Discharge Measurement of the Pampanga River – Arayat Station Using Direct and Indirect Methods

By

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Abstract

In the world of hydrology, it is important to account for water parameters and study them in order to make better decisions with respect to human lives and properties at stake. Discharge measurements are taken in order to somewhat project the behaviour of the streams especially when there are weather systems such as typhoons which induce rains and later on enhance flooding events. It is imperative that the hydrologists have an idea as to when, where and how much water will overflow. In this study, the author was exposed in a post-flood investigation survey in order to determine the extent of flooding caused by Typhoon Santi in portions of the Pampanga River specifically in the Arayat Station. Together with colleagues in the Hydrologists Training Course, the author measured several cross sections downstream of the San Agustin bridge using four commonly used direct and indirect methods of discharge measurements namely : a.) float method; b.) slope-area method; c.) Acoustic Doppler Current Profiler (ADCP) method; and d.) conventional current meter method. Results of the four methods vary due to several factors such as the length of time spent in each method, lowering of water level, presence of a dam upstream of the station and errors in the use and handling of instruments as well as human-induced errors. Nevertheless, the objective of the fieldwork which is to do an actual river cross-sectioning and compare the four methods of discharge measurement was attained.

Keywords: Hydrometry, Discharge Measurement, Stream Gauging, Pampanga River Basin, Slope-Area, Current Meter, Acoustic Doppler Current Profiler, Float Method, H-Q, Rating Curve

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1. 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 (WMO). It is usually computed using some parameters such as the stream width, depth and flow velocity which is later expressed in cubic metres per second (m^3/s).

Discharge measurement is particularly critical especially that Philippines lies in the path of tropical cyclones with an annual average of twenty tropical cyclones that enter the Philippine Area of Responsibility. 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.

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.

Catastrophic events like tropical cyclones and inundations cannot be eliminated however precautions can always be developed. A 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. These 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.

2. Background

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

Discharge Measurement of the Pampanga River – Arayat Station Using Direct and Indirect Methods

The author is a hydrologist trainee with a technical background in Remote Sensing and Geographic Information System (GIS) and is guided by Engr. Hilton T. Hernando, Engr. Roy A. Badilla and Engr. Socrates F. Paat, Jr. for this course.

This study was selected and designed on the basis of the following factors:

- Practical application of discharge measurement/stream gauging;
- Proximity of the study area to Metro Manila; and
- Availability of instruments/equipment which minimizes fieldwork costs.

3. 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.

Specifically, the study seeks to:

a.) investigate and describe the behaviour of the flooding event caused by Typhoon Santi in the Arayat Station of Pampanga River; and

b.) compare and contrast the four discharge measurement methods such as the Float, Slope-Area, ADCP and Current Meter Methods in terms of practical applications, advantages and disadvantages.

4. Review of Previous Works

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, a joint river cross-sectioning of the major river systems within the PRB was done, 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.

Moreover, the center has managed to do several hydrographic works in 2010 including collaborative undertakings with other agencies such as a.) river cross-sectioning and determination of elevation of "0" gage reading of SG at various stream gauging stations and within the basin from February 9-15; b.) river cross-sectioning along Angat River on April 26-30; c.) ocular survey of Brgy. Bancal, Guagua for selection of possible sites for staff gauges and flood markers on August 09; d.) river cross-sectioning within the Sta. Maria River Basin and installation of staff gages at various stations within the said river basin system on August 5-6; e.) assisted and supported the Barangay Disaster Coordinating Council (BDCC) of Brgy. Bancal, Guagua in the installation of staff gauges and flood markers on August 23; f.) assisted the JICA expert (Mr. Kurauchi) in the selection of discharge sections along Pampanga River as part of rehabilitation program of PRB and FFWSDO on August 19; and g.) assisted and supported the JICA consultant in monitoring of the river velocity measurement activities of the river measurement contractors at Arayat stream gauging station as part of the rehabilitation project of the FFWSDO.

5. 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. It is within the metes and bounds of the

Pampanga River Basin which is the 4th largest basin in the Philippines with an aggregate area of 10,434 km^2. Pampanga River has a channel length of around 265 km and headwaters originating in the Caraballo Mountains north of the basin. It flows into Pantabangan Dam. From the dam it further flows southward meeting with several tributaries until emptying into Manila Bay.

River cross-sectioning was done at Barangay San Agustin in the municipality of Arayat. Measurements were taken downstream of 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.

6. 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. An additional task by one of the groups was to take a cross section of the river reckoning from the bridge top which will be used for the derivation of a rating curve and a rating table for Arayat.

6.1. 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.

