မင်္ဂလာပါ

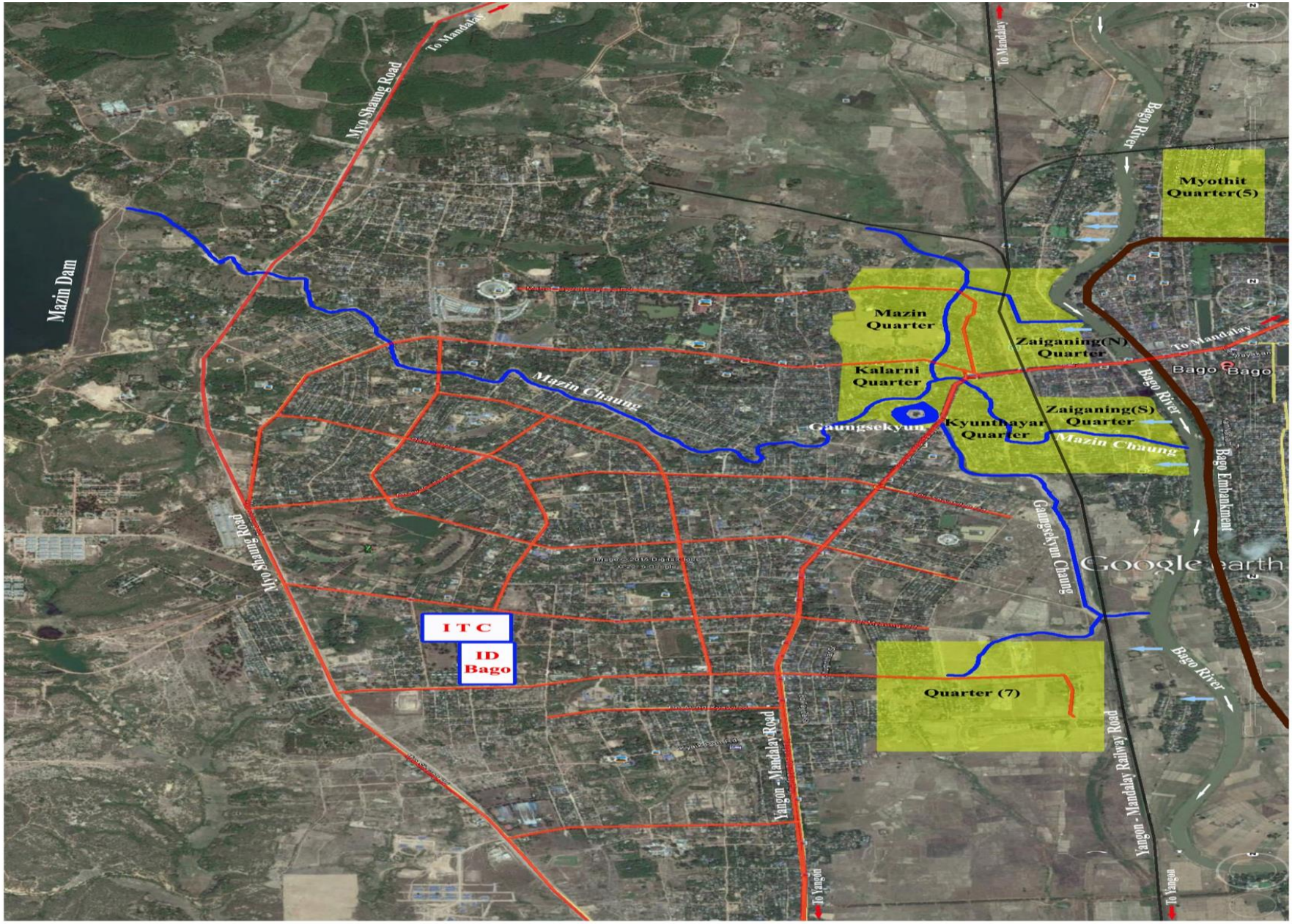
Exp Infrastructure Engineering Consultants Co.,Ltd

- ပဲခူးမြစ်ဝှမ်း ရေကြီးရေလျှံမှုမှ ကာကွယ်ရေးအတွက် ဇလဗေဒမော်ဒယ်များ အသုံးပြု၍ အဖြေရှာခြင်း

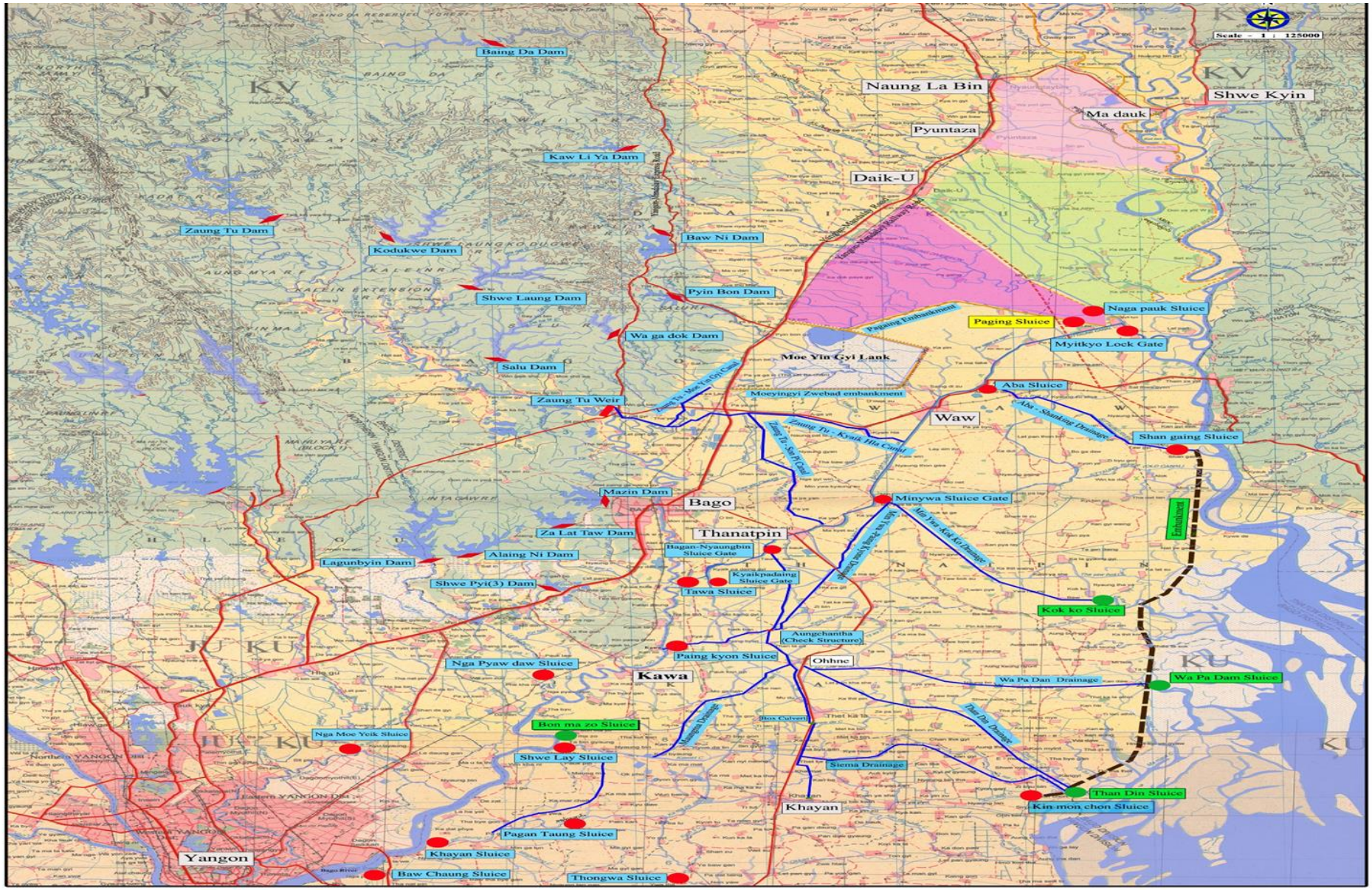
- FLOOD MITIGATION OF BAGO RIVER BASIN USING HYDROLOGY MODELS

Flooded Areas in Bago City

Location Map of the Flooded Area (Bago City)



