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

A TECHNICAL REPORT

Prepared by:

VIVIAN GAY C. AGGASID
HTC Trainee
PAGASA, DOST

Submitted to:

Engr. Hernando T. Hilton, AWSC
Engr. Socrates F. Paat Jr., SWS
Engr. Roy A. Badilla, AWSC

I. INTRODUCTION

Field work was carried out by thirty-two PAGASA Hydrologist trainees at Pampanga River basin specifically at the vicinity of San Agustin Bridge, Arayat Pampanga from October 17, 18, 21 and 22, 2013.

Prior to the fieldwork, the trainees were divided into four groups. Each group employed different direct and indirect methods of discharge measurement each day. The measurement methods employed were: ADCP (Acoustic Doppler Current Profiler), Current Meter, Float, and Slope-Area and Direct Method using Manning's formula. The data gathered were used to compute the discharge, rating curve, rating equation and finally the rating table of the river. Highest flood marks due to the passage of Typhoon Santi in the area were also noted observed and noted.

This report describes results of the fieldwork program which employed the methods of discharge measurements from collation, collection and analysis of data from field investigations and physical measurements.

Part of this learning, we also visited some dams and dikes in Pampanga, Nueva Ecija, Bulacan and the MDRRMC office at Calumpit, Bulacan.

II. STUDY AREA AND SITE DESCRIPTION

The site for the hydrological field work was chosen at the Arayat Station in Pampanga River located approximately at bridge 15°09'51.59"N and 120°46'58.56"E. The weather during was fair with no rainfall amount recorded over the area and the water level continued to recede during the course of the fieldwork.

The recent rainfall intensity experienced at the basin brought by the passage of Typhoon Santi caused the river to swell and overtopped its bank and inundated the flat area downstream and upstream of the bridge crossing the river. The critical water level of the river is 5.97 m. while the alert level is 5.0 m. During the flood, the water level of the river reached 8.78 meters high. The flood left its trace of debris, high water level marks, loam soils, clay and silt that is visible around the area.

There are two water level stations available in the site. A telemetered water level recording station is located at the approaching end of the bridge at downstream right bank . The other at upstream of bridge is the old water level recorder (counter weight system) structure where the station datum was established. The water level 0 -5m staff gauge is attached to the bridge center pier with stacking debris covering it.

Figure 1. The study area showing the San Agustin Bridge and the channel geometry of the Pampanga River

III. PURPOSE OF THE FIELDWORK

The purpose of this paper is to document procedures employed and to present the results of the fieldwork in collection, processing and analysis of streamflow discharge using direct and indirect methods.

IV. OBJECTIVES OF THE FIELDWORK

The major objectives of the field work program were:

1. To perform direct and indirect methods of discharge measurements such as:
    a. Acoustic Doppler Current Profiler (ADCP)
    b. Velocity Meter
    c. Float Method

d. Slope –Area Method

2. To be able to determine the highest flood marks during the occurrence of Tropical Cyclone Santi
3. To obtain physical measurements relating to discharge measurements

V. METHODOLOGY

Methods - The objectives will be met by conducting tasks that are described in detail below according to the different methods employed each day.

1. ACOUSTIC DOPPLER CURRENT PROFILER (ADCP) METHOD

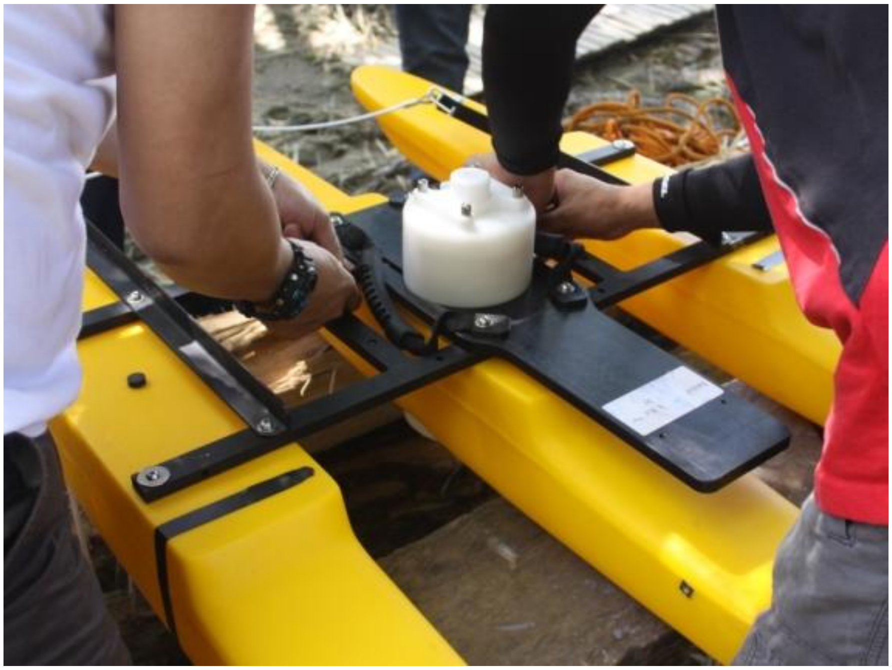

Figure 2. Assembling the ADCP intstrument.

The ADCP was used to measure the discharge over the study area in the first day of the fieldwork on October 18, 2013. Assembly and set up of the instrument was positioned at the left bank approximately 50 meters upstream of the bridge. The ADCP deployment platform used was by a tethered boat equipped with ADCP mount.

After the ADCP was mounted and communication between the ADCP and field computer was established, the instrument was checked to ensure all components were operating properly. Yaw, pitch and roll movement rotations were employed to calibrate the ADCP with the use of the laptop computer. The calibration procedure included determining the orientation of each transducer with respect to the bow and the compass calibration.

This ADCP deployment platform thru tethered boat was then attached to a manned boat which guided the platform thru its transect across the cross section. The ADCP was mounted, measurement cross section was selected upstream of the San Agustin Bridge. The manned boat guided the ADCP as it transects the river. Second transect was performed from the right bank going through the left bank.
The data were automatically stored in the computer.

Figure 3. Tethered ADCP boat used for making discharge measurements attached to a manned boat

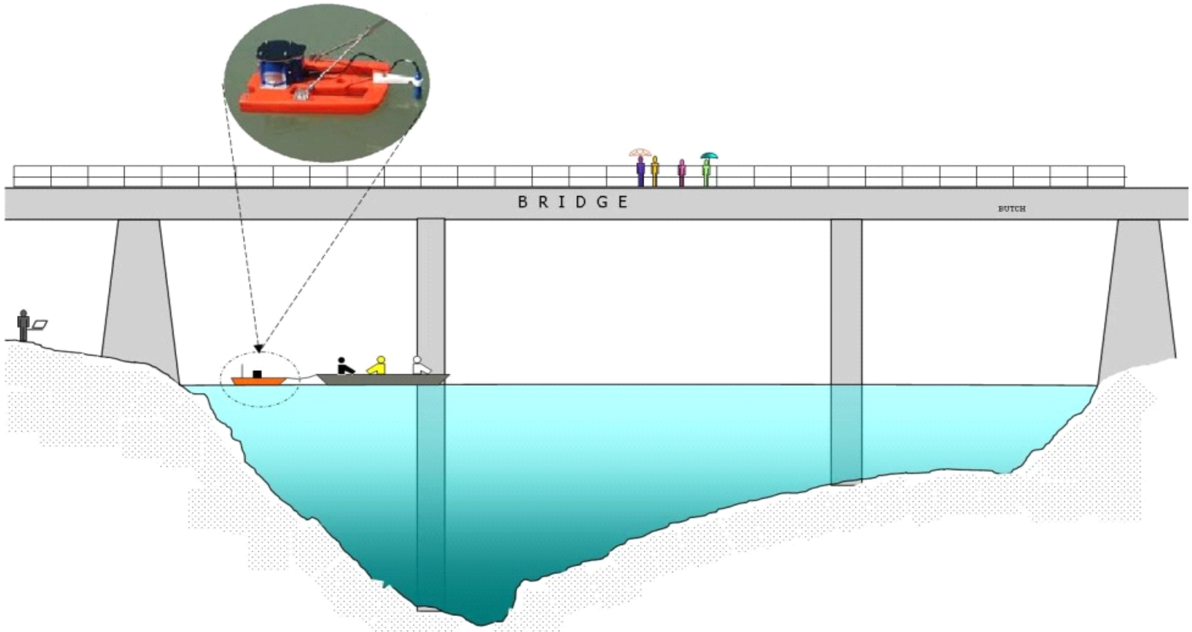

Figure 4. Deployment platform of the ADCP upstream the bridge

2. CURRENT METER METHOD

Measurements using Price AA current meter was carried out on top of San Agustin bridge facing downstream the river. Bridge width was divided into several intervals of 5 meters which made up the vertical observations starting from the left bank at the left water edge point.