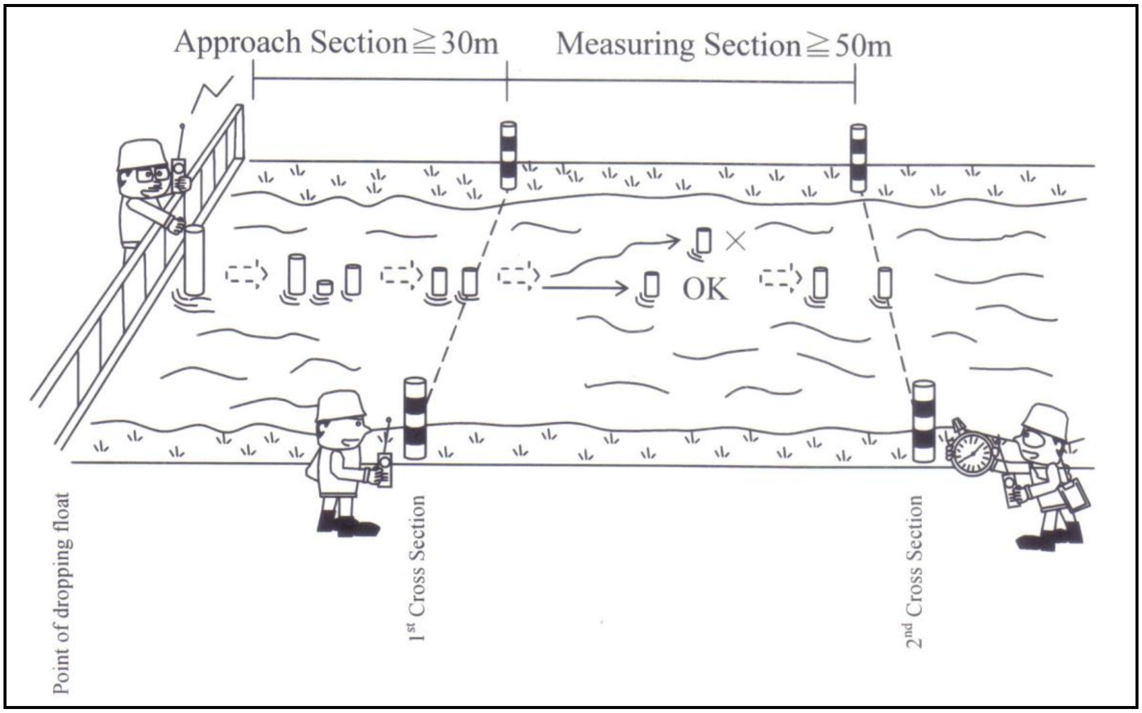

Figure 2. Discharge measurement by float method.

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 and utilizing an echo sounder to record water depth and a range-finder to determine the horizontal 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 $Q_i = V_i \times A_i$.

6.2. 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:

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

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.

The slope, σ, or the fall may be determined by dividing the difference in the water surface elevations at the two ends of the reach represented by the high water marks in cross sections 1 and 3 by the total length of the reach. A value of greater than or equal to 0.15 or greater than or equal to the velocity head should be attained.

The hydraulic radius, R_h, is defined as the area of the cross section divided by its wetted perimeter. Where the channel or canal is of regular cross section, and the depths at the ends of the course are equal, the area and the wetted perimeter will be constant through-out the course. In irregular channels, the area and the wetted perimeter at several cross sections will be required, and a mean value will be used in computing the hydraulic radius.

Figure 3. Fairly straight river reach

The factor, *n*, depends on the character of the channel. It may vary from 0.010, where conditions approaching the ideal are maintained, to 0.060, where the channel is strewn with stones and debris or is about one-third full of vegetation.

Because the proper selection of the roughness factor, *n*, for many streams is difficult and is, at best, an estimate, the discharge determined by the slope-area method is only approximate. Care must be taken to determine the slope and areas simultaneously if the water levels are changing.

Figure 4. Actual slope area using a total station.

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 Backsights 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 + Height of Prism Rod – BS

Unknown Elevation = HI + FS – Height of Prism Rod

where: HI = height of Instrument
BM = Benchmark Elevation
BS = Back Sight (VD reading from total station)
FS = Fore Sight (VD reading from total station)

For easy computations, an excel suite provided by the PRFFWC for automatic discharge computation by slope-area method was provided.

6.3. 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.

Figure 5. The ADCP instrument with the team.

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.

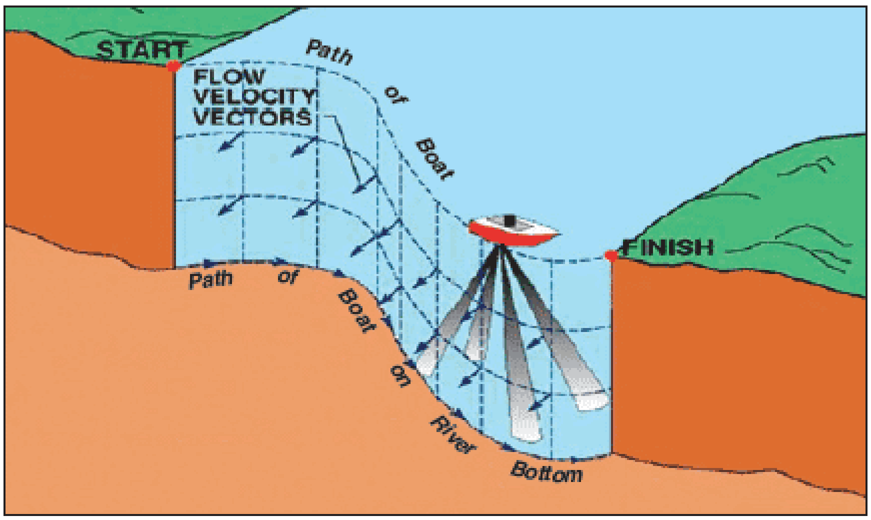

Figure 6. The ADCP Principle of discharge measurement.

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.

6.4. Conventional 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 7. 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:

$$V = 0.702N + 0.013$$

6.5. 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.