Areas in Bago, Waw, Thanatpin and Kawa Townships



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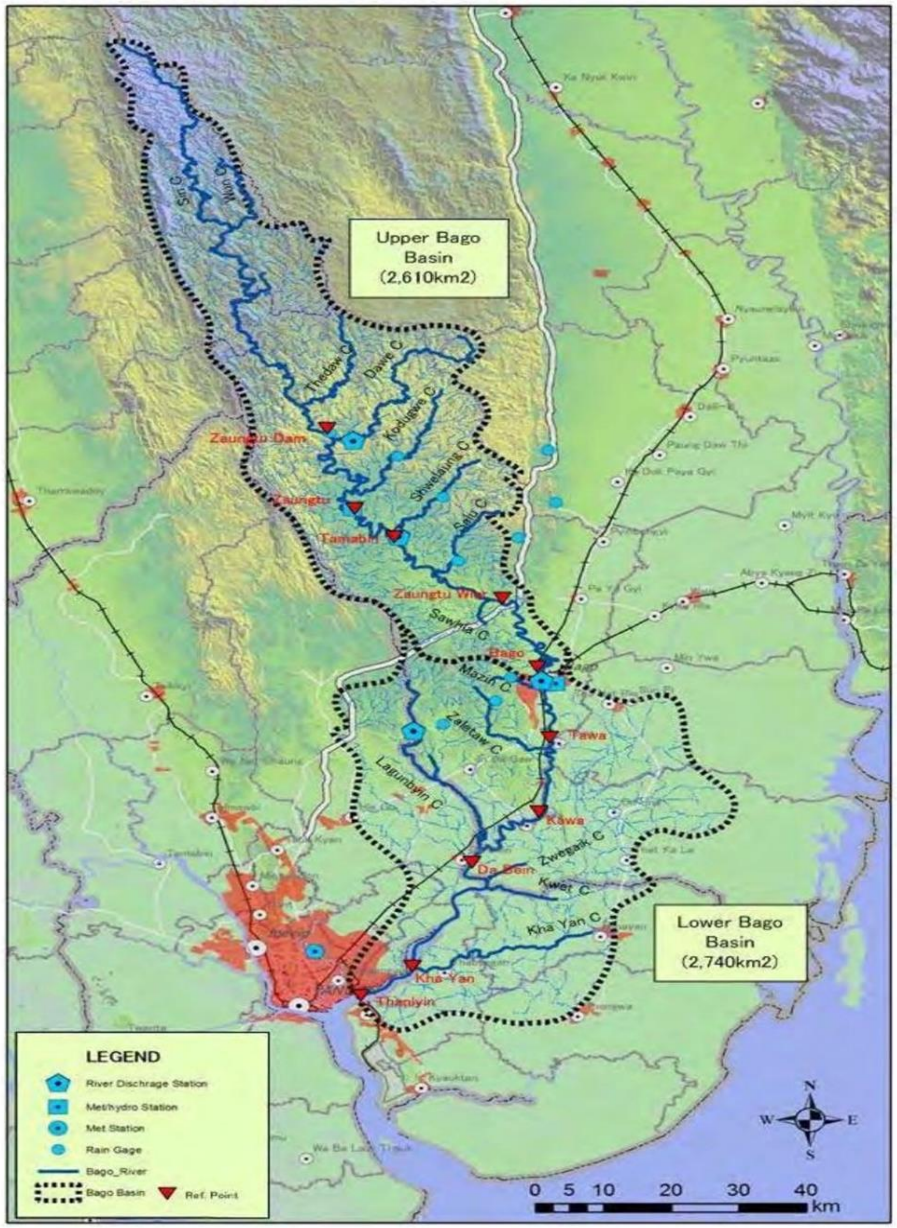
FLOOD MITIGATION OF BAGO RIVER BASIN USING HYDROLOGY MODELS

Major Components Involved in the Study

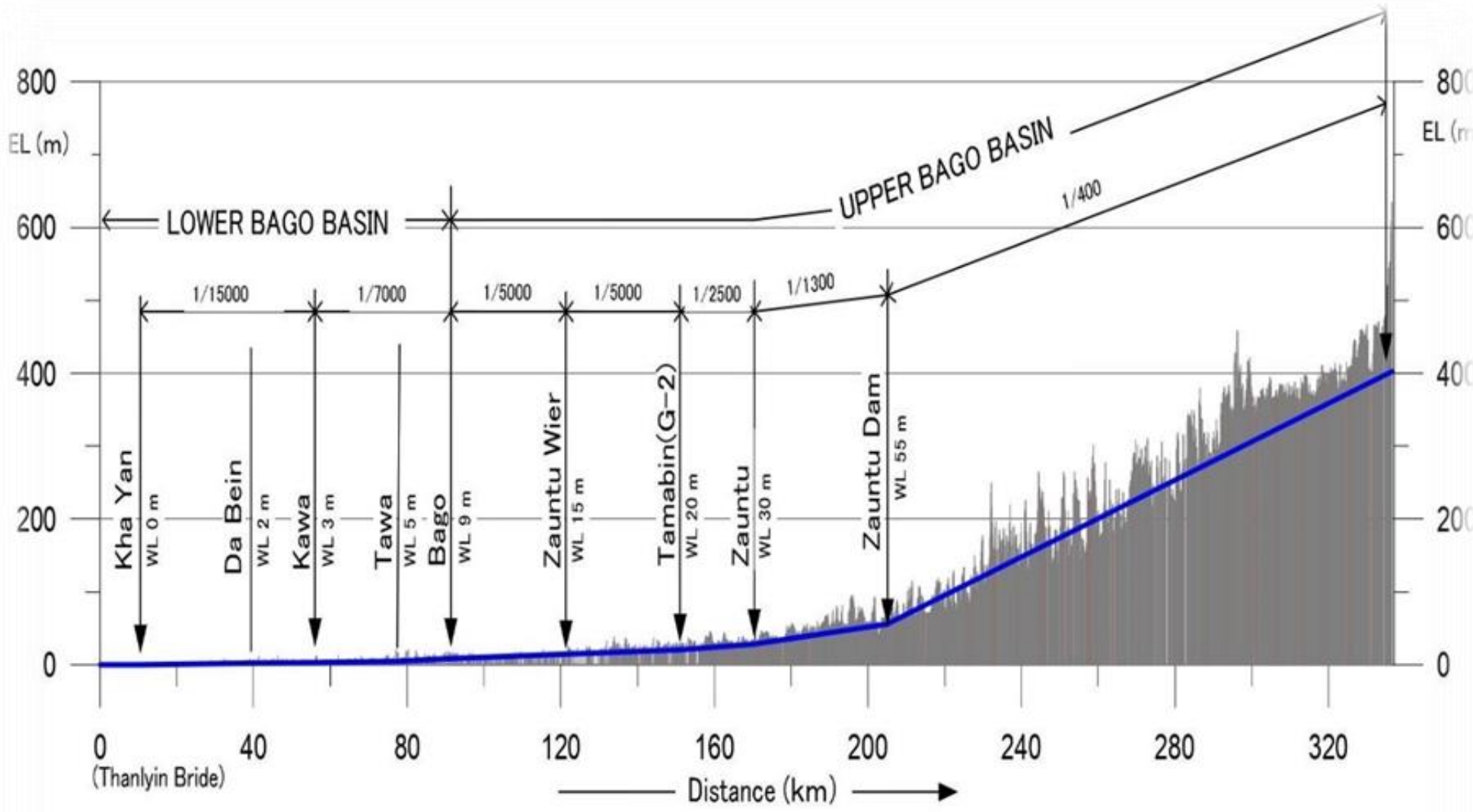
- **Estimation of Bago River Design Floods Using HEC-GeoHMS Hydrology Model**
- **Production of Bago River Flood Profiles Using HEC-RAS Hydraulic Model**
- **Alleviation of Flood Levels at Bago City by Reducing About 30% of the Design Discharges Using Diversion Channel from Upstream**

FLOOD MITIGATION OF BAGO RIVER BASIN USING HYDROLOGY MODELS

Bago River Catchment



Bago River Bed Profile



Source: JICA Study Team: Figure is made based on SRTM topo-data taken from USGS(http://dds.cr.usgs.gov/srtm/)