Current meter parts were assembled by coupling the meter and the Columbus weight thru a hanger bar and attached to the cable from the reel, and connecting depth indicator and the current meter timer which counts every revolution of the rotor made during a specified time interval.

Suspension of the Columbus and propeller was conducted in taking the depth from water surface to riverbed applying the two-point velocity profile method. If strong current flow which may drag the length of the line out of the reel was observed, correction was applied. The step by step procedures that were conducted are enumerated below.

a. Record the staff gauge reading

b. Starting from the first established point on the left bank side, the equipment was positioned and set the depth counter indicator to zero.
c. The current meter was lowered thru a cable until it reaches the water surface. At this time the height of the bridge to the water surface was read and recorded as the depth of the water at that point.
d. From the water surface the current meter was lowered until it reached the river bed.
e. Knowing now the depth of the river on that specific column, the revolutions of the current meter was counted and recorded at the depth of 0.2 and 0.8 of the total depth. These were done actually by counting the beep (which was set to 1 beep per 5 revolutions) within 60 seconds after the device was stabilized on that point in the water.
f. Record the staff gauge reading
g. Combining the results of 0.2 and 0.8 measurements will give an average value and will be used as the mean velocity of the particular vertical observation.
h. These steps were repeated on every 5-meter interval until at the last established point on the bridge

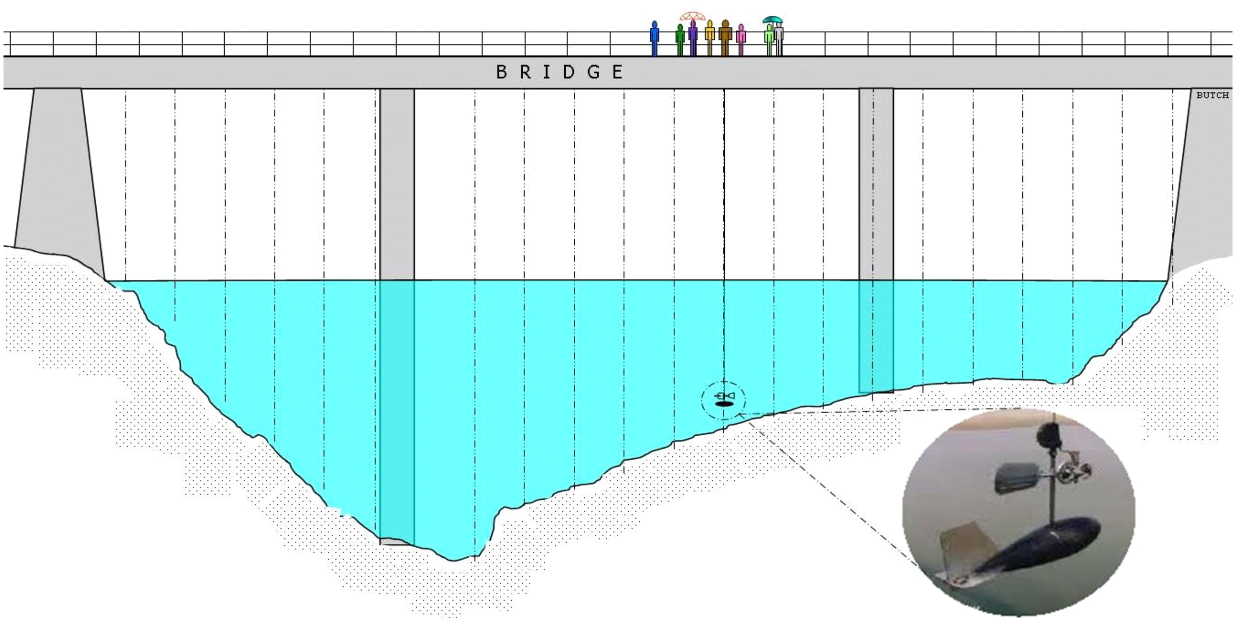

Figure 5. Current meter method of measuring discharge

3. FLOAT METHOD

The basic idea of using float method is to measure the time that it takes the object to float a specified distance downstream. For an increased accuracy to be desired and because stream was wide enough to allow one float as representative for the whole width, we divided the stream into 5 sections of float lanes and measure surface velocities in each lane. Each section was marked accordingly at top of the bridge.

The bamboo was designed as a floater to represent surface water velocity measurement in time. The following procedures were undertaken.

a. Selection and identification of straight reach with minimum turbulence at least 50 meters from the downstream of the bridge was done.
b. Along the river reach downstream of the bridge the first check section was marked 50 meters and further 50 meters for the second check section.
c. Marked 5 drop points along the bridge starting from the river centerline at 21.5m average both sides.
d. The floater was dropped from its vertical width correspond to its velocity streamline. The first check marker has to raise up the flag and simultaneously press his stopwatch to start the timer reading which indicated that it has crossed the first marker
e. When the second marker is reached pressing the stopwatch will signify the end of travelling time of the float. The total elapsed time from start to end of the reading was recorded.
f. These steps were done twice on each dropping point for every point two floats will be dropped from the bridge and use the average in further calculations. Each reading on the timer was recorded.

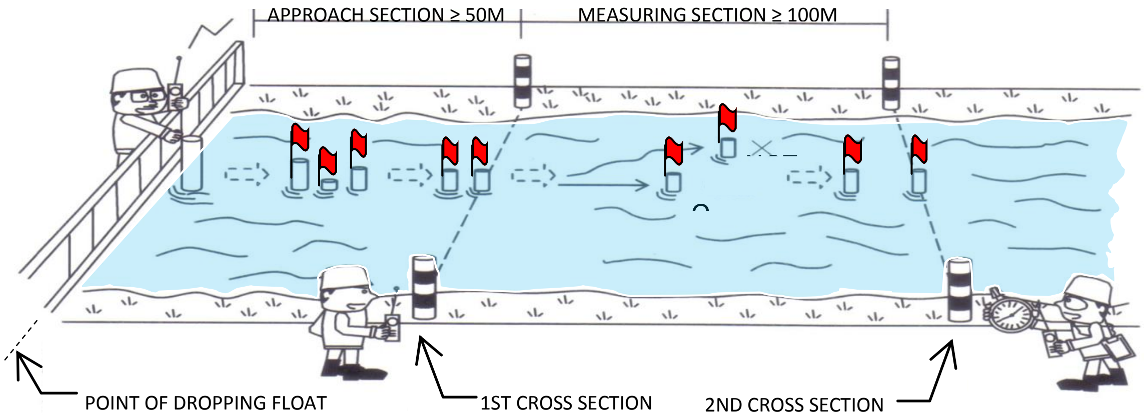

Figure 6. Discharge Measurement by Float Method

The river's cross section was obtained by means of echo sounding device. It was done by riding a boat while traversing the river. Depth of the river bed was recorded at every few meters along the river from the left bank to the right bank. The recorded depths determines the depth of the river which eventually to be used in the discharge measurement in this method.

4. SLOPE-AREA METHOD

The Slope-Area method is an indirect method of obtaining peak discharge of flood event. Residents were approached informally at their residences. They were asked to recollect any information and to identify where the flood waters had reached during the previous flood event caused by typhoon Santi. High water marks were identified and recorded.

By carrying out this method an instrument total station survey was performed from a geodetic bench mark located near the Arayat old water level recorder at the left bank of the river upstream the bridge with an elevation of 9.11 meters. From this starting reference point of survey was carried out and transferred to the right bank.
The area after 50m downstream of the bridge was divided into three cross sections 150 meters apart. In section 1, points were established from the flood mark to the

right bank and from the left bank to the flood mark (on the other side of the river). In each point, elevation and distance were determined using the Total Station. These steps were repeated in cross sections 2 & 3. Figure 3 illustrates the cross sections selected.