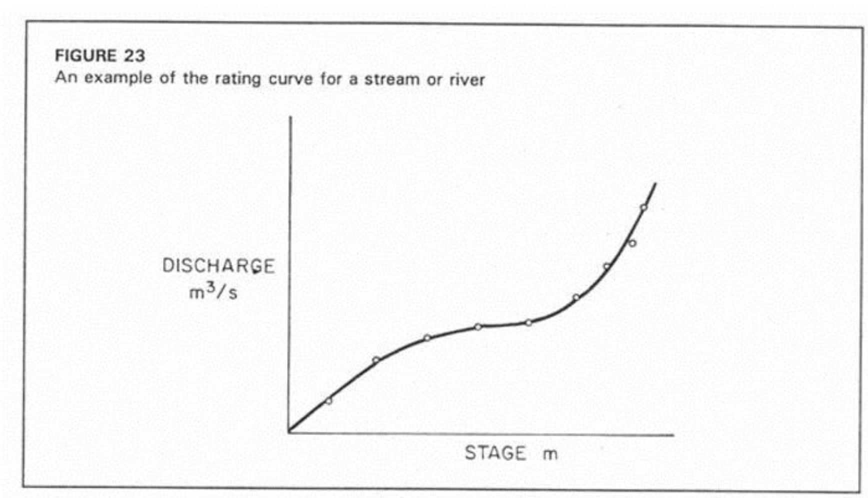

Figure 8. Rating curve sample.

For this particular method, a cross section of the river measured from the bridge top using a sounding rope with weights was obtained. With the aid of the excel suite for rating curve from the PRFFWC, the rating curve and table were derived.

7. Results and Discussion

After all data has been harmonized, integrated and analyzed, results of the study from the four different discharge measurement methods were summarized in the succeeding tables below. Table 1 summarizes the data for the float method. Since during the actual measurement, water level is relatively high, a discharge of 738.24 m^3 was computed by averaging the discharges at the first and second cross sections established.

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**			
*Mid-section method was used to compute for the Q									

Based on the table of measurements above, the two cross sections were plotted as shown in the succeeding figures. The plots of the cross sections show that the water depth increases from right to left bank with the deepest portion recorded at about 11.6 and 7.6 meters, for the first and second cross sections, respectively.

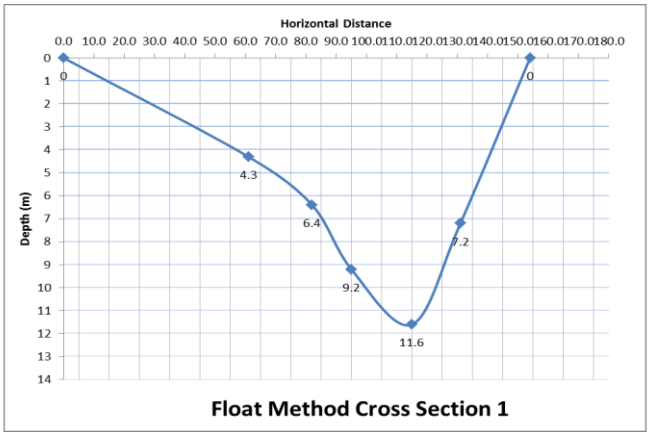

Figure 9. Float Cross Section 1 Profile

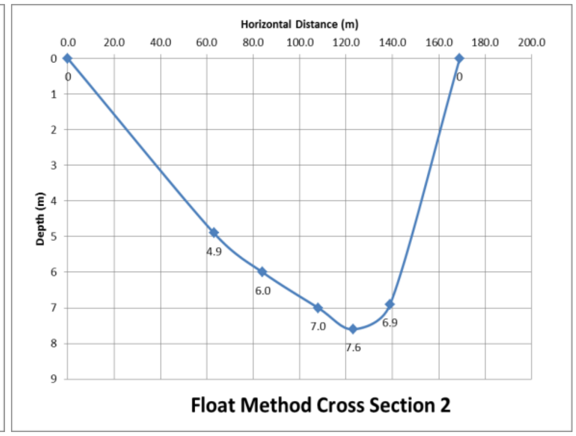

Figure 10. Float Cross Section 2 Profile

On the other hand, the slope area measurements were summarized in Table 2. It appears that the highest water elevation during the flood was at 8.274 meters at the right bank of the first cross section.

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

Given the data in Table 2, the three cross sections of the river were plotted taking into consideration the highest water mark at both banks as shown in the figures below. All the measurements were then used in the excel suite for the automation of calculations and is summarized in the figures below.