BAGO RIVER ANNUAL MAXIMUM FLOOD RECORD

$Q(m^3/sec) = 0.0082*(h-203)^{1.7424}$ **h in cm AMSL**

Year	Maximum WL, h (cm)	Estimated Discharge, Q (m3/sec)	Estimated Discharge, Q (cusecs)	Occurred Date & Month
1989	858	661.95	23,376	26-Aug
1990	905	746.90	26,376	22-Aug
1991	887	713.85	25,209	31-Jul
1992	945	822.62	29,050	17-Aug
1993	890	719.32	25,402	21-Jun
1994	947	826.50	29,187	20-Jul
1995	908	752.48	26,573	5-Sep
1996	928	790.05	27,900	27-Jul
1997	930	793.85	28,034	6-Aug
1998	844	637.48	22,512	3-Jul
1999	869	681.43	24,064	8-Aug
2000	883	706.60	24,953	14-Sep
2001	892	722.97	25,531	3-Aug
2002	887	713.85	25,209	17-Sep
2003	901	739.51	26,115	11-Aug
2004	918	771.20	27,234	15-Aug
2005	874	690.38	24,380	20-Aug
2006	893	724.81	25,596	22-Jul
2007	934	801.50	28,304	8-Jul
2008	943	818.77	28,914	15-Aug
2009	878	697.57	24,634	11-Aug
2010	926	786.29	27,767	31-Aug
2011	959	849.86	30,012	11-Aug
2012	902	741.35	26,180	5-Aug
2013	890	719.32	25,402	23-Aug
2014	936	805.32	28,439	8-Aug
2015	905	746.93	26,377	1-Aug
2016	849	646.20	22,820	9-Jul
2017	871	685.03	24,191	25-Jul
2018	968	867.56	30,637	29-Jul
2019	917	769.30	27,167	13-Sep
2020	742	471.31	16,644	22-Aug

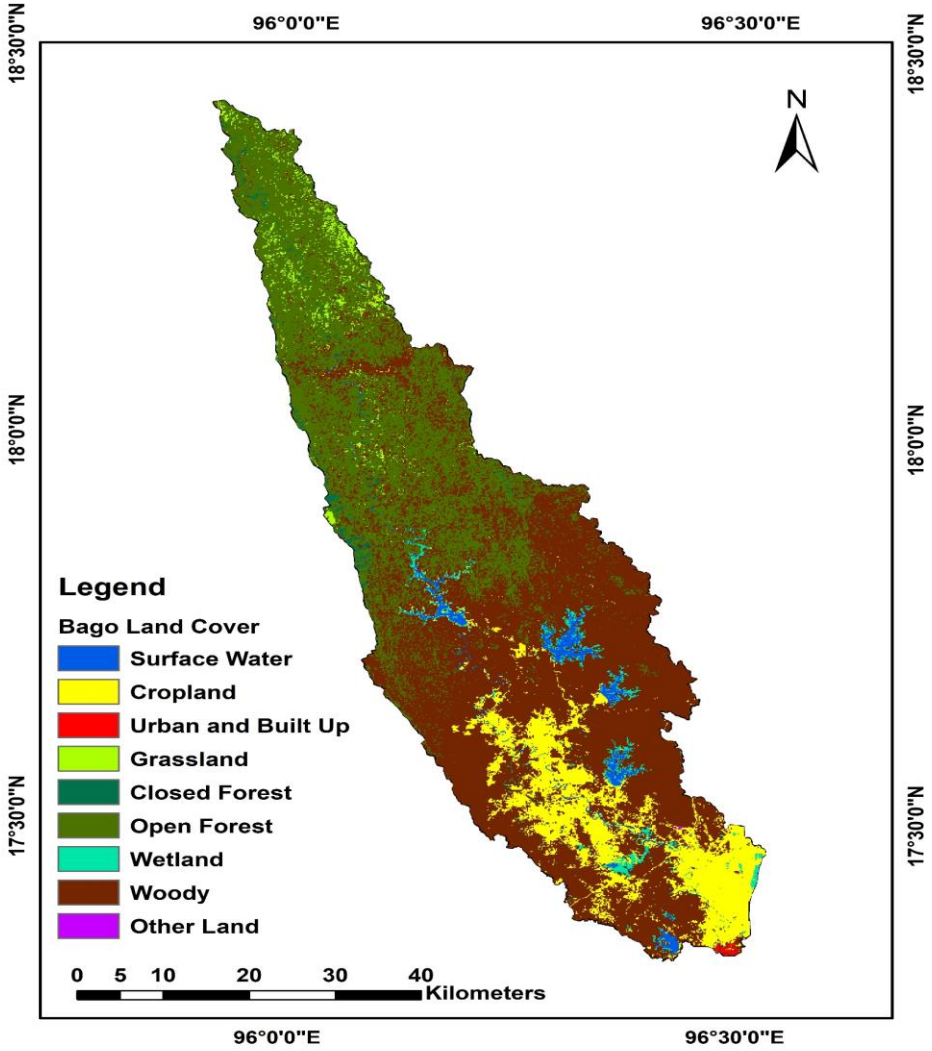
Hydrological Modeling
Estimation of the Design High Flood Levels

❖ ***HEC-GeoHMS Hydrologic Model***

- **Catchment area of Bago River Bridge (BRB) at the U/S of the station**
- **Sub-catchments such as Zaungtu, Kodukwe, Shwelaung and Salu reservoirs and dam sites**
- **Daily rainfall records of available stations for the calibration periods**
- **Salient features of the above dams and reservoirs**
- **Dam height-area-capacity curves of the above reservoirs**
- **Daily reservoir release and spillway outflow of the above reservoirs for the calibration periods**
- **Daily water level (WL) of Bago river at the city Road Bridge site (BRB)**
- **Stage (WL)-Discharge (H vs Q), Rating Curve, at the BRB**

Hydrology Model Calibration

Land Cover Characteristics of The Bago River Catchment

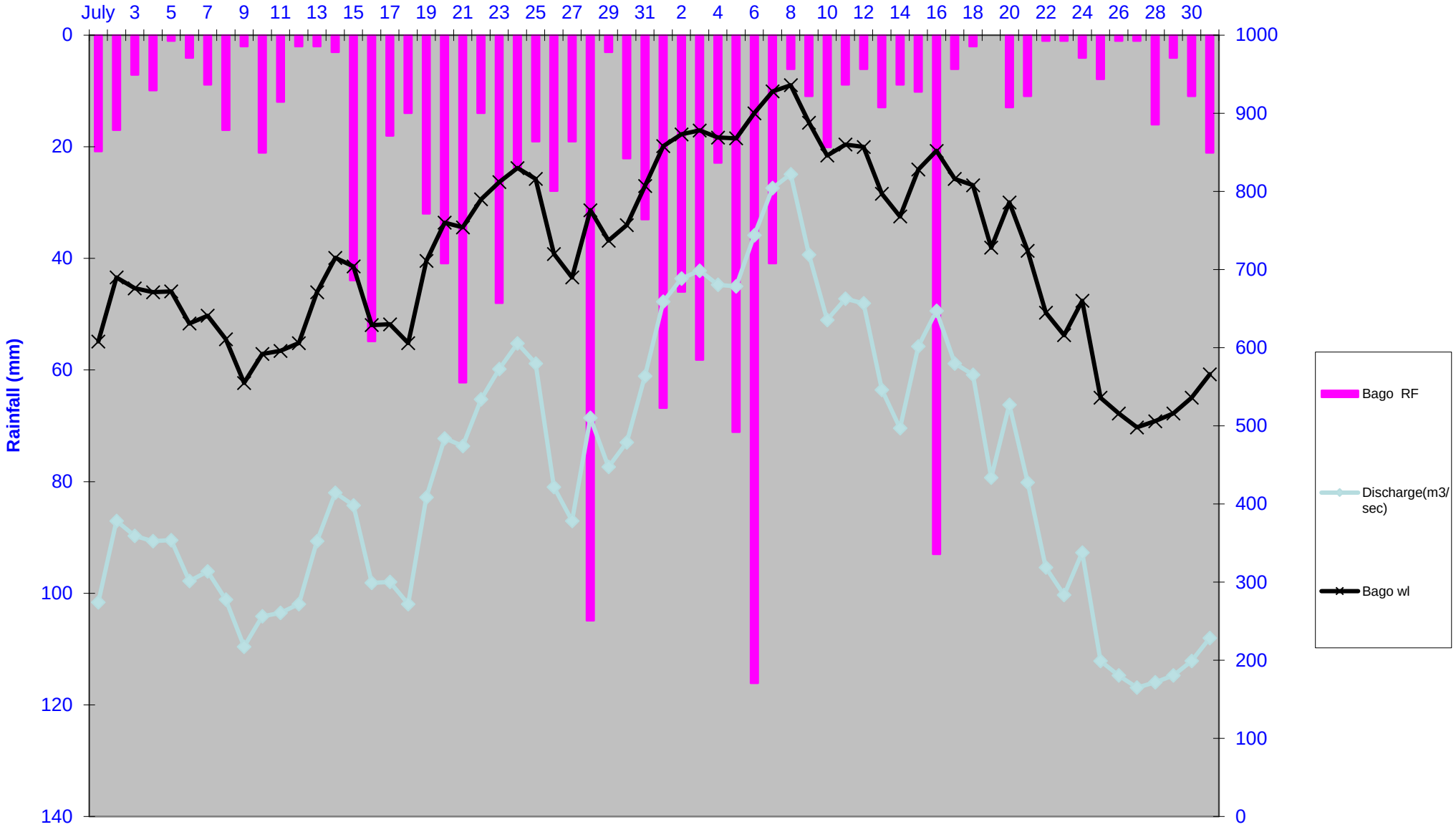


HEC-GeoHMS Hydrology Model Calibration

Available Information of the Existing Dams and Reservoirs

Number	Name	Catchment Area (Sq ml)	Dam Height (Feet)	Reservoir Capacity (Ac-ft)
1	Zaung Tu	427.03	148	324,400
2	Kodukwe	62.93	80	148,413
3	Shwe Laung	32.20	92	99,753
4	Salu	28.88	80	90.832