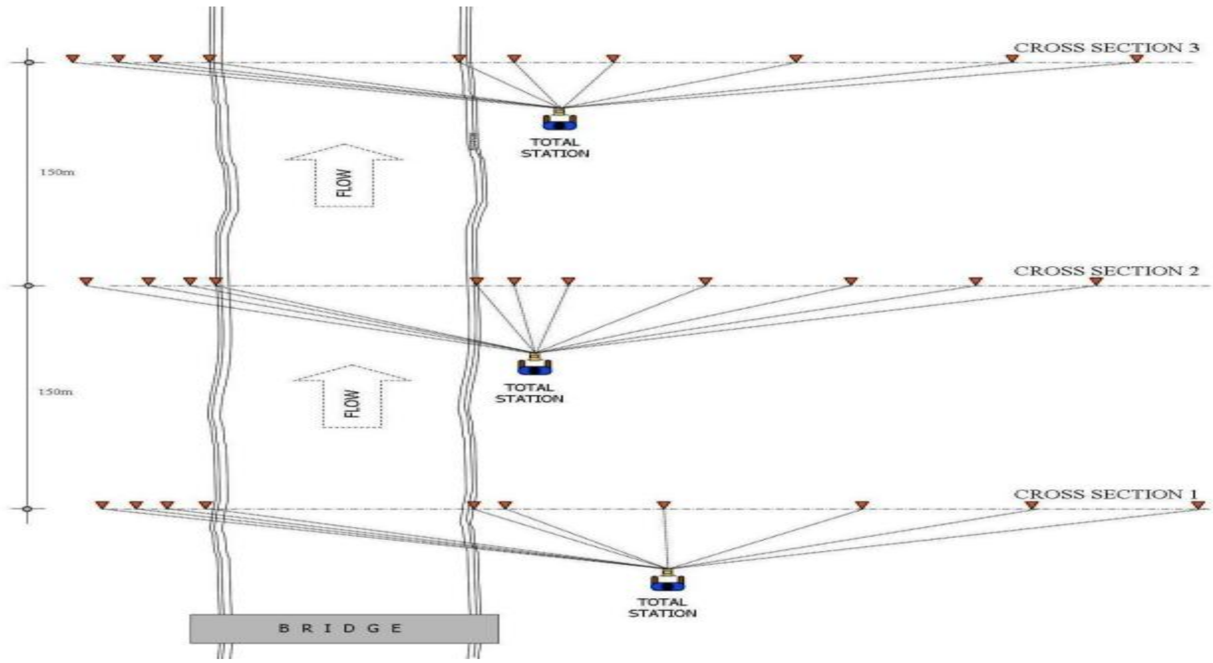

Figure 7. Slope – Area Method of Discharge Measurment showing the three cross sections

The river's cross section was obtained by means of echo sounding device. It was done by riding a boat while crossing the river. Depth of the river bed was recorded at every few meters along the river from the left bank to the right bank. The recorded depths determines the depth of the river which eventually to be used in the discharge measurement in this specific method. Figure 5 below represents the profile of each section on the river.

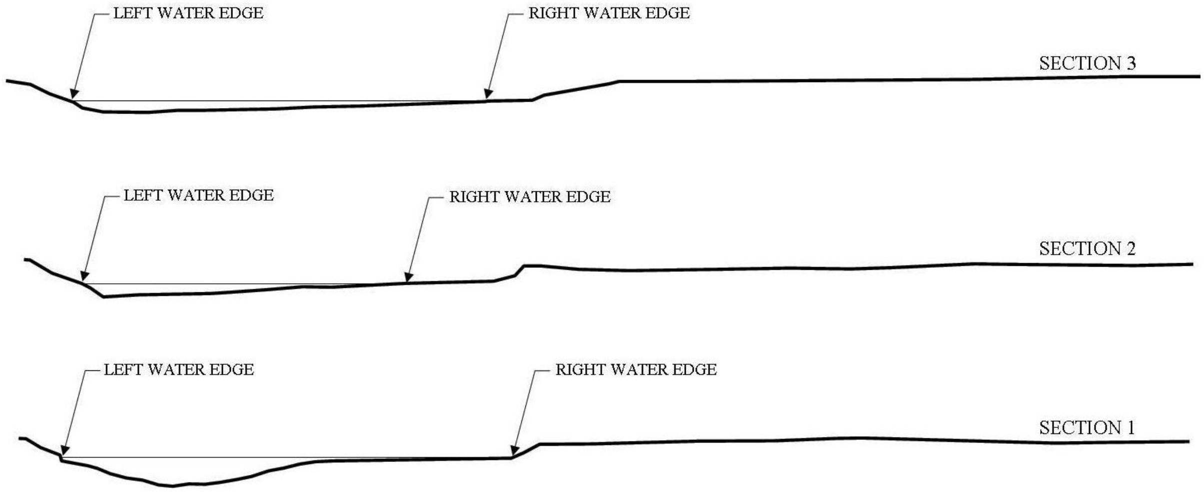

Figure 7. Left and right water edges of the SA Method with the three cross sections

VI. RESULTS

Results and discussions from the different methods of discharge measurements are presented below. The advantages and disadvantages of each method were also discussed.

1. ACOUSTIC DOPPLER CURRENT PROFILER (ADCP) METHOD

The capability of ADCPs to measure water velocity, depth, and boat velocity allows them to be used to measure discharge in river. The output from the ADCP measurement is shown below.

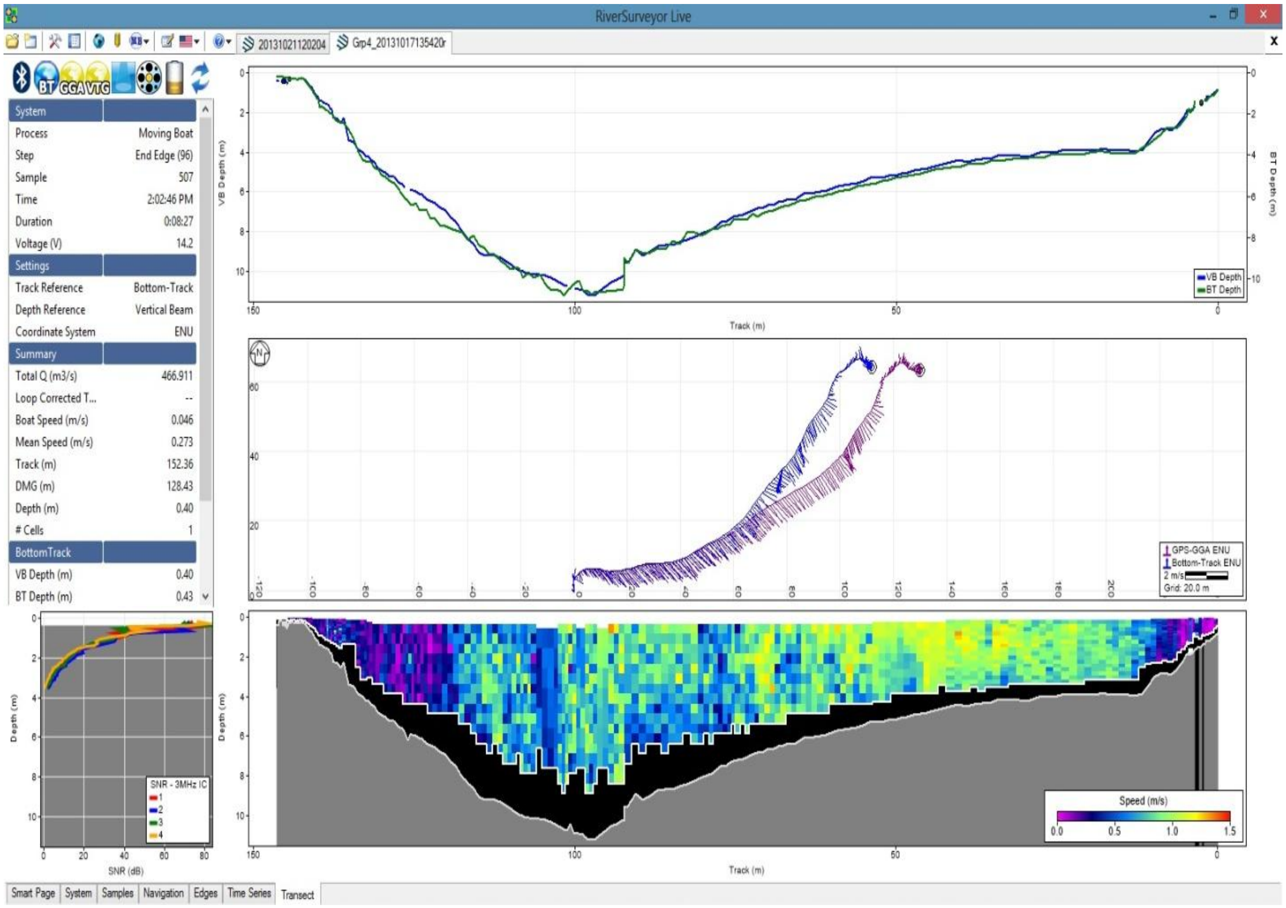

Figure 7. ADCP output

The discharge computed using ADCP was 466.911 m^3/s. The water level at 1:30 pm when we started traversing the instrument across the river by boat was 5.5 meters as read on the staff gauge under the bridge. The water level was under the critical level which can be described as high flow.