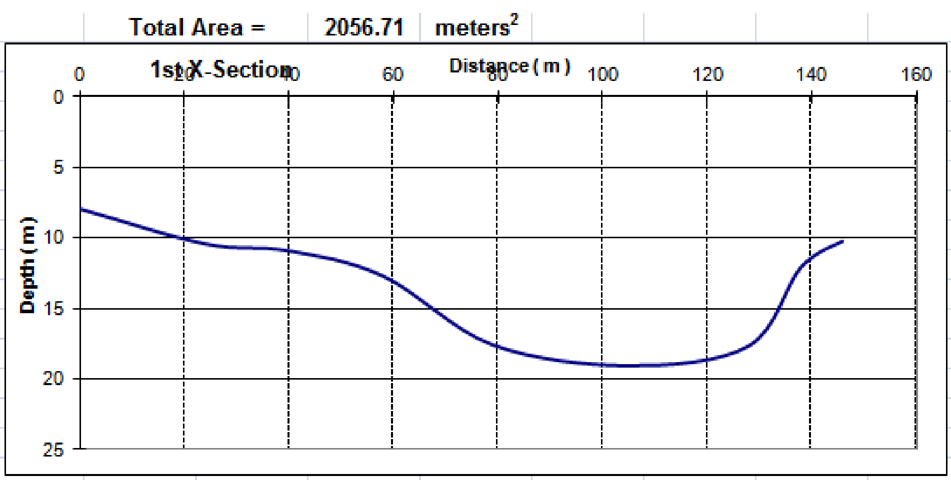

Figure 11. Slope Area first Cross Section

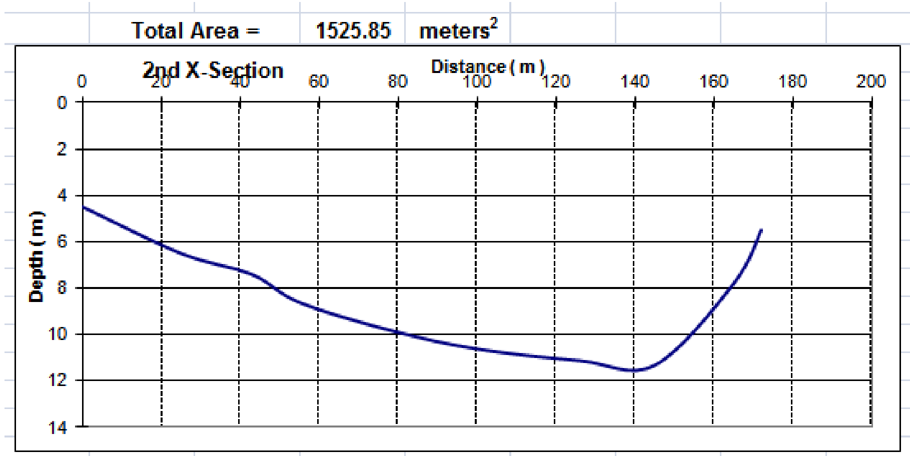

Figure 12. Slope Area Cross Second Section

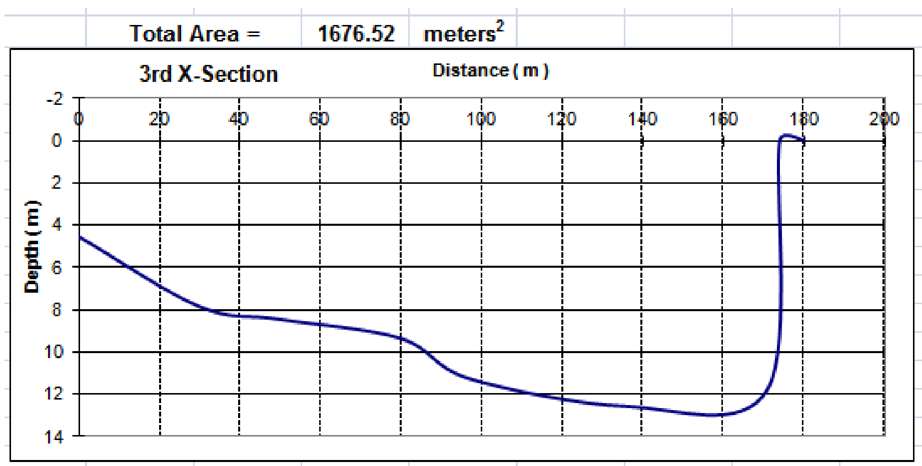

Figure 13. Slope Area Thrird Cross Section

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. #:	

hth/ 97

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	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

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	0.068878	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:

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 betw een 2 sections.
h_v - velocity head
h_f - energy loss due to boundary friction in the reach.
S - friction slope

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

Discharge

Figure 14. Slope-Area Summary using the PRFFWC Excel Suite

The slope of the river which was obtained by taking the difference of the highest water elevations from the first and the last cross sections divided by the total reach. A slope value of 0.00015 was then computed. The roughness coefficient used was 0.030.

Substituting these values together with other parameters computed in the Manning's formula, a discharge of 2,389.70 was obtained for this method.

For the ADCP method, the discharges computed by the instrument in the eight transects were summarized in Table 3. An average discharge of 288.881 m^3 was recorded. Supporting graphs and time series plots were included in the succeeding figures.

Table 3. 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**

The first transect was measured starting off at the downstream of the bridge reckoning from the left bank. A discharge of 292.871 m^3 was recorded.