2014 Rainfall and Discharge of Bago Station



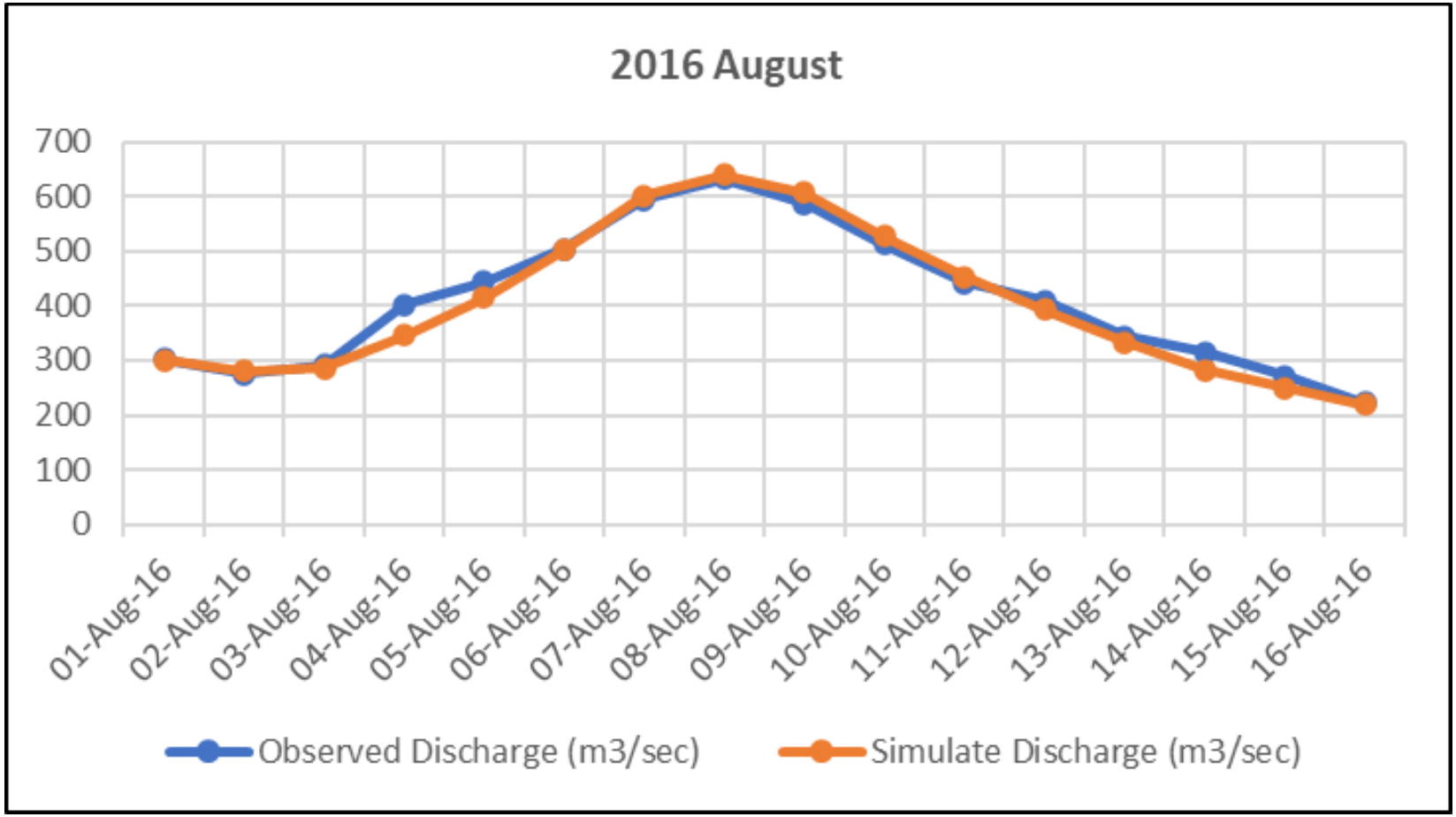
HEC-GeoHMS Hydrology Model Calibration

Selection of Flood Events for Calibration

Year	Months	Dates		Peak Discharge m^3/sec	Peak Water Level (cm)	Simulation Efficiency %
		From	To			
2011	August	2	28	849.90	959	94.7
2013	July / August	27	30	627.10	838	94.2
2014	July / August	29	14	805.30	936	94.3
2015	July / August	27	12	746.90	905	92.2
2016	June	5	25	660.20	849	97.5
2016	August	1	16	632.30	841	99.0

Hydrology Model Calibration

HEC-GeoHMS model calibration for 2016 – August



HEC-GeoHMS Hydrology Model

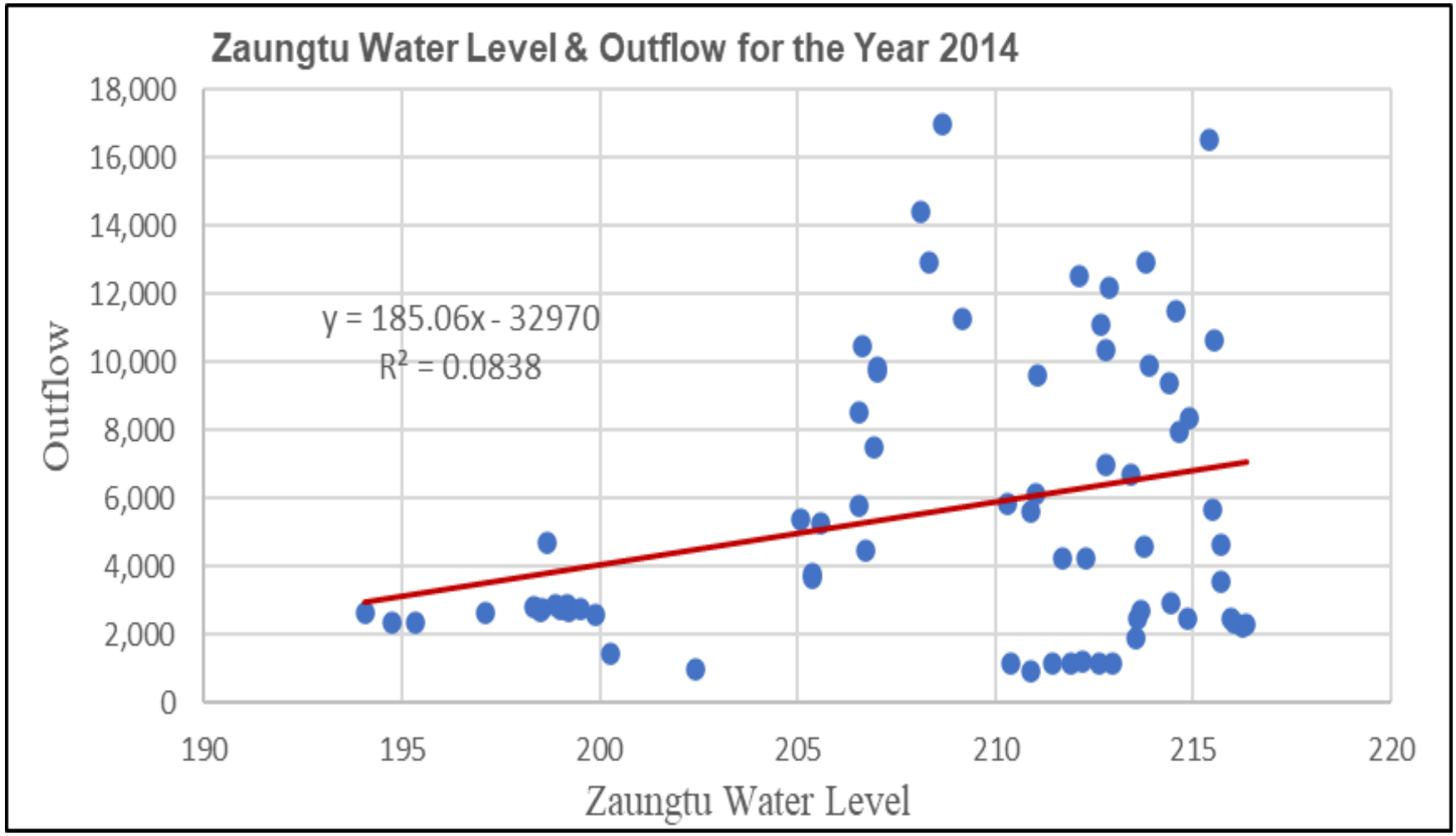
Simulation Runs for Bago River Flood Mitigation Design

