372.55	373.74	374.94	376.14	377.35	378.56	379.77	380.98
2.0	382.20	383.42	384.64	385.87	387.10	388.33	389.56	390.80	392.04	393.28
2.1	394.53	395.77	397.03	398.28	399.54	400.80	402.06	403.33	404.60	405.87
2.2	407.14	408.42	409.70	410.99	412.27	413.56	414.86	416.15	417.45	418.75
2.3	420.06	421.37	422.68	423.99	425.31	426.63	427.95	429.28	430.61	431.94
2.4	433.28	434.61	435.95	437.30	438.65	440.00	441.35	442.71	444.07	445.43
2.5	446.80	448.17	449.54	450.91	452.29	453.67	455.06	456.44	457.84	459.23
2.6	460.63	462.03	463.43	464.84	466.25	467.66	469.08	470.50	471.92	473.34
2.7	474.77	476.20	477.64	479.08	480.52	481.96	483.41	484.86	486.32	487.78
2.8	489.24	490.70	492.17	493.64	495.11	496.59	498.07	499.55	501.04	502.53
2.9	504.02	505.52	507.02	508.52	510.03	511.54	513.05	514.57	516.09	517.61
3.0	519.14	520.67	522.20	523.74	525.28	526.82	528.37	529.92	531.47	533.03
3.1	534.59	536.15	537.72	539.29	540.86	542.44	544.02	545.61	547.19	548.78
3.2	550.38	551.98	553.58	555.18	556.79	558.40	560.01	561.63	563.25	564.88
3.3	566.51	568.14	569.78	571.41	573.06	574.70	576.35	578.00	579.66	581.32
3.4	582.98	584.65	586.32	588.00	589.67	591.36	593.04	594.73	596.42	598.12
3.5	599.81	601.52	603.22	604.93	606.65	608.36	610.08	611.81	613.53	615.27
3.6	617.00	618.74	620.48	622.23	623.98	625.73	627.49	629.25	631.01	632.78