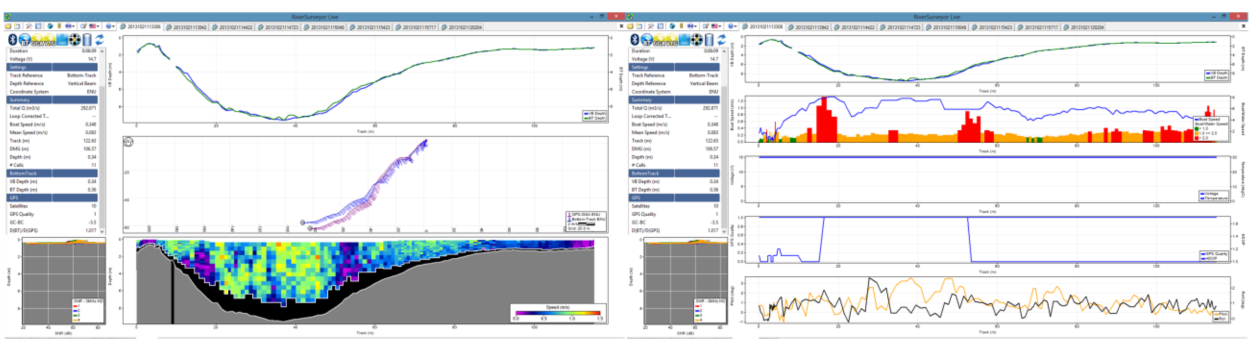

Figure 15. Transect and Time Series Plot 1

The second transect was measured from the right bank after the first transect. A discharge of 292.668 m^3 was recorded. A little difference was noted.

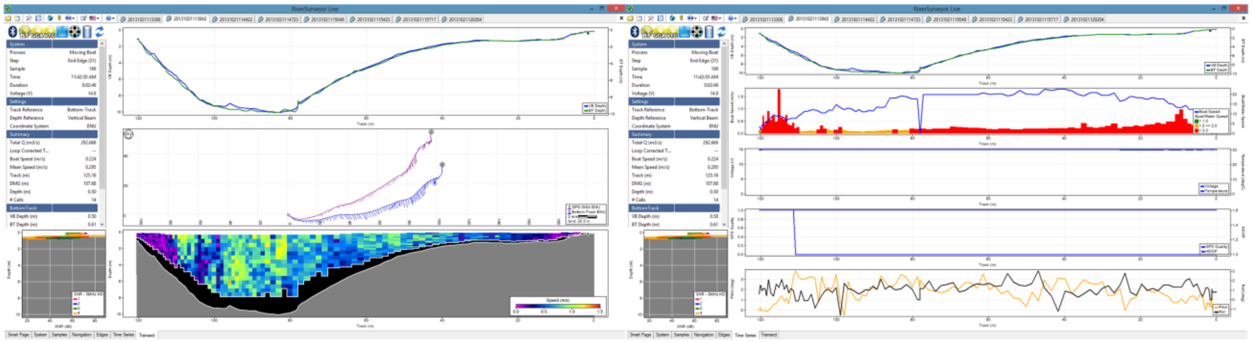

Figure 16. Transect and Time Series Plot 2

The third transect was measured from the left bank which is a few meters away from the first transect. A discharge of 304.15 m^3 was recorded. An increase of about 12 m^3 was noted.

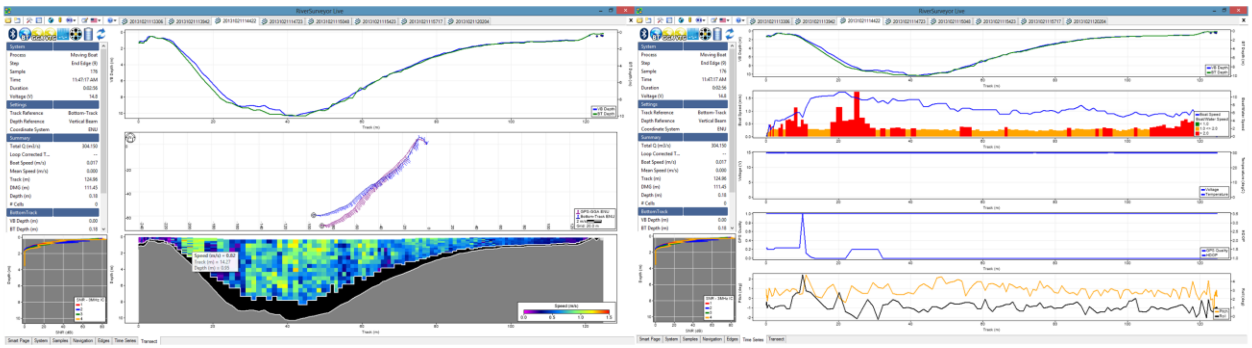

Figure 17. Transect and Time Series Plot 3

The fourth transect was measured from the right bank which is a few meters away from the second transect. A discharge of 334.503 m^3 was recorded. Another increase of about 30 m^3 was noted. This transect gave the highest discharge out of the eight.

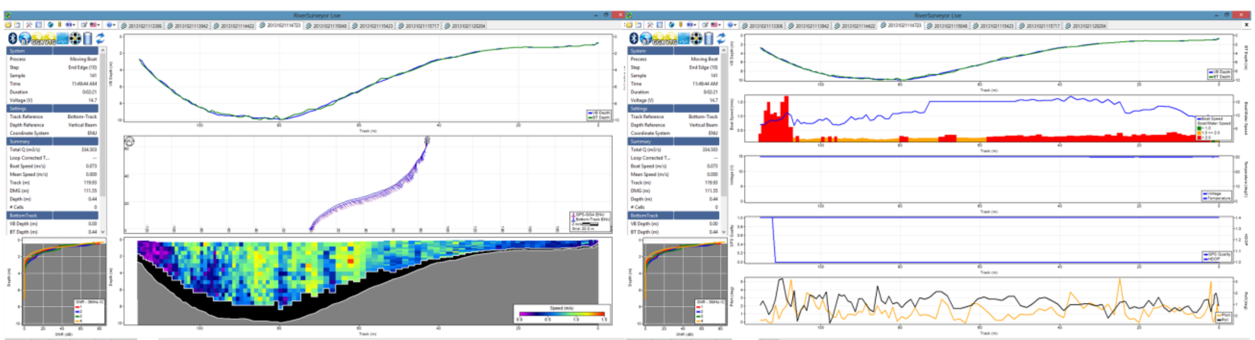

Figure 18. Transect and Time Series Plot 4

The fifth transect was measured from the left bank which is a few meters away from the third transect. A discharge of 250.691 m^3 was recorded. An abrupt decrease was noted which may be due to elevation gradient.