- **Designated outflow from the Zaung Tu Reservoir(ZTR) according to the design return period**
- **Design rainfall according to the design return period**
- **Calibrated parameters of the Bago River catchment**

- **ZTR Mean Total Outflow, $Y = 185.06X - 32970 + CL(X-69.2)^{1.5}$**
- X is the Reservoir Level, L is Emergency Spillway Length, C is Coefficient

HEC-GeoHMS Hydrology Model

Design outflow from the Zaung Tu Reservoir (ZTR)



HEC-GeoHMS Hydrology Model

Water Levels at BRB for Various Outflows from the ZTR

Sr.	Proposed Scenario		Model Results for Zaungtu Reservoir					Model Results at Bago Road Bridge				Remark
	Reservoir Outflow Curve	Return Period Year	Total Maximum Outflow, m^3/sec	Total Minimum Outflow, m^3/sec	Outflow Volume, mm	Maximum Reservoir Level, m	Runoff Coefficient %	Peak Discharge m^3/sec	Outflow Volume, mm	Maximum Water Level, cm	Runoff Coefficient %	
1	Mean Curve	2	185.8	142.8	214.74	65.10	61.45	515.9	228.41	183	65.36	
2		5	223.9	143.2	242.92	67.30	57.79	656.0	272.96	348	64.93	
3		10	260.7	143.5	264.77	69.00	55.86	764.5	307.50	506	64.87	
4		25	413.0	143.9	334.11	69.90	61.31	908.4	371.58	753	68.19	
5		50	601.6	144.3	392.24	70.40	65.52	1029.5	423.21	993	70.70	
6		100	793.0	144.6	451.43	70.90	69.21	1166.8	475.77	1298	72.94	
7	Mean Curve 10 % Percentile	2	195.9	153.4	228.05	64.70	65.26	526.1	235.16	193	67.30	
8		5	236.8	154.7	258.88	66.80	61.58	667.8	280.79	364	66.80	
9		10	267.4	155.1	281.12	68.40	59.30	778.3	315.42	528	66.54	
10		25	403.8	155.5	339.71	69.70	62.34	924.0	374.99	782	68.81	
11		50	586.3	155.9	396.57	70.30	66.25	1039.5	425.75	1014	71.12	Initial Level 63m
12		100	753.0	156.3	455.53	70.80	69.84	1168.5	478.09	1301	73.30	
13	Mean Curve 30 % Percentile	2	213.0	172.8	251.18	63.80	71.88	544.1	247.20	212	70.74	
14		5	259.7	176.0	287.21	65.90	68.32	689.9	294.98	395	70.17	
15		10	293.7	176.5	312.91	67.40	66.01	803.3	331.02	569	69.83	
16		25	377.8	177.1	353.6	69.30	64.89	952.5	382.25	837	70.14	
17		50	489.1	177.6	406.31	69.90	67.88	1064.9	431.36	1068	72.06	
18		100	679.4	178.0	463.83	70.40	71.11	1188.6	482.89	1349	74.03	
19	Mean Curve 50 % Percentile	2	227.2	186.4	270.37	63.10	77.37	559.0	257.60	229	73.72	
20		5	279.1	193.5	311.34	65.10	74.06	708.7	307.42	422	73.13	
21		10	317.1	196.2	340.57	66.60	71.85	825.1	344.93	605	72.77	Not acceptable
22		25	366.2	196.9	377.65	68.50	69.30	978.0	393.98	887	72.30	
23		50	473.8	197.4	419.61	69.50	70.10	1092.9	438.28	1129	73.22	
24		100	604.5	197.9	473.27	70.10	72.56	1207.8	488.05	1395	74.82	

HEC-GeoHMS Hydrology Model

Design Rainfalls for the Bago River Catchment

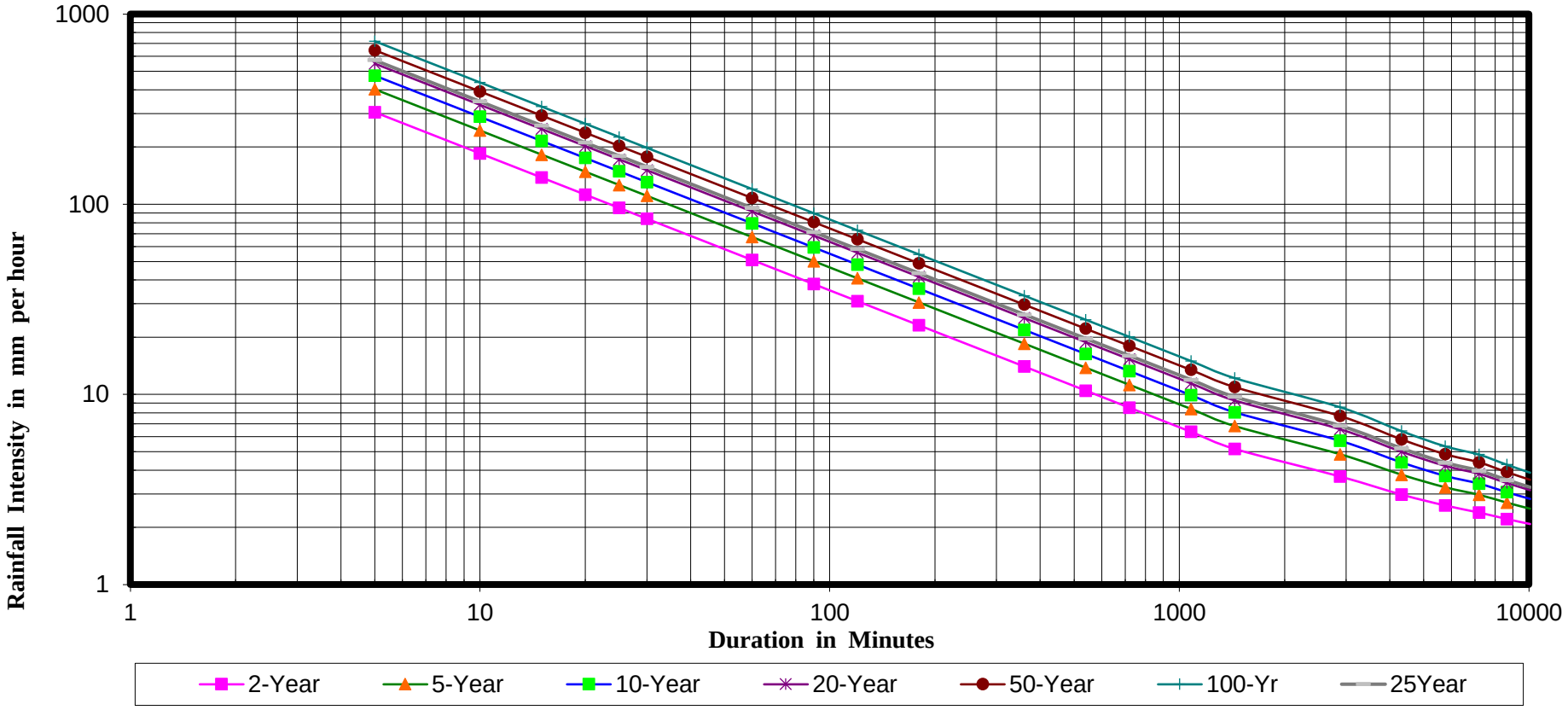
Table TR1-6: Intensity - Duration - Frequency Relationship For Bago Station (1967 - 2020)