3.7	634.55	636.32	638.10	639.88	641.67	643.46	645.25	647.05	648.85	650.66
3.8	652.46	654.28	656.09	657.91	659.73	661.56	663.39	665.22	667.06	668.90
3.9	670.75	672.60	674.45	676.31	678.17	680.03	681.90	683.77	685.65	687.53
4.0	689.41	691.30	693.19	695.09	696.99	698.89	700.79	702.70	704.62	706.54
4.1	708.46	710.38	712.31	714.25	716.18	718.13	720.07	722.02	723.97	725.93
4.2	727.89	729.85	731.82	733.80	735.77	737.75	739.74	741.73	743.72	745.71
4.3	747.71	749.72	751.73	753.74	755.75	757.77	759.80	761.83	763.86	765.89
4.4	767.93	769.98	772.03	774.08	776.13	778.19	780.26	782.33	784.40	786.48
4.5	788.56	790.64	792.73	794.82	796.92	799.02	801.13	803.23	805.35	807.47
4.6	809.59	811.71	813.84	815.98	818.11	820.26	822.40	824.55	826.71	828.87
4.7	831.03	833.20	835.37	837.54	839.72	841.91	844.09	846.29	848.48	850.68
4.8	852.89	855.10	857.31	859.53	861.75	863.98	866.21	868.44	870.68	872.92
4.9	875.17	877.42	879.68	881.94	884.20	886.47	888.74	891.02	893.30	895.59
5.0	897.88	900.18	902.47	904.78	907.09	909.40	911.71	914.04	916.36	918.69
5.1	921.02	923.36	925.71	928.05	930.40	932.76	935.12	937.49	939.86	942.23
5.2	944.61	946.99	949.38	951.77	954.16	956.56	958.97	961.38	963.79	966.21
5.3	968.63	971.06	973.49	975.93	978.37	980.82	983.27	985.72	988.18	990.64
5.4	993.11	995.58	998.06	1000.54	1003.03	1005.52	1008.01	1010.51	1013.02	1015.53
5.5	1018.04	1020.56	1023.08	1025.61	1028.14	1030.68	1033.22	1035.77	1038.32	1040.87
5.6	1043.43	1046.00	1048.57	1051.14	1053.72	1056.30	1058.89	1061.48	1064.08	1066.68
5.7	1069.29	1071.90	1074.52	1077.14	1079.76	1082.39	1085.03	1087.67	1090.31	1092.96
5.8	1095.62	1098.28	1100.94	1103.61	1106.28	1108.96	1111.64	1114.33	1117.02	1119.72
5.9	1122.42	1125.13	1127.84	1130.56	1133.28	1136.01	1138.74	1141.47	1144.22	1146.96
6.0	1149.71	1152.47	1155.23	1157.99	1160.76	1163.54	1166.32	1169.10	1171.89	1174.69
6.1	1177.49	1180.29	1183.10	1185.92	1188.74	1191.56	1194.39	1197.22	1200.06	1202.91
6.2	1205.76	1208.61	1211.47	1214.34	1217.20	1220.08	1222.96	1225.84	1228.73	1231.63
6.3	1234.53	1237.43	1240.34	1243.26	1246.18	1249.10	1252.03	1254.96	1257.90	1260.85
6.4	1263.80	1266.76	1269.72	1272.68	1275.65	1278.63	1281.61	1284.60	1287.59	1290.58
6.5	1293.59	1296.59	1299.60	1302.62	1305.64	1308.67	1311.70	1314.74	1317.78	1320.83
6.6	1323.89	1326.95	1330.01	1333.08	1336.15	1339.23	1342.32	1345.41	1348.50	1351.60
6.7	1354.71	1357.82	1360.94	1364.06	1367.19	1370.32	1373.46	1376.60	1379.75	1382.90
6.8	1386.06	1389.23	1392.40	1395.57	1398.75	1401.94	1405.13	1408.33	1411.53	1414.74
6.9	1417.95	1421.17	1424.39	1427.62	1430.85	1434.09	1437.34	1440.59	1443.85	1447.11
7.0	1450.37	1453.65	1456.92	1460.21	1463.50	1466.79	1470.09	1473.40	1476.71	1480.02
7.1	1483.35	1486.67	1490.01	1493.34	1496.69	1500.04	1503.39	1506.75	1510.12	1513.49
7.2	1516.87	1520.25	1523.64	1527.03	1530.43	1533.84	1537.25	1540.67	1544.09	1547.52
7.3	1550.95	1554.39	1557.83	1561.28	1564.74	1568.20	1571.67	1575.14	1578.62	1582.10
7.4	1585.59	1589.09	1592.59	1596.10	1599.61	1603.13	1606.65	1610.18	1613.72	1617.26
7.5	1620.81	1624.36	1627.92	1631.48	1635.05	1638.63	1642.21	1645.80	1649.39	1652.99
7.6	1656.60	1660.21	1663.82	1667.45	1671.07	1674.71	1678.35	1681.99	1685.65	1689.30
7.7	1692.97	1696.64	1700.31	1703.99	1707.68	1711.37	1715.07	1718.78	1722.49	1726.20
7.8	1729.93	1733.66	1737.39	1741.13	1744.88	1748.63	1752.39	1756.15	1759.92	1763.70
7.9	1767.48	1771.27	1775.06	1778.86	1782.67	1786.48	1790.30	1794.12	1797.95	1801.79
8.0	1805.63	1809.48	1813.34	1817.20	1821.06	1824.94	1828.82	1832.70	1836.59	1840.49
8.1	1844.39	1848.30	1852.22	1856.14	1860.07	1864.00	1867.94	1871.89	1875.84	1879.80

8.2	1883.76	1887.74	1891.71	1895.70	1899.69	1903.68	1907.68	1911.69	1915.71	1919.73
8.3	1923.76	1927.79	1931.83	1935.87	1939.93	1943.98	1948.05	1952.12	1956.20	1960.28
8.4	1964.37	1968.47	1972.57	1976.68	1980.79	1984.92	1989.04	1993.18	1997.32	2001.47
8.5	2005.62	2009.78	2013.94	2018.12	2022.30	2026.48	2030.67	2034.87	2039.08	2043.29
8.6	2047.50	2051.73	2055.96	2060.19	2064.44	2068.69	2072.94	2077.21	2081.48	2085.75
8.7	2090.03	2094.32	2098.62	2102.92	2107.23	2111.54	2115.86	2120.19	2124.52	2128.87
8.8	2133.21	2137.57	2141.93	2146.29	2150.67	2155.05	2159.44	2163.83	2168.23	2172.64
8.9	2177.05	2181.47	2185.90	2190.33	2194.77	2199.22	2203.67	2208.13	2212.60	2217.07
9.0	2221.55	2226.04	2230.53	2235.03	2239.54	2244.05	2248.57	2253.10	2257.63	2262.17
9.1	2266.72	2271.27	2275.83	2280.40	2284.98	2289.56	2294.15	2298.74	2303.34	2307.95
9.2	2312.57	2317.19	2321.82	2326.45	2331.09	2335.74	2340.40	2345.06	2349.73	2354.41
9.3	2359.09	2363.79	2368.48	2373.19	2377.90	2382.62	2387.34	2392.07	2396.81	2401.56
9.4	2406.31	2411.07	2415.84	2420.61	2425.39	2430.18	2434.98	2439.78	2444.59	2449.40
9.5	2454.23	2459.06	2463.89	2468.74	2473.59	2478.45	2483.31	2488.19	2493.06	2497.95
9.6	2502.84	2507.75	2512.65	2517.57	2522.49	2527.42	2532.36	2537.30	2542.25	2547.21
9.7	2552.17	2557.14	2562.12	2567.11	2572.10	2577.10	2582.11	2587.13	2592.15	2597.18
9.8	2602.21	2607.26	2612.31	2617.37	2622.43	2627.51	2632.59	2637.67	2642.77	2647.87
9.9	2652.98	2658.10	2663.22	2668.35	2673.49	2678.64	2683.79	2688.95	2694.12	2699.29
10.0	2704.47	2709.66	2714.86	2720.07	2725.28	2730.50	2735.72	2740.96	2746.20	2751.45
10.1	2756.71	2761.97	2767.24	2772.52	2777.81	2783.10	2788.40	2793.71	2799.03	2804.35