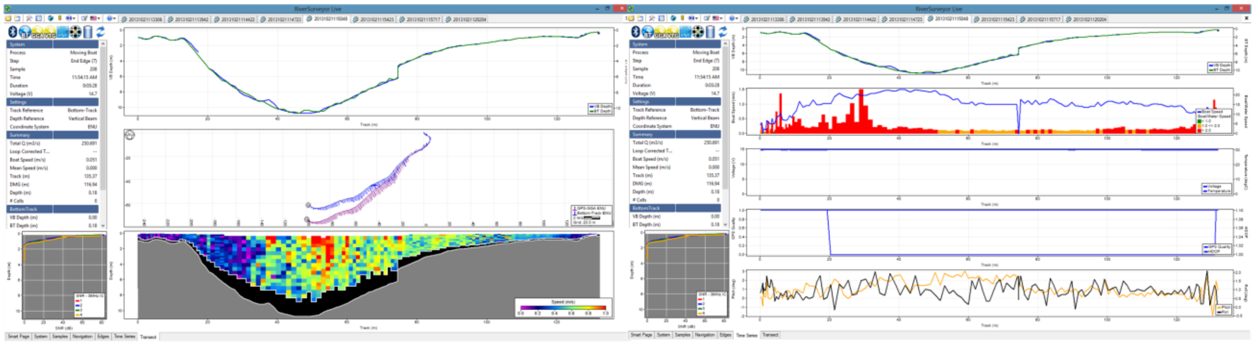

Figure 19. Transect and Time Series Plot 5

The sixth transect was measured from the right bank which is a few meters away from the fourth transect. A discharge of 238.568 m^3 was recorded. Now the water elevation might be decreasing.

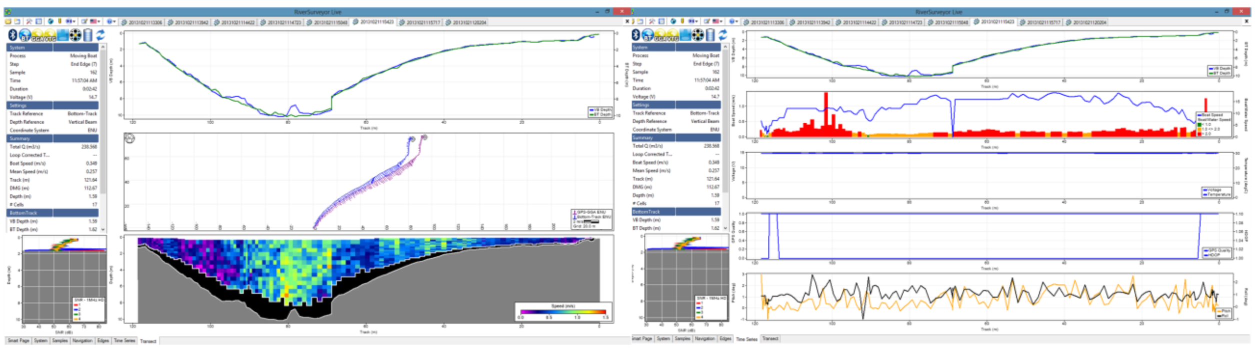

Figure 20. Transect and Time Series Plot 6

The seventh transect was measured from the right bank which is a few meters away from the fifth transect. A discharge of 296.384 m^3 was recorded.

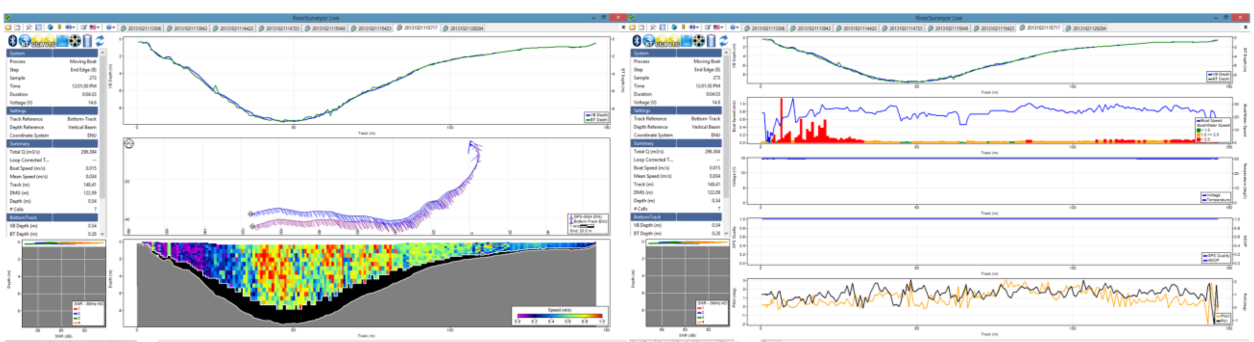

Figure 21. Transect and Time Series Plot 7

Finally, the eighth transect was measured from the right bank which is a few meters away from the sixth transect. A discharge of 301.213 m^3 was recorded.