Duration	Rainfall (mm)							Rainfall Intensity (mm / hr)						
Minutes	2-Year	5-Year	10-Year	20-Year	25-Year	50-Year	100-Yr	2-Year	5-Year	10-Year	20-Year	25-Year	50-Year	100-Yr
5	25.40	33.49	39.61	45.73	47.70	53.82	59.94	304.83	401.91	475.36	548.80	572.44	645.89	719.33
10	30.84	40.67	48.10	55.53	57.92	65.35	72.78	185.06	244.00	288.59	333.18	347.53	392.12	436.70
15	34.55	45.56	53.88	62.21	64.89	73.21	81.53	138.21	182.22	215.52	248.82	259.54	292.84	326.14
20	37.45	49.38	58.40	67.42	70.33	79.35	88.37	112.35	148.13	175.20	202.27	210.98	238.05	265.12
25	39.86	52.56	62.17	71.77	74.86	84.47	94.07	95.67	126.15	149.20	172.25	179.67	202.72	225.77
30	41.95	55.31	65.42	75.53	78.78	88.89	99.00	83.90	110.63	130.84	151.06	157.57	177.78	198.00
60	50.94	67.16	79.43	91.71	95.66	107.93	120.20	50.94	67.16	79.43	91.71	95.66	107.93	120.20
90	57.06	75.24	88.98	102.73	107.16	120.91	134.66	38.04	50.16	59.32	68.49	71.44	80.60	89.77
120	61.85	81.55	96.45	111.35	116.15	131.05	145.95	30.92	40.77	48.22	55.68	58.07	65.52	72.98
180	69.28	91.35	108.04	124.74	130.11	146.81	163.50	23.09	30.45	36.01	41.58	43.37	48.94	54.50
360	84.12	110.92	131.19	151.46	157.98	178.25	198.52	14.02	18.49	21.86	25.24	26.33	29.71	33.09
540	94.24	124.25	146.96	169.67	176.97	199.68	222.39	10.47	13.81	16.33	18.85	19.66	22.19	24.71
720	102.14	134.68	159.29	183.90	191.82	216.43	241.04	8.51	11.22	13.27	15.32	15.98	18.04	20.09
1080	114.42	150.87	178.44	206.01	214.88	242.45	270.02	6.36	8.38	9.91	11.44	11.94	13.47	15.00
1440	124.02	163.52	193.41	223.29	232.91	262.79	292.67	5.17	6.81	8.06	9.30	9.70	10.95	12.19
2880	177.65	232.50	273.99	315.48	328.84	370.33	411.82	3.70	4.84	5.71	6.57	6.85	7.72	8.58
4320	213.96	272.13	316.14	360.15	374.31	418.32	462.33	2.97	3.78	4.39	5.00	5.20	5.81	6.42
5760	249.96	311.56	358.15	404.74	419.74	466.34	512.93	2.60	3.25	3.73	4.22	4.37	4.86	5.34
7200	286.87	355.49	407.40	459.31	476.02	527.93	579.84	2.39	2.96	3.39	3.83	3.97	4.40	4.83
8640	318.34	388.06	440.81	493.55	510.53	563.27	616.01	2.21	2.69	3.06	3.43	3.55	3.91	4.28
10080	349.44	420.37	474.03	527.68	544.96	598.61	652.27	2.08	2.50	2.82	3.14	3.24	3.56	3.88

HEC-GeoHMS Hydrology Model

Intensity – Duration – Frequency Curves for the Bago River Catchment

FIGURE TR1-5 : INTENSITY - DURATION - FRENQUENCY CURVES FOR BAGO AREA
(Bago Rainfall Record = 1967 - 2020)



HEC-GeoHMS Hydrology Model

Design Rainfalls for the Bago River Catchment

Temporal and Areal Rainfall Excess for Bago River Catchment

Catchment Area = 2681 Sq Km

Table TR1 - 7

Total Duration	Interval Hours	Percent of Total	Return Period, years						Remark
			2	*5*	*10*	*25*	*50*	*100*	
168 Hours	***Point Rain***	100.00	349.44	420.37	474.03	544.96	598.61	652.27	
	Areal Rain	93.00	324.98	390.94	440.85	506.81	556.71	606.61	
	24.00	14.34	46.61	56.07	63.22	72.68	79.84	87.00	
	48.00	14.63	47.56	57.21	64.51	74.17	81.47	88.77	
168 Hours	***72.00***	11.33	36.82	44.29	49.95	57.42	63.07	68.73	
	96.00	13.95	45.32	54.52	61.48	70.68	77.64	84.60	
	120.00	16.14	52.47	63.12	71.17	81.82	89.88	97.94	
	144.00	16.32	53.03	63.79	71.93	82.70	90.84	98.98	
	168.00	13.29	43.18	51.95	58.58	67.34	73.97	80.60	
	TOTAL	100.00	324.98	390.94	440.85	506.81	556.71	606.61	

NOTE: 1. A factor for catchment areal rainfall for 240 hour duration is obtained from Figure 26 of Australian Rainfall - Runoff

2. Above temporal rainfall for 7 days is obtained from the analysis Bago rainfall of 54 years record. (1967 - 2020)

HEC-GeoHMS Hydrology Model

Adopted Parameters for Simulation Runs

Sub-basin	Initial Loss (mm)	Constant Loss Rate (mm/hr)	Lag Time (min)	Initial Discharge (m^3 /s /km^2)	Recession Constant	Ratio to Peak
W320	5.04	0.82	26.67	0.6174	0.7732	0.5417
W330	5.00	1.20	43.30	0.1194	0.8500	0.8000
W340	5.00	1.20	22.00	0.1281	0.8500	0.8000
W350	5.05	1.07	11.73	0.0947	0.8500	0.8086
W370	4.90	1.27	16.93	0.0988	0.7182	0.8500
W380	4.71	1.78	17.36	0.1904	0.7283	0.4306
W390	5.00	1.20	16.85	0.1802	0.8000	0.8000
W400	5.00	1.73	12.56	0.1276	0.7496	0.8997
W410	5.00	1.20	14.26	0.0939	0.8500	0.8000
W430	5.00	0.74	12.66	0.1594	0.7466	0.2147
W440	5.00	1.58	12.96	0.0179	0.7506	0.8284
W450	5.00	0.78	17.94	0.1791	0.7506	0.8852
W460	4.80	0.71	27.06	0.1184	0.7797	0.8908
Mean	**4.96**	**1.18**	**19.41**	**0.1635**	**0.7844**	**0.7346**