ADVANTAGES AND DISADVANTAGES

The primary advantages of making discharge measurements using the ADCP as compared with point velocity meters, such as the Price AA current meter (Rantz and others, 1982), are that in most situations (1) the time required to complete a measurement is reduced, an advantage for personnel safety and for making measurements in unsteady-flow conditions; (2) the ADCP allows for data to be collected throughout most of the water column and cross section rather than at discrete points; (3) the ADCP is deployed at the water surface appreciably reducing the chance of snagging by debris, another safety advantage; (4) the instrument can be boat-mounted; thus, eliminating the installation, maintenance, and liability of costly manned cableways; (5) complex flow regimes, such as vertical bi-directional flow, can be accurately identified and measured; and (6) many parameters are available for analyzing measurement quality. The primary disadvantages of using the ADCP, compared with point velocity meters, are the high initial cost of an ADCP (costs range from approximately 3 million to 5 million in year); complexity, requiring some understanding of the physics, electronics, and system software prior to use; and the frequent changes in ADCP technology

2. CURRENT METER METHOD

Current meter discharge method is an A×V method. The discharge through the cross – section is the wet cross section area multiplied by the average stream flow velocity. The mean velocity was obtained by measuring the velocity at point by counting the number of revolutions current metre during a short time period of 60secs.

The data gathered were encoded in the excel workbook provided by Mr. Hilton Hernando, which automatically computed the discharge of the said section by using hydro formula discussed in the class. The results and the output of the current meter method are presented in figure 8.

When the Columbus weight is carried by the current creating an angle to the dry line, correction factor was employed. The excel table in figure 8 shows that with an area of 405.42 m^2, the discharge obtained was 325.70 m^3/s. The average velocity was 0.803. The water level when we started was 4.68m and 4.57m when we ended.

Discharge Measurement (Current Meter) for :		***Arayat***		River:	***Pampanga***		**PRFFC**
DM #: 2	Date:	Oct. 18, 2013	Team:		Group 4		**FFB**
Gage Height: Start: 4.68	End: 4.57	Inst. # :	Price AA	Wx:	fair		**PAGASA**
Observation Time: Start: 10:55	End: 3:00	Calibration Eqtn.: V =	0.702	N+	0.013	note: just input negative value	hth/ 97
Vertical dist. to water surface (m) =	11.00					for latter if eqtn. is minus.	
Total Area (m^2) =	**405.42**	**Ave. Gage Height =**	**4.63**		**Sectional Width (m) =**		**120.0**
Total Q (m^3/s) =	**325.70**	**Ave. Vel. (m/s) =**	**0.803**				

Dist. from Initial point	Width (mts.)	Depth (ep for pier) (mts.)	Vert. Angle 4^0-36^0	Angle Corrected Depth	Observation Depth 0.2 Rev.	0.2 Time	0.6 Rev.	0.6 Time	0.8 Rev.	0.8 Time	Velocity at point for 0.6 only	Velocity Mean (0.2,0.6 (0.2 & 0.8)	Area (m^2)	Q (cumecs)	Remarks Excellent, Good Fair, Poor
0				0											LWE
5	5	2.3		2.300	60	62			60	65	x	0.677	11.50	7.78	
10	5	4.11	8	3.989	90	64			75	62	x	0.931	19.95	18.57	
15	5	4.56	10	4.368	95	65			80	65	x	0.958	21.84	20.92	
20	5	8.18	5	8.129	95	63			30	64	x	0.707	40.65	28.73	ripples
25	5			x							x	x	x	x	turbulent
30	5			x							x	x	x	x	pier
35	5			x							x	x	x	x	too deep
40	5			x							x	x	x	x	too deep
45	5	9.72	19	8.881	85	62			75	60	x	0.933	44.40	41.43	
50	5	9.63	4	9.597	90	60			50	62	x	0.823	47.99	39.47	
55	5	8.1	5	8.049	85	64			60	65	x	0.803	40.25	32.32	
60	5	6.72	5	6.671	85	65			60	63	x	0.806	33.35	26.89	
65	5	5.2		5.200	85	62			70	62	x	0.891	26.00	23.15	
70	5	5.25		5.250	85	64			65	62	x	0.847	26.25	22.24	
75	5	5.05		5.050	80	61			60	64	x	0.802	25.25	20.26	
80	5	4.45		4.450	80	61			60	62	x	0.813	22.25	18.09	
85	5	4		4.000	60	63			65	64	x	0.704	20.00	14.08	
90	5			x							x	x	x	x	waterlily
95	5			x							x	x	x	x	pier
100	5			x							x	x	x	x	turbulent
105	5			x							x	x	x	x	pier
110	5	2.55		2.550	55	63			50	61	x	0.607	12.75	7.74	
115	5	2.6		2.600	30	66			25	64	x	0.310	13.00	4.03	
120	x			x							x	x	x	x	RWE
	#REF!			x							x	x	x	x	shallow

Rem:	At distance 25 - 40 & 90 - 105, no velocity measurement was made due to obstraction from the pier that may alter the true measurement from ripples or turbulent. Also, at stn 35-40 the elevation from surface water to river bed is too deep.	**Total Area =**	**405.42**
		Total Discharge =	**325.70**
		Ave. Velocity =	**0.803**

Figure 8. Current meter tabulated output in excel

ADVANTAGES AND DISADVANTAGES

The primary advantages of using the currents meter method for discharge measurements are; (1) easy to assemble and durable, (2) rugged and also easy to disassemble and (3) can be used on the bridge and on the boat as well. The disadvantages of suing t his method for discharge measurements are; (1) It takes longer to finish the discharge measurement compared to ADCP, because of it the change in water level has a big factor on the measured discharge (2) Tedious and takes more men to do the task. (3) Prone to error because the Columbus weight is carried by the current creating an angle to the dry line, (4) The Pryce current meter is sometimes (electric) grounded and keeps on beeping because some water or dirt has enteredinto the cat whiskers. (5) Not suited for very high flow or flooding or when the river is full of debris because the cable attached to the weights and current might be snapped.

3. FLOAT METHOD

	Time	Staff gage (m)	As of	Distance (m)
Start	11:30	3.16	11:00 AM	100
End	12:05	3.12	12:00 NN	100
Average	6:05			100

								Divided Area			
Measuring Line		Time of Drop	Traveling Time (secs)	Average traveling time (1st trial + 2nd trial)/2	Velocity of Float (m/s)	Corr. Coef.	Corr. Velo. (m/s)	Section 1	Section 2	Average Area (sq.m.)	Divided Q (cu.m/s)
No. 1	1st trial	11:30	186	186	0.5376	0.85	0.45699	27.75	27.33	27.54	12.5855
	2nd trial	failed	0								
No. 2	1st trial	failed	0	123	0.8130	0.85	0.69106	105.9	62.025	83.9625	58.0229
	2nd trial	11:44	123								
No. 3	1st trial	11:47	118	127	0.7874	0.85	0.66929	229.65	113.5	171.575	114.834
	2nd trial	11:51	136								
No. 4	1st trial	11:55	120	128	0.7813	0.85	0.66406	338.7	144.7	241.7	160.504
	2nd trial	11:58	136								
No. 5	1st trial	12:02	140	140	0.7143	0.85	0.60714	338.05	146.9	242.475	147.217
	2nd trial	failed	0								
									Total Q		493.163

Figure 9 . Current meter tabulated output in excel

The discharge gathered in Float Method was **493.16 m^3/s** with an area of **767.3 m^2**. The average velocity of water was **0.62 m/s**. Some of the floats did not travel with the current; it went to the bank and became stationary because the current was not as fast or high flow compared to the previous day.

ADVANTAGES AND DISADVANTAGES

The advantages of using float method for discharge measurements are (1) Practical and simple to conduct and materials/equipment are locally available (2) Can be performed during very high flow or flooding (3) The measurement can be finished on a very short time (1-2 hours). Its disadvantages are; (1) Not suitable during low flow when the current is slow because the floats will not move or just be stationary in the water or will go to the banks and (2) Selection of section of the river with uniform flow is critical before dropping the floats in order to make sure that the floats will move with the current.

4. SLOPE AREA METHOD

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*
Flood Date:	*12-Oct-13*	Drainage Area:	*6,487*
Gauge Height:	*8.78*	Meas. #:	*4*

X - Section Properties:

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	321.65	1627.90	6.713	8.129	7.421	5.061	0.035	4.99	136572	1E+09	1	0.312	tranquil
2	420.50	1107.31	6.086	8.001	7.0435	2.633	0.035	2.62	60263.8	2E+08	1	0.636	tranquil
3	335.94	1378.26	5.667	7.979	6.823	4.103	0.035	4.08	100968	5E+08	1	0.410	tranquil

note: Assume no sub-divided sections, hence α is always 1!!