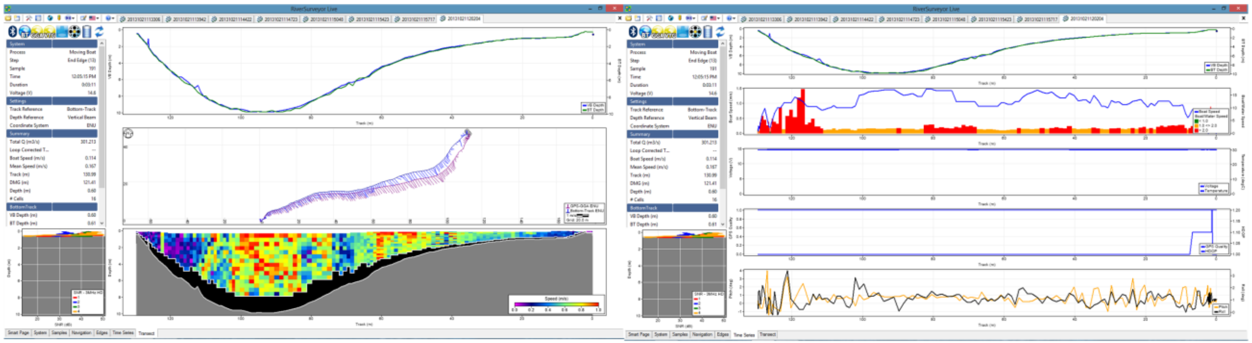

Figure 22. Transect and Time Series Plot 8

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.

As for the current meter method, velocity was measured at 0.6 of the water depth and beeps were recorded within a minute. Out of the 20 verticals, a few were not able to measure velocity due to decreasing water depth from the left bank to the right bank. Another factor which has made measurement impossible is that the flow of the water is controlled by the closing of the Cong Dadong Dam upstream. Water level also decreased since Day 1 of the fieldwork measurements. Several notes in the table below can be found such that entries for the No. of beeps = "unable" which accounts for the negligible flow of water although the current meter can still measure and No. of beeps

= "NA" wherein water depth is too shallow or the river bed is already exposed which make it impossible to make measurements.

Table 4. 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

Discharge measurement taken from the current meter method is a little unreliable due to some limitations during the fieldwork. The flow of the river is affected by the presence of a dam upstream which was closed in order to divert waters coming from the headwaters for irrigation purposes. Water level decreased significantly from day one up to day four thereby making it difficult to measure velocity at a given depth. One more thing is, the instrument used is quite old and is no longer at par with its calibration status.

The discharge measurements from all the groups during the fieldwork was collated and summarized in Table 5 for comparison.

Table 5. Summary of discharge measurements (m^3) for the four methods.

Method	Float	Slope-Area	ADCP	Current Meter
Day 1	**738.24**	3, 983.73	466.911	311.48
Day 2	614.02	**2, 389.70**	441.287	325.7
Day 3	493.163	3, 440.34	**288.881**	293.42
Day 4	240.62	3, 579.19	237.668	**13.86**

Results from the different methods for the four-day actual fieldwork reveal a decreasing pattern from Day 1 to Day 4. Discharge is practically high on the first day for all of the methods while a few deviations were also seen. All the measurements taken were implemented and analyzed presenting some problems in the final computations. Although the values computed vary, it is important to note that the correct process was understood and measurements can be improve in the future if similar task will be done.
Aside from the four methods of discharge measurement, an additional cross section taken from the bridge was also taken and used in the determination of the rating curve and rating table for Arayat. At different gauge heights, discharges were computed and plotted to come up with the rating curve. Similarly, a graph of the gauge height and area was also derived.

Table 6. Discharge at several gauge heights in Arayat.

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	

Given the information on the table above, the rating equation was derived as shown below. The values in this equation were then used to compute for the rating table values.

Rating Curve Equation: $$Q = 0.026\ [H - (-10.10)]^{3.851}$$

Table 7. Rating Table for Arayat Station in October, 2013

Rating Table for:	*Arayat*		Date:	*October, 2013*	
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

The succeeding figures describe the relationship between the stage and discharge for Arayat station. Similarly, a graph of the stage-area relationship was also made.