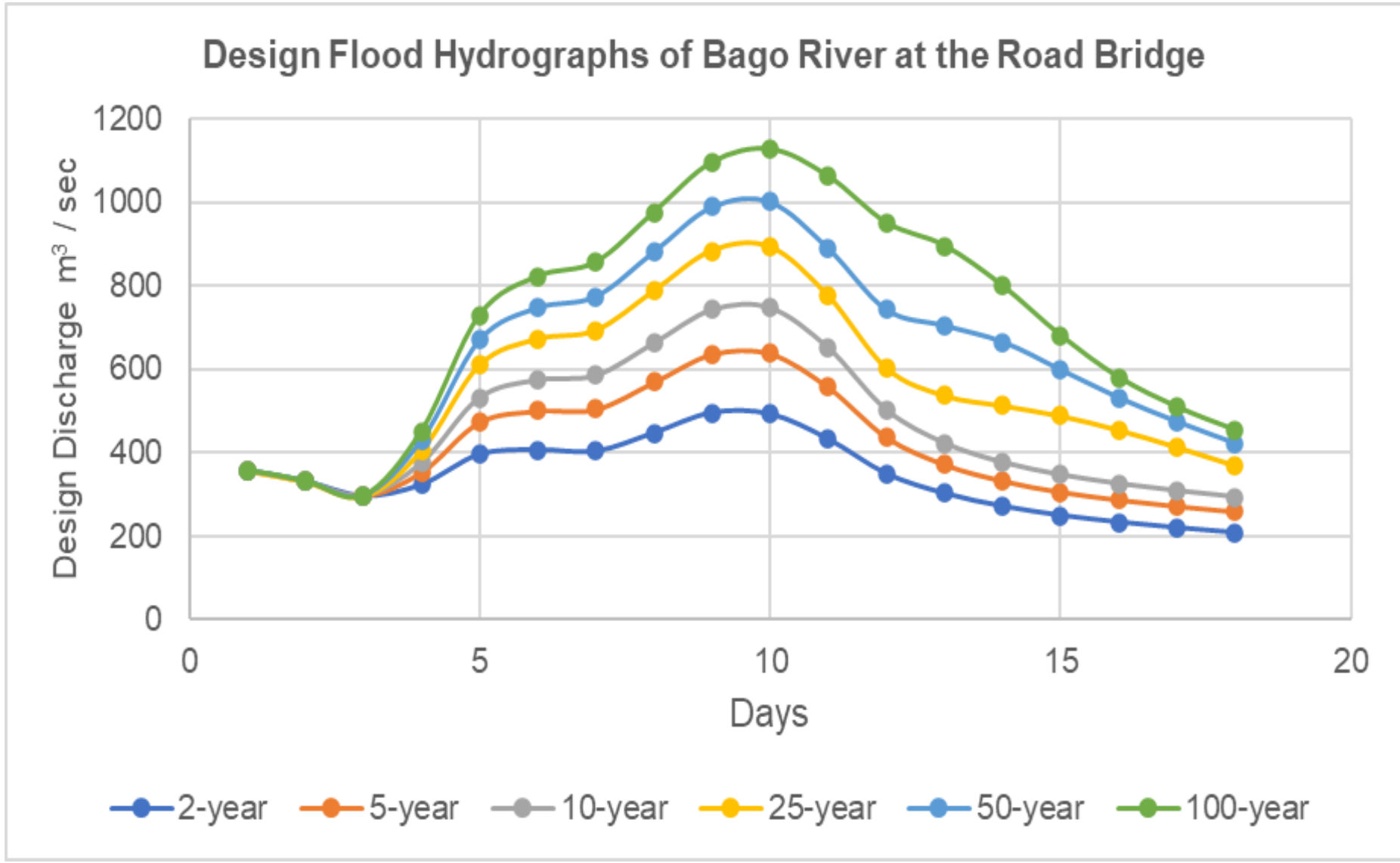
HEC-GeoHMS Hydrology Model

Design Flood Discharges at BRB Produced by HEC-GeoHMS Model

	Discharge Q (m^3/sec)					
Day	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
1	357.0	357.0	357.0	357.0	357.0	357.0
2	331.3	331.3	331.3	331.3	331.3	331.3
3	295.8	295.8	295.8	295.8	295.8	295.8
4	322.7	352.1	374.7	404.8	427.7	450.7
5	395.4	472.7	531.5	609.8	669.2	728.7
6	406.5	499.8	573.7	672.1	746.6	821.1
7	403.1	503.7	584.8	692.6	774.0	855.4
8	447.0	568.7	662.7	787.3	881.3	975.2
9	495.3	636.2	742.6	883.1	989.0	1094.8
10	492.2	637.7	747.3	891.8	1000.8	1126.0
11	431.8	557.0	651.0	774.4	889.4	1060.9
12	349.0	436.8	502.3	602.2	742.1	949.7
13	301.9	371.1	422.4	536.4	704.0	894.6
14	271.1	331.6	376.4	512.4	664.9	798.4
15	249.3	305.2	346.4	487.9	597.8	679.1
16	233.0	286.2	325.2	454.1	530.4	579.1
17	219.7	270.9	308.2	413.3	473.2	508.0
18	208.0	257.6	293.6	369.7	421.3	453.0

HEC-GeoHMS Hydrology Model

Design Flood Hydrographs at BRB



HEC-GeoHMS Hydrology Model

Design Flood Discharges & Levels at BRB

Sr.	Return Period, Year	Design Flood Peak, m^3/sec	Design Flood Level, meter	Approximate Time to Peak, Days	Runoff Coefficient Percent	Remark
1	2	495.3	758	7.0	61.62	Initial reservoir level of ZTR kept at 61m
2	5	637.7	844	7.0	61.90	
3	10	747.3	905	7.0	62.08	
4	25	891.8	980	7.0	64.74	
5	50	1000.8	1033	7.0	67.40	
6	100	1126.0	1091	7.0	69.91	

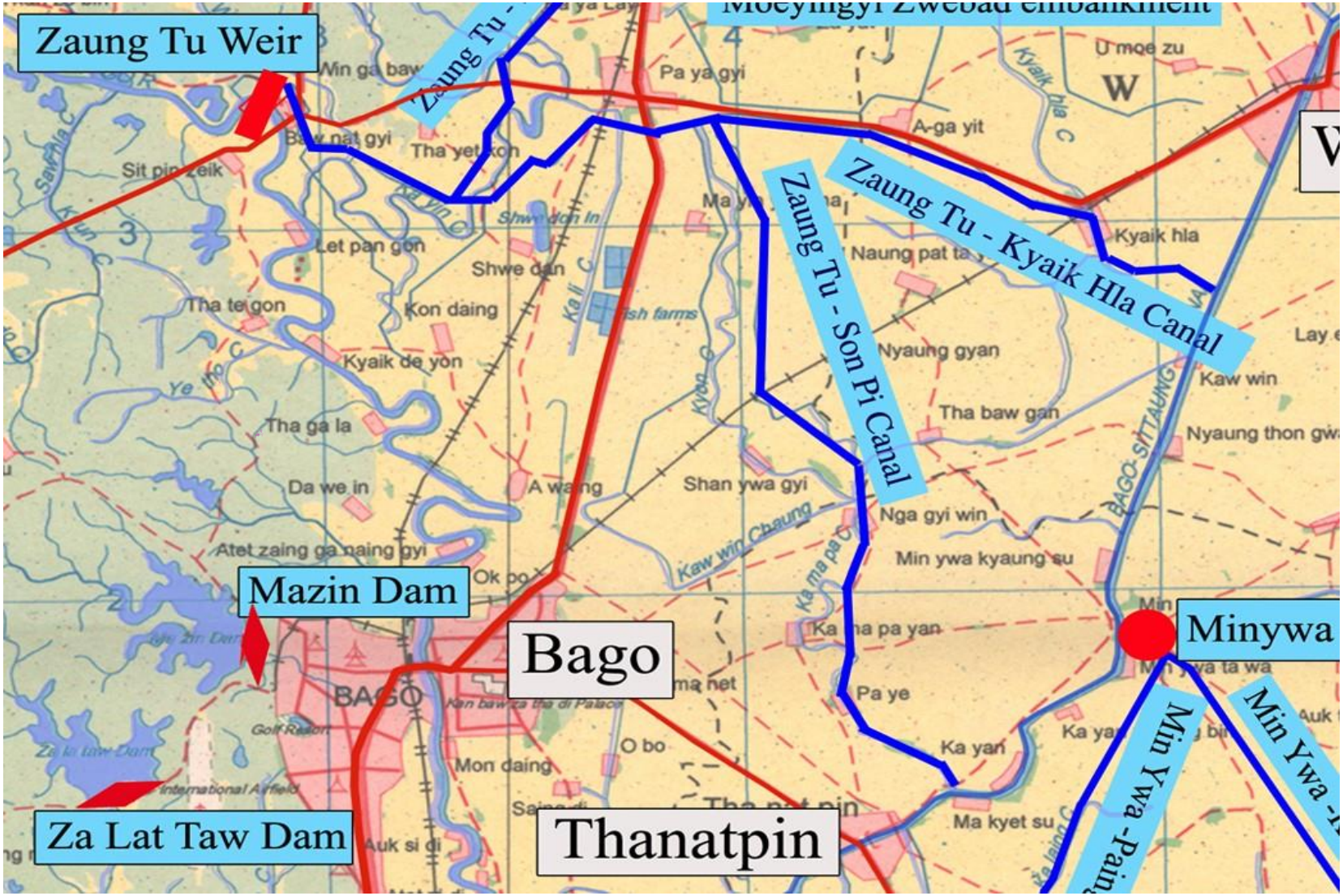
HEC-GeoHMS Hydrology Model

Design Flood Discharges Along the Bago River

Return Periods (year)	Design Flood Peaks (m^3/sec)				
	ZaungTu Dam	ZaungTu Weir	Letpangon village	BRB	Tawa
2	172.9	409.7	409.7	495.3	510.8
5	212.3	526.6	526.6	637.7	657.7
10	241.4	614.6	614.6	747.3	770.7
25	372.1	730.8	730.8	891.8	919.8
50	524.4	818.3	818.3	1000.8	1032.2
100	682.2	924.3	924.3	1126.0	1161.3