Reach Properties:

Reach	Length	Δh Fall	k	reach condition	K_u/K_D	K_u/K_D Condition	Ave. A	Q by formula	Ave V
1-2	150	0.3775	0	contracting	2.26624	poor	1367.606	3049.9	2.230
2-3	150	0.2205	0.5	expanding	0.59686	poor	1242.785	3572.59	2.875
1-2-3	300	0.598	0	contracting	1.35263	good	1371.156	**3579**	2.610

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	3049.9	0.24664	0.53305	-0.2864	0.09108	0.00061	0.02464	90721.3	2235.53
2-3	3572.59	0.53305	0.34407	0.18898	0.31499	0.0021	0.04583	78004.6	3574.56

Rem:

Q_{1-2-3} = 3579.19 cumecs

Discharge

Figure 9 . Current meter tabulated output in excel

The computed discharge for slope 1-2-3 of the slope-area method that we conducted on the fourth day of field work was 3,579.19 m^3/s. This was the computed discharge during the flood at Arayat station caused by the passage of Typhoon Santi on October 12, 2013 at Pampanga River basin.

The graphs of the three sections from the Slope Area Method are presented on the next page.

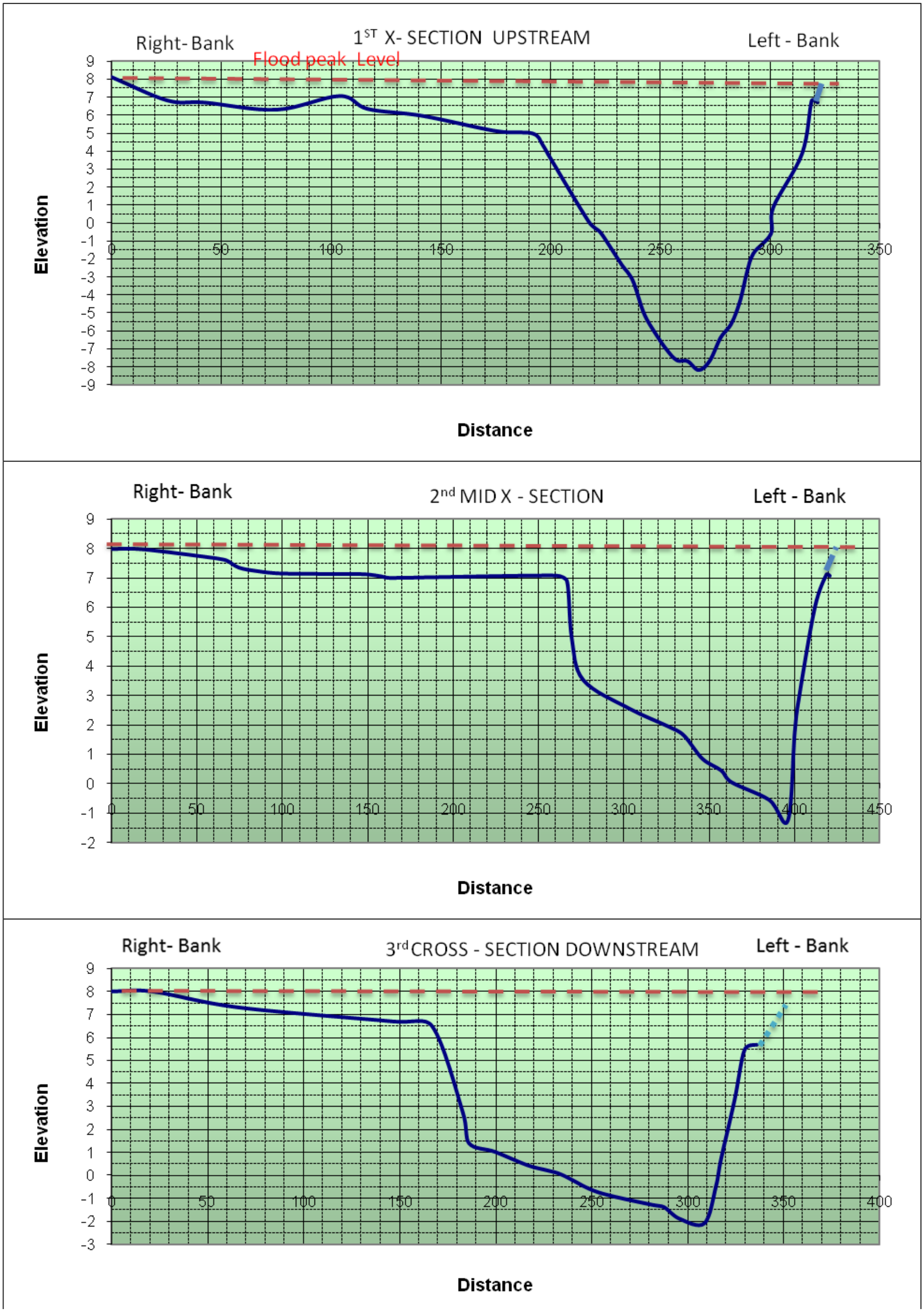

Figure 10 . Slope- Area Method's Cross sections plotted looking downstream

From figure 10, which is a graph of distance vs elevations of the three cross sections, slope of cross section 1 is steeper compared to cross sections 2 and 3 which looks almost similar.

5. USING MANNINGS EQUATION

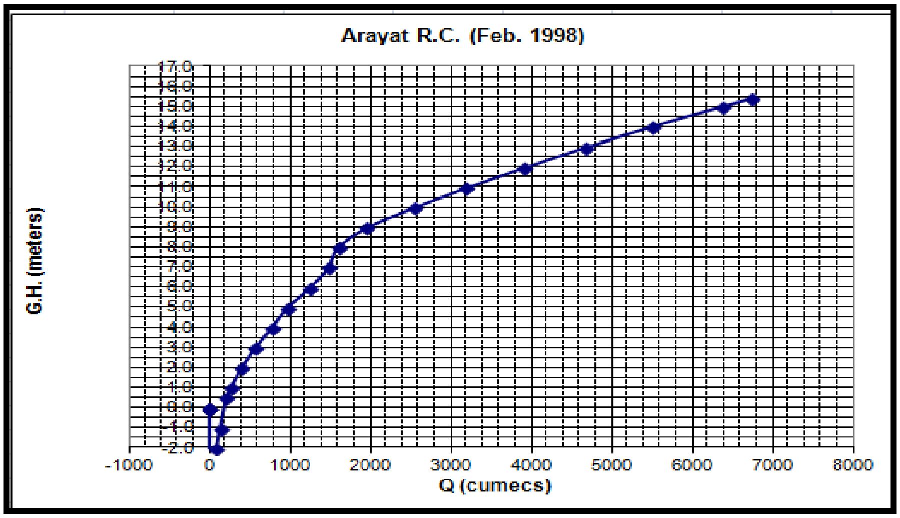

Figure 11. Rating Curve (Hvs.Q)

The graph in figure 11 shows the relationship of gauge height versus the discharge. The gauge height was converted to the mean sea level elevation at zero (0) datum. For every height of gauge (H) there is a corresponding discharge (Q).

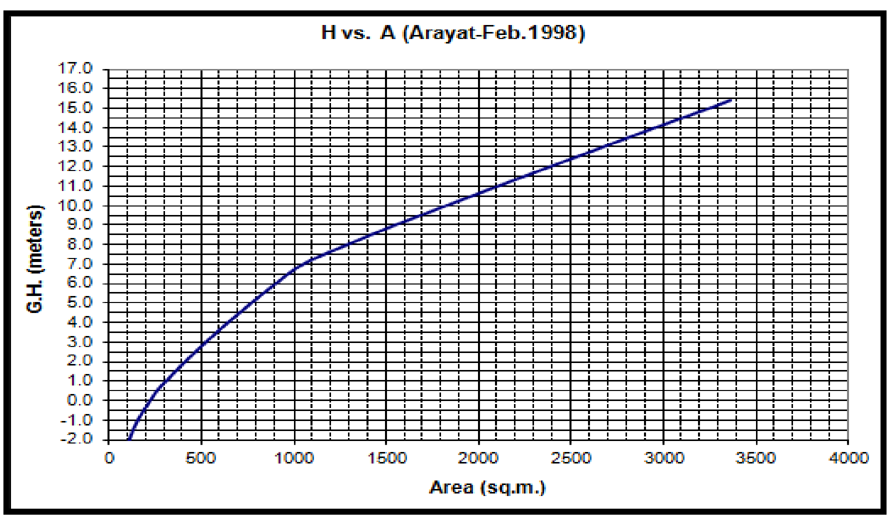

Figure 12. Fig. 10 H vs. A

The graph in figure 12 shows the relationship of gauge height versus the area. The increase in gauge height of the river corresponds to the area that the discharge of the river could inundate an area.