9. Summary and Conclusions

Indirect and direct methods of discharge measurement have their limitations and strengths depending on the practical use of each during flood and non-flood seasons. For the float method, it is the most practical and most effective method for peak discharge determination when all other methods are impossible to be performed.

On the other hand, the slope – area method, a tedious and iterative method provides good information on the discharge of the streams given accurate instruments.

Meanwhile, the ADCP has proven to be beneficial to stream gauging in several ways. The use of ADCPs has reduced the time it takes to make a discharge measurement. The ADCP allows discharge measurements to be made in some flooding conditions that were not previously possible. Lastly, the ADCP provides a detailed profile of water velocity and direction for the majority of a cross section instead of just at point locations with a mechanical current meter; this improves the discharge measurement accuracy.

Current meter method is the most common among the methods for measuring discharge. In this method, a stream channel cross-section is divided into numerous vertical subsections and the water velocity is determined using a Price AA current meter.

Finally, we derived the rating curve equation of,

Having a slope of 0.00015, roughness coefficient of 0.030 and elevation of "0" S.G. = 0.082.

10. Future Developments

This fieldwork activity is a practical application of the four discharge measurement techniques. Problems were encountered and there were deviations from the standard specifications of each method as expected. Results of this study may not provide very accurate results given some limitations on the conduct of the activity. Thus, comparison of the results in this study can be verified or cross-referenced with the information available at the PRFFWC. The use of materials under standard specifications for this activity can be improved in future similar hydrographic survey to ensure optimal results. Proper calibration of equipment is likewise recommended.

11. Travel Insights

Day 1 - La Mesa Dam

The La Mesa Watershed is the first destination, and the first of the four dams visited during the field work. The visit to the dam includes a brief discussion of how significant is the La Mesa watershed from the waters processed by Manila Water and Maynilad, to the waters consumed by residents of Metro Manila.

Day 5 - Pantabangan Dam

In general, the visit to Pantabangan Dam was literally warm but welcoming. The nearly four-hour trip to the dam was compensated with a sophisticated ambience of the hall and a heavy snack. In addition, the flood forecasting and warning center for dam operations of Pantabangan has a mix of modern and old school facilities. Above all, the dam's watershed and spillway turned out to be a breathtaking landscape. It was very nice taking pictures within the area.

Day 7 - Cong Dadong Dam

Cong Dadong Dam was visited right after the third field work. It was located upstream of Pampanga River from San Agustin Bridge, a few kilometers away. The dam was said to be mainly for irrigation purposes, thus, its construction is fairly simple compared to other dams.

Day 9 - Calumpit/Bacolor/Clark

First of the three trips during Day 9 is the Municipal Disaster Risk Reduction and Management Council (MDRRMC) in Calumpit, Bulacan. The town of Calumpit claims itself to be flood-loving people. This is the reason why they came up with a flood monitoring system using Microsoft Excel Suite. This is an impressive move on the part of the municipality of Calumpit and a good initiative for other nearby towns to follow suit.

Next stop is the San Guillermo Parish Church, also known as the Sunken Church of Bacolor in Pampanga. By the name itself, it was noticed how the church sank by a few meters after the Mount Pinatubo eruption in 1991, giving the impression that it has a low elevation. However, it was admirable to see how the church was saved while still preserving its historical attributes.

Last stop for the day was the tour of Clark Freeport Zone near Angeles City, Pampanga. The place is best known for its airport and leisure hubs, but the group decided to stop again at Duty Free. Clark looked clean and peaceful in general.

Day 10 -Angat Dam

The last destination of the field work and the last of the four dams, is the Angat Dam in Norzagaray, Bulacan. The way to the dam, as well as its landscapes and spillway, is closely similar to that of Pantabangan dam. However, the trainees were given a closer look inside the Angat Hydroelectric Power Plant which contains huge electrical rotors, armatures, and transformers.

12. References

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