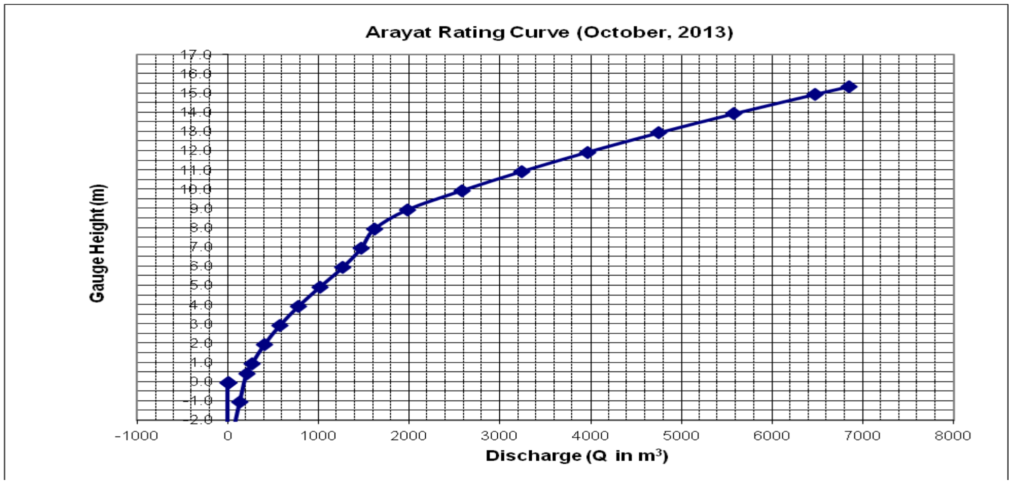

Figure 23. Rating Curve of Arayat Station on October, 2013

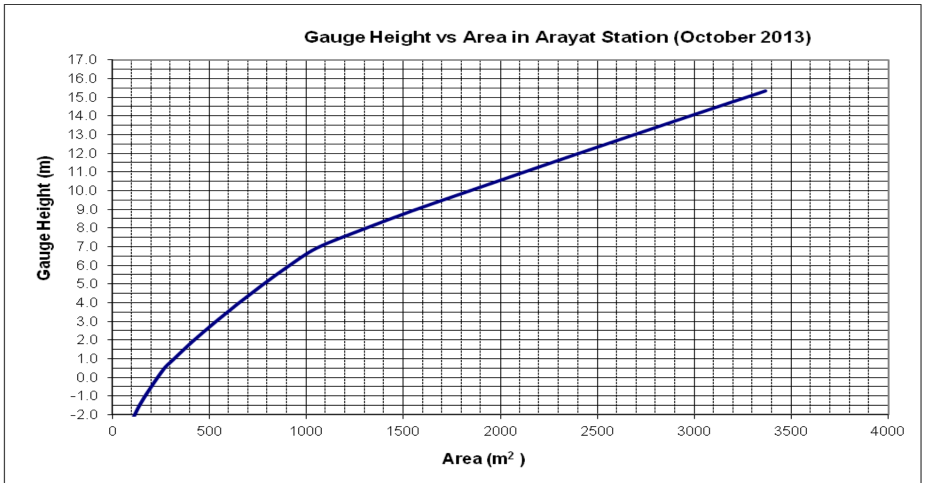

Figure 24. Gauge Height and Area Relationship in Arayat Station.

8. Summary and Conclusions

Based on all the cross section data analyze and plotted, it was found out that the Pampanga River in the Arayat station has its deep portions near the left bank and shallows towards the right bank. The deepest portion was measured at 11 meters from the water surface at the time of the fieldwork survey.

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. Aside from the easy set-up, materials needed are readily available and can be improvised. No sophisticated instruments are needed to perform the task.

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. Proper understanding on the mechanism of the slope-area will definitely make computations easy in the long run.

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.

In the case of current meter method, a more reliable result should have been arrived at if the limitations on the quality of the instrument and the presence of dam upstream were addressed.

Finally, the derivation of a rating curve is a good way to see the relationship between water level (stage) and the corresponding discharge of the river. It is the best input as boundary conditions for flood modelling.

9. 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 for future similar fieldworks.

10. Travel Insights

Aside from the actual river cross sectioning activity, the ten-day fieldwork provided an opportunity for us to reach several places in Central Luzon and gain insights with regards to hydrology and the environment in general. Dam visits were particularly exciting as these gigantic reservoirs take a great role in ensuring availability of water for different purposes at different times. I was particularly amazed on how these dams operate providing water for irrigation, power generation and water supply for domestic consumption.

Figure 23. La Mesa Da Visit

The La Mesa Dam which is most of the time blamed for flooding in Metro Manila and nearby provinces is a great control structure which helps in the water treatment process before it goes to the designated treatment plants in Balara for final processing. Designed to last up to a hundred years, La Mesa and Pantabangan dams are surprisingly capable of rehabilitating themselves as they are called earth-filled dams. This is a good feature which makes it easy to maintain in terms of structural maintenance.

Angat Dam, on the other hand is a concrete embankment which is programmed for water supply to Metro Manila. These three dams are of paramount importance in order to ensure that the needs of Metro Manila for water are sufficed.

Cong Dadong Dam is likewise a control structure which protects the downstream areas to excessive flooding. It's also an enabling structure which irrigates farmlands in Pampanga. All these dams are built to manage our water resources and they must be managed well in order to meet our needs for sustainability.

Figure 24. Pantabangan Dam Visit.

Figure 25. Cong Dadong Dam Visit

Figure 26. Angat Dam Visit

On the other hand, Flood Early Warning Systems developed in Calumpit, Bulacan is a great endeavour and should be replicated in other municipalities. This is a good indicator of spreading awareness and care to prepare in case of calamities. This technology is likewise one way to equip the local government units for disaster preparedness which will eventually lead to a resilient community.

Finally, the Bacolor Church is a symbol of hope for Pampanga. Although submerged by the eruption of Mt. Pinatubo, it stood still and remain strong until this time.

Figure 27. Bacolor Church Visit.

11. Acknowledgement

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

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