Pampanga River @ Arayat

(based on cross-section undertaken on October 22, 2013)

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

n= 0.030 I= 0.000145

Elevation MSL (m)	Equivalent G.H.(m)	Area a (m²)	Width w (m)	W.P. s	hyd radius r	Discharge Q (cumecs)	Remarks
15.402	15.402	3363.89	292.34	302.21	11.13	6731.22	bank full/ level with bridge road
15.00	15.000	3248.91	292.00	301.39	10.78	6363.70	
14.00	14.000	2955.37	288.00	296.88	9.95	5489.44	
13.00	13.000	2670.34	286.20	294.31	9.07	4662.74	
12.00	12.000	2386.55	284.00	291.09	8.20	3894.88	
11.00	11.000	2105.19	282.00	288.03	7.31	3182.43	
10.00	10.000	1824.65	278.00	283.48	6.44	2534.26	
9.00	9.000	1548.15	274.54	279.46	5.54	1945.52	
8.00	8.000	1290.17	233.34	238.42	5.41	1596.19	
7.00	7.000	1051.66	157.00	161.11	6.53	1474.34	
6.00	6.000	902.86	138.20	142.09	6.35	1243.23	
5.00	5.000	769.53	128.20	139.43	5.52	964.64	
4.00	4.000	643.79	122.00	125.37	5.14	769.16	
3.00	3.000	524.68	116.20	119.20	4.40	565.64	
2.00	2.000	412.88	109.00	111.57	3.70	396.49	
1.00	1.000	310.25	98.00	100.34	3.09	264.30	
0.50	0.500	260.25	90.00	93.00	2.80	207.44	
-1.00	-1.000	157.28	52.00	53.74	2.93	129.17	
-2.00	-2.000	110.66	41.00	42.45	2.61	84.14	
-3.00	-3.000	72.18	36.14	37.17	1.94	45.10	
-4.00	-4.000	39.03	30.80	31.40	1.24	18.11	
-5.00	-5.000	12.09	26.00	26.25	0.46	2.90	1.168m from thalweg (thalweg @ 6.168 below MSL)

Figure 13. Rating curve table

The Rating Curve Table in figure 13 shows the parameters computed in order to arrive to the curve and rating equation.

Summary test for Ho . . .
. . .

Ho	a	b	*SX*^{2}
-7.50	0.28	2.699	54776.66
-7.36	0.93	2.359	54435.55
-7.22	1.08	2.315	54396.79
-7.08	1.26	2.270	54360.07
-6.94	1.47	2.224	54326.15
-6.80	1.72	2.177	54296.04
-6.66	2.02	2.128	54271.1
-6.52	2.39	2.079	54253.22
-6.38	2.83	2.028	54244.99
-6.24	3.36	1.975	54250.16
-6.10	4.03	1.920	54274.25
-5.96	4.86	1.862	54325.67
-5.82	5.93	1.800	54417.88
-5.68	7.33	1.733	54573.75

Minimum *SX*^{2} = 54244.987

Figure 13. Summary tests for Ho

Q = 1.422 [H - (-6.38)] $^{2.695}$

Figure 14. Rating equation

Figure 13 shows the computation of Ho value, it is the lowest point of the river where we assumed of zero flow at that point. The computed value of Ho is -6.38 m below mean sea level. It is computed from -5.0 m. and 15.402 m. elevation (men sea level).The Ho value was computed through manipulation of the values in the excel table in figure 12 to get the least sum of squares. The thalweg is at -6.168, the (Ho= -6.38) is .212 m. lower than the thalweg.

Rating Table for: ***Arayat*** Date:

River: *Pampanga* Location: *San Agustin, Arayat, Pampanga*

Elevation of S.G. "0" reading: *0*

Rating Curve Equation Coefficients: **a = *1.422*** **Ho= *-6.380*** **b^= *2.695***

Range of G.H.: Min. G.H. = ***0*** Max. possible G.H.= ***11.00***

Remarks: *G.H. is based on staff gauge and not MSL.*

G.H.(m)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	209.84	210.73	211.62	212.51	213.41	214.30	215.20	216.10	217.01	217.91
0.1	218.82	219.73	220.65	221.56	222.48	223.40	224.33	225.25	226.18	227.11
0.2	228.04	228.98	229.92	230.86	231.80	232.74	233.69	234.64	235.59	236.55
0.3	237.50	238.46	239.43	240.39	241.36	242.33	243.30	244.27	245.25	246.23
0.4	247.21	248.19	249.18	250.17	251.16	252.15	253.15	254.15	255.15	256.15
0.5	257.16	258.17	259.18	260.19	261.21	262.23	263.25	264.27	265.30	266.32
0.6	267.36	268.39	269.43	270.46	271.51	272.55	273.59	274.64	275.69	276.75
0.7	277.80	278.86	279.92	280.99	282.05	283.12	284.19	285.27	286.35	287.42
0.8	288.51	289.59	290.68	291.77	292.86	293.95	295.05	296.15	297.25	298.36
0.9	299.46	300.57	301.69	302.80	303.92	305.04	306.16	307.29	308.41	309.55
1.0	310.68	311.81	312.95	314.09	315.24	316.38	317.53	318.68	319.84	321.00
1.1	322.15	323.32	324.48	325.65	326.82	327.99	329.17	330.34	331.52	332.71
1.2	333.89	335.08	336.27	337.47	338.66	339.86	341.06	342.27	343.48	344.69
1.3	345.90	347.11	348.33	349.55	350.77	352.00	353.23	354.46	355.69	356.93
1.4	358.17	359.41	360.66	361.90	363.15	364.41	365.66	366.92	368.18	369.45
1.5	370.71	371.98	373.25	374.53	375.81	377.09	378.37	379.65	380.94	382.23
1.6	383.53	384.82	386.12	387.43	388.73	390.04	391.35	392.66	393.98	395.30
1.7	396.62	397.94	399.27	400.60	401.93	403.27	404.61	405.95	407.29	408.64
1.8	409.99	411.34	412.69	414.05	415.41	416.78	418.14	419.51	420.88	422.26
1.9	423.63	425.01	426.40	427.78	429.17	430.56	431.96	433.36	434.76	436.16
2.0	437.56	438.97	440.38	441.80	443.22	444.64	446.06	447.48	448.91	450.35
2.1	451.78	453.22	454.66	456.10	457.55	458.99	460.45	461.90	463.36	464.82
2.2	466.28	467.75	469.22	470.69	472.16	473.64	475.12	476.60	478.09	479.58
2.3	481.07	482.57	484.07	485.57	487.07	488.58	490.09	491.60	493.11	494.63
2.4	496.15	497.68	499.21	500.74	502.27	503.81	505.35	506.89	508.43	509.98
2.5	511.53	513.09	514.64	516.20	517.77	519.33	520.90	522.47	524.05	525.62
2.6	527.20	528.79	530.38	531.96	533.56	535.15	536.75	538.35	539.96	541.57
2.7	543.18	544.79	546.41	548.03	549.65	551.28	552.90	554.54	556.17	557.81
2.8	559.45	561.09	562.74	564.39	566.04	567.70	569.36	571.02	572.69	574.35
2.9	576.03	577.70	579.38	581.06	582.74	584.43	586.12	587.81	589.51	591.20
3.0	592.91	594.61	596.32	598.03	599.75	601.46	603.18	604.91	606.63	608.36
3.1	610.10	611.83	613.57	615.31	617.06	618.81	620.56	622.31	624.07	625.83
3.2	627.60	629.36	631.13	632.91	634.68	636.46	638.24	640.03	641.82	643.61
3.3	645.41	647.21	649.01	650.81	652.62	654.43	656.24	658.06	659.88	661.71
3.4	663.53	665.36	667.20	669.03	670.87	672.72	674.56	676.41	678.26	680.12
3.5	681.98	683.84	685.70	687.57	689.44	691.32	693.20	695.08	696.96	698.85
3.6	700.74	702.63	704.53	706.43	708.33	710.24	712.15	714.06	715.98	717.90
3.7	719.82	721.75	723.68	725.61	727.55	729.49	731.43	733.37	735.32	737.28
3.8	739.23	741.19	743.15	745.12	747.08	749.06	751.03	753.01	754.99	756.98

3.9	758.96	760.96	762.95	764.95	766.95	768.95	770.96	772.97	774.99	777.00
4.0	779.03	781.05	783.08	785.11	787.14	789.18	791.22	793.26	795.31	797.36
4.1	799.42	801.47	803.53	805.60	807.67	809.74	811.81	813.89	815.97	818.05
4.2	820.14	822.23	824.33	826.42	828.52	830.63	832.74	834.85	836.96	839.08
4.3	841.20	843.32	845.45	847.58	849.72	851.86	854.00	856.14	858.29	860.44
4.4	862.60	864.75	866.92	869.08	871.25	873.42	875.60	877.77	879.96	882.14
4.5	884.33	886.52	888.72	890.92	893.12	895.33	897.53	899.75	901.96	904.18
4.6	906.41	908.63	910.86	913.10	915.33	917.57	919.82	922.06	924.31	926.57
4.7	928.83	931.09	933.35	935.62	937.89	940.16	942.44	944.72	947.01	949.30
4.8	951.59	953.89	956.19	958.49	960.79	963.10	965.42	967.73	970.05	972.38
4.9	974.70	977.03	979.37	981.71	984.05	986.39	988.74	991.09	993.45	995.80
5.0	998.17	1000.53	1002.90	1005.27	1007.65	1010.03	1012.41	1014.80	1017.19	1019.58
5.1	1021.98	1024.38	1026.79	1029.19	1031.61	1034.02	1036.44	1038.86	1041.29	1043.72
5.2	1046.15	1048.59	1051.03	1053.47	1055.92	1058.37	1060.82	1063.28	1065.74	1068.21
5.3	1070.68	1073.15	1075.62	1078.10	1080.59	1083.07	1085.56	1088.06	1090.55	1093.06
5.4	1095.56	1098.07	1100.58	1103.10	1105.61	1108.14	1110.66	1113.19	1115.73	1118.26
5.5	1120.80	1123.35	1125.90	1128.45	1131.00	1133.56	1136.13	1138.69	1141.26	1143.83
5.6	1146.41	1148.99	1151.58	1154.17	1156.76	1159.35	1161.95	1164.55	1167.16	1169.77
5.7	1172.38	1175.00	1177.62	1180.25	1182.88	1185.51	1188.14	1190.78	1193.43	1196.07
5.8	1198.72	1201.38	1204.04	1206.70	1209.36	1212.03	1214.70	1217.38	1220.06	1222.74
5.9	1225.43	1228.12	1230.82	1233.52	1236.22	1238.93	1241.64	1244.35	1247.07	1249.79
6.0	1252.51	1255.24	1257.97	1260.71	1263.45	1266.19	1268.94	1271.69	1274.44	1277.20
6.1	1279.96	1282.73	1285.50	1288.27	1291.05	1293.83	1296.62	1299.40	1302.20	1304.99
6.2	1307.79	1310.60	1313.40	1316.21	1319.03	1321.85	1324.67	1327.50	1330.33	1333.16
6.3	1336.00	1338.84	1341.69	1344.53	1347.39	1350.24	1353.10	1355.97	1358.84	1361.71
6.4	1364.58	1367.46	1370.35	1373.23	1376.12	1379.02	1381.92	1384.82	1387.73	1390.64
6.5	1393.55	1396.47	1399.39	1402.32	1405.25	1408.18	1411.12	1414.06	1417.00	1419.95
6.6	1422.90	1425.86	1428.82	1431.78	1434.75	1437.72	1440.70	1443.68	1446.66	1449.65
6.7	1452.64	1455.63	1458.63	1461.63	1464.64	1467.65	1470.67	1473.68	1476.71	1479.73
6.8	1482.76	1485.80	1488.83	1491.88	1494.92	1497.97	1501.02	1504.08	1507.14	1510.21
6.9	1513.28	1516.35	1519.43	1522.51	1525.59	1528.68	1531.77	1534.87	1537.97	1541.07
7.0	1544.18	1547.30	1550.41	1553.53	1556.66	1559.78	1562.92	1566.05	1569.19	1572.34
7.1	1575.48	1578.64	1581.79	1584.95	1588.11	1591.28	1594.45	1597.63	1600.81	1603.99
7.2	1607.18	1610.37	1613.57	1616.77	1619.97	1623.18	1626.39	1629.60	1632.82	1636.05
7.3	1639.27	1642.51	1645.74	1648.98	1652.22	1655.47	1658.72	1661.98	1665.24	1668.50
7.4	1671.77	1675.04	1678.32	1681.60	1684.88	1688.17	1691.46	1694.75	1698.05	1701.36
7.5	1704.67	1707.98	1711.29	1714.61	1717.94	1721.27	1724.60	1727.93	1731.27	1734.62
7.6	1737.97	1741.32	1744.68	1748.04	1751.40	1754.77	1758.14	1761.52	1764.90	1768.28
7.7	1771.67	1775.07	1778.46	1781.87	1785.27	1788.68	1792.09	1795.51	1798.93	1802.36
7.8	1805.79	1809.22	1812.66	1816.10	1819.55	1823.00	1826.46	1829.91	1833.38	1836.84
7.9	1840.31	1843.79	1847.27	1850.75	1854.24	1857.73	1861.23	1864.73	1868.23	1871.74
8.0	1875.25	1878.77	1882.29	1885.81	1889.34	1892.88	1896.41	1899.96	1903.50	1907.05
8.1	1910.60	1914.16	1917.73	1921.29	1924.86	1928.44	1932.02	1935.60	1939.19	1942.78
8.2	1946.37	1949.97	1953.58	1957.19	1960.80	1964.41	1968.03	1971.66	1975.29	1978.92
8.3	1982.56	1986.20	1989.85	1993.50	1997.15	2000.81	2004.47	2008.14	2011.81	2015.49
8.4	2019.17	2022.85	2026.54	2030.23	2033.93	2037.63	2041.33	2045.04	2048.76	2052.47
8.5	2056.20	2059.92	2063.65	2067.39	2071.13	2074.87	2078.62	2082.37	2086.12	2089.88
8.6	2093.65	2097.42	2101.19	2104.97	2108.75	2112.54	2116.33	2120.12	2123.92	2127.72
8.7	2131.53	2135.34	2139.16	2142.98	2146.80	2150.63	2154.46	2158.30	2162.14	2165.99
8.8	2169.84	2173.69	2177.55	2181.41	2185.28	2189.15	2193.03	2196.91	2200.79	2204.68

8.9	2208.57	2212.47	2216.37	2220.28	2224.19	2228.11	2232.02	2235.95	2239.88	2243.81
9.0	2247.74	2251.69	2255.63	2259.58	2263.53	2267.49	2271.45	2275.42	2279.39	2283.37
9.1	2287.35	2291.33	2295.32	2299.31	2303.31	2307.31	2311.32	2315.33	2319.35	2323.36
9.2	2327.39	2331.42	2335.45	2339.49	2343.53	2347.57	2351.62	2355.68	2359.74	2363.80
9.3	2367.87	2371.94	2376.01	2380.10	2384.18	2388.27	2392.36	2396.46	2400.57	2404.67
9.4	2408.78	2412.90	2417.02	2421.15	2425.28	2429.41	2433.55	2437.69	2441.84	2445.99
9.5	2450.14	2454.30	2458.47	2462.64	2466.81	2470.99	2475.17	2479.36	2483.55	2487.75
9.6	2491.95	2496.15	2500.36	2504.58	2508.79	2513.02	2517.24	2521.48	2525.71	2529.95
9.7	2534.20	2538.45	2542.70	2546.96	2551.22	2555.49	2559.76	2564.04	2568.32	2572.60
9.8	2576.89	2581.19	2585.49	2589.79	2594.10	2598.41	2602.73	2607.05	2611.38	2615.71
9.9	2620.04	2624.38	2628.73	2633.07	2637.43	2641.78	2646.15	2650.51	2654.88	2659.26
10.0	2663.64	2668.02	2672.41	2676.81	2681.21	2685.61	2690.02	2694.43	2698.85	2703.27

Figure 15. Rating table for Arayat

Figure 15 shows the Rating Table of Arayat Pampanga which is the final output of the Direct Method using Manning's Equation. It shows the discharge of the river (Q) at different gauge height (not based on mean sea level).

VII. SUMMARY

River discharge measurements conducted at the Arayat Station in Pampanga River using direct and indirect methods were generally successful. The different methods had different results even though it was conducted at the same day. There are many factors that affected the different results like each measured section was not exactly conducted on the same section; the longer the time that it takes to finish for each method, the more it is prone to error because the receding or rising water level affects the measurement. The faster that the measurement is finished, the accurate the result is like the ADCP and the float method.

The different methods have advantages and disadvantages and its applications depends on several factors previously discussed.

VIII. CONCLUSIONS AND RECOMMENDATIONS

- The practical exercises served as a good experience on how the high discharge method carried out after a flood event or medium flow measurement to obtain its discharge.
- The shorter the time doing discharge measurement on the site, the better quality and more accurate data gathered.
- The tagline and boat should be aligned perpendicular to the flow of the river during measurement
- Standard gauging card and survey level book should be used.
- More boats, two way radios and range finder should be provided to each group.

SITES VISITED

Part of our field work, we visited some hydrological structures like dams and dikes in Central Luzon and also some offices which conduct flood mitigation on flood-prone areas like the Municipal Disaster Risk Reduction and Management Council (MDRRMC) of Calumpit, Bulacan. The following were the sites visited:

LA MESA WATERDHED AND ECO-PARK

The La Mesa Watershed and Eco-Park consists of the La Mesa Dam and an ecological nature reserve site in Quezon City commissioned in 1929 in the Philippines. It is part of the Angat-Ipo-La Mesa water system, which supplies most of the water supply of Metro Manila. The La Mesa Dam is an earth dam whose reservoir can hold up to 50.5 million cubic meters and occupying an area of 27 square kilometers.

The water collected in the reservoir is treated on-site by the Maynilad Water Services, and at the

Balara Treatment Plant further south by the Manila Water. Both water companies are private concessionaires awarded by the Metropolitan Waterworks and Sewerage System, the government agency in charge of water supply. It is a vital link to the water requirements of 12 million residents of Metro Manila considering that 1.5 million liters of water pass through this reservoir every day. It is also the last forest of its size in the metropolis.

A lecture was given by Mr. Ortega at the La Mesa Headwork office on some informations about the visited area. He also discussed the Headworks and water treatment Plant Facilities, Water Treatment Process and Treatment Plant Complex.

PANTABANGAN MULTIPURPOSE DAM

The Pantabangan reservoir, which is the country's biggest reservoir, can store up to three billion cubic meters of water and services more than 100,000 hectares of rice lands.

Pantabangan Dam is an earth-fill embankment dam on the Pampanga Riverlocated in Pantabangan in Nueva Ecija province of the Philippines. The multi-purpose dam provides water for irrigation and hydroelectric power generation while its reservoir, Pantabangan Lake, affords flood control. The reservoir is considered one of the largest in Southeast Asia and also one of the cleanest in the Philippines. Construction on the dam began in 1971 and it was complete in 1977.

In May 1969, the Congress of the Philippines authorized the development of the Pampanga Basin with Republic Act No. 5499. In October of that year, detailed studies of the Pantabangan site were carried out and lasted two years. The dam went into operation in February 1977 and was completed later in May. Approximately 1,300 people were relocated from the dam's reservoir zone.

The dam is a 107 m (351 ft) tall and 1,615 m (5,299 ft) long embankment-type with 9,174,658 m^3 of homogeneous earth-fill and an impervious core. The crest of the dam is 12 m wide while the widest part of its base is 535 m. The dam's crest sits at an elevation of 232 m and is composed of three sections: the main dam, a saddle dam, and an auxiliary dam located with the spillway. The spillway is a chute-type controlled by three radial gates but equipped with an overflow section. The design discharge of the spillway is 4,200 m^3/s. The dam's reservoir has a gross capacity of 2,996,000,000 m^3 and 2,083,000,000 m^3 of that volume is active (or useful) for irrigation and power. The dam sits at the head of a 853 km^2catchment area and its reservoir has a surface area of 69.62 km^2 and elevation of 230 m when at its maximum level. The reservoir's life is estimated at 107 years due to silt from denudation. The dam was design to withstand an intensity 10 earthquake.

First Gen Hydro Power Corporation (FG Hydro) owns and operates the Pantabangan-Masiway Hydroelectric Complex (PMHEP). The Pantabangan and Masiway plants are cascading hydroelectric power plants located in Nueva Ecija, approximately 180 kilometers northeast of Metro Manila. Commissioned in 1977 and 1981, respectively, the Pantabangan and Masiway plants are part of a multipurpose hydro complex that supplies irrigation water for the vast rice fields of Nueva Ecija.

The power house is located at the base of the main dam and contains two 50 MW turbine-generators for an installed capacity of 100 MW. Each turbine receives water via a 6 m diameter penstock. When the water is discharged, it is released into a 250 m long tailrace channel where it re-enters the river.

ANGAT DAM FLOOD FORECASTING AND WARNING SYSTEM

Angat dam covers the area of 10,540sq.km. And have a normal high water level of 210 meters and a critical high level of 219m.

Piloted by the Government in 1973, this dam is 50 kilometers upstream from the Bustos Dam. It has coordinates of 14°57'25"N 120°57'15"E serving nearby cities like Real, Quezon, Rodriguez (Montalban), Rizal, Antipolo City, Rizal.

Angat Dam is a concrete water reservoir embankment/hydroelectric dam that supplies water the Metro Manila area. It was a part of the Angat-Ipo-La Mesa water system. The reservoir supplies more or less 90 percent of raw water requirements for Metro Manila through the facilities of the Metropolitan Waterworks and Sewerage System and it irrigates about 28,000 hectares of farmland in the provinces of Bulacan and Pampanga which are their present main priority.

It has three gates opening a total of 1.5

meters to gradually release water that had accumulated due to continues rains during typhoons. Prior to the actual opening of gates public warning is discriminated 3-4 hours before.

Angat dam supplies potable water and energy to Metro Manila and nearby areas. Surrounded by lush greens, this place is also ideal for fishing, boating and hunting.

Angat Dam is being controlled by the National Power Corporation (NPC) Flood Forecasting and Warning System. Angat dam has a customized flood model designed by JICA.

It has a hydro-electric power plant that has a capacity of 256MW. But due to the present demand of water in metro manila area and the irrigation requirements of farmlands in Bulacan and Pampanga, only partial power is generated by the said power plant.

The dam vicinity is monitored by 4 rain gauges & 1 water level gauge strategically installed with hourly recording thru telemetry. It discharges water in 60 cu.m. per second.

The water from Angat to La Mesa Dam is for domestic use in metro manila. Meanwhile, water going to Bustos Dam is for NIA for their irrigation network.

CALUMPIT MDRRMC

Calumpit is a first class urban municipality in the Province of Bulacan, Philippines. According to the 2010 census, it has a population of 101,068 people. Fifty-four (54) kilometers north of Manila, the Municipality of Calumpit bounded on the north and west by Apalit and Macabebe, Pampanga, respectively; southwest, southeast and east by Hagonoy, Malolos, and Pulilan, Bulacan respectively.

The climate of Calumpit is practically similar with that of the rest of the other municipalities in the province of Bulacan. It is characterized by two (2) distinct seasons namely; the rainy and the dry. The rainy seasons starts from May to around November, while the dry season is from December to April. The average annual rainfall is 255.3 millimeters (10.05 in) with the month of August having the highest month average rainfall is about 304 millimeters (12.0 in). The annual number of rainy days is 175 days.

Since the location of Calumpit is lower than the other nearby municipalities it usually experiences flooding every time there is continues rainfall for several days over the area. The flooding usually results to damage of life, properties, infrastructures and agricultural crops.

Because flooding has been a perennial problem on that area, the local government designed a means to reduce disasters risk by creating a flood preparedness program within their locality. They create a monitoring center to keep track of the four major dams within their area of concern. The center acquires data from PAGASA website, Project NOAH, MMDA, Google Maps, DSWD, GMA7; documenting events like flooding in the area into their database every 6 hours including High and Low tides; and coordinating with other nearby LGU whenever the need arises.

Besides from monitoring and gathering data, they develop warning and response capabilities against flooding by creating rescue teams geared with various life-saving equipment. These teams are ready to react anytime there is an incoming disaster that will pass by their area.

These risk reduction practices of the said local government unit is nearly perfected and have been effective, thus, they were awarded as one of the outstanding LGU on risk reduction management.

CONG DADONG DAM IN ARAYAT, PAMPANGA

The P3.4-billion Cong Dadong Dam was designed to irrigate 10,270 hectares of farms in seven eastern towns, feeds only some 3,500 ha despite a slight surplus amid the long dry spell in Luzon.

The dam is also servicing a fraction of its service area because some canals had been damaged, a number of farms had been converted to commercial uses and the maps used to estimate the farmlands were old and did not reflect actual land use by the time the project resumed in 1996.

Its critical level is 7 meters but the water level has never fallen to that point. The dam operates year round, dispersing water through a network of canals supposed to be 31.8-km long.

Because water was enough, the dam has occasionally fed 200 ha of rice land in Barangay Sta. Isabel in Cabiao, Nueva Ecija. The potential irrigable area on the dam’s Nueva Ecija side is some 3,000 ha.The dam should benefit thousands of farmers in that area.