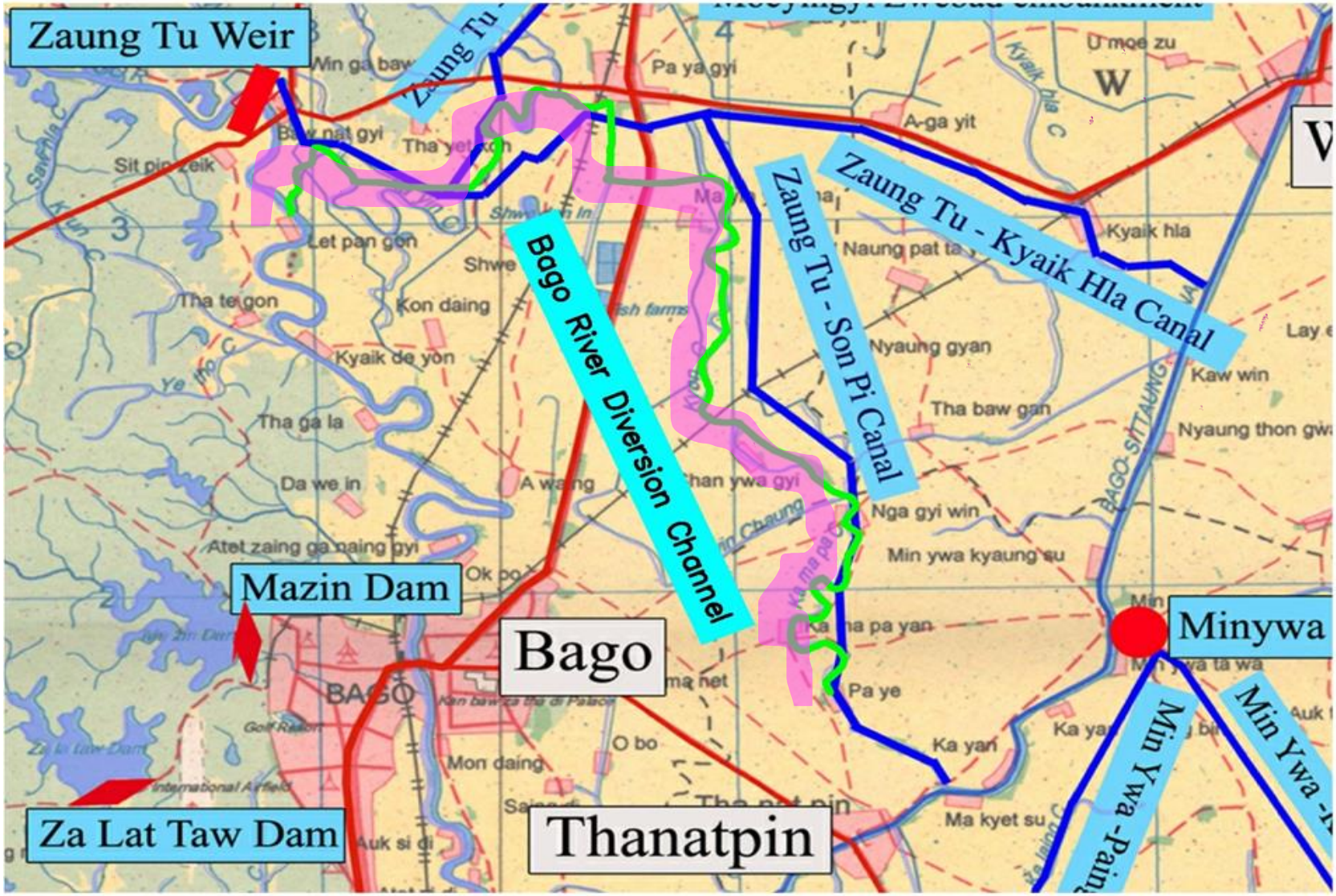
HEC-GeoHMS Hydrology Model

Existing Drainage System in The Bago River Basin



HEC-GeoHMS Hydrology Model

Proposed Bago River Diversion Channel



HEC-GeoHMS Hydrology Model

Flood Discharges & Levels at BRB Mitigated by The Diversion Channel

Sr.	Return Period, Year	Design Flood Peaks *Without Diversion Spillway*		Discharge through Diversion Spillway, m^3/sec	Design Flood Peaks *With Diversion Spillway (Optimized)*	
		Discharge, m^3/sec	WL, cm		Discharge, m^3/sec	WL, cm
1	2	495.3	758	184.4	312.8	629
2	5	637.7	844	237.0	403.6	696
3	10	747.3	905	276.6	472.9	743
4	25	891.8	980	328.9	564.2	801
5	50	1000.8	1033	368.2	633.2	**842**
6	100	1126.0	1091	415.9	711.1	885

Hydraulic Modeling of Bago River

Available Information for HEC-RAS Hydraulic Model

(i) ***Design flows at critical locations of the streams*****: Design flood hydrographs of 2-year to 100-year return periods at the critical locations generated from the HEC-GeoHMS hydrologic model**.

(ii) ***Cross sections (XS) at every 100 meters*****: XS information of the Bago River and proposed diversion channel (DC)**

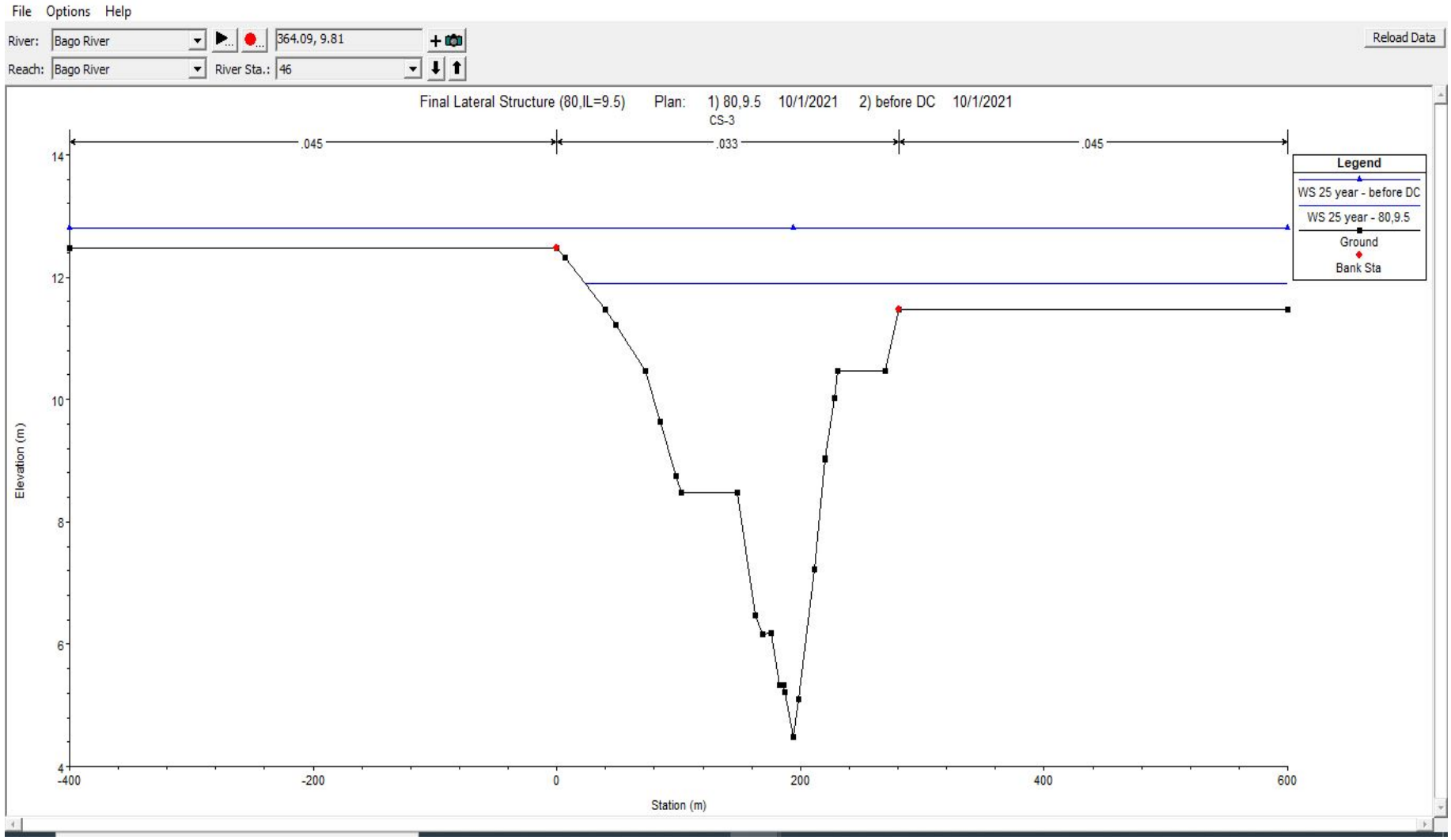
(iii) ***Detail configuration of cross drainage structures such as bridges, culverts and associated afflux bunds***

(iv)***Stage-discharge rating curve at key location(s):*** **Discharge measurement records are available with the Client, IWUMD & DMH.**

(v) ***Tidal data at the D/S boundary of the hydraulic model at Tawa:*** **Daily two times WL records are available with the Client, IWUMD**.

HEC-RAS Hydraulic Modeling

Cross Section at Upstream of the Diversion Channel (25-Year ARI)



HEC-RAS Hydraulic Modeling

Observed Stage-Discharge Data Available at BRB

Table TR1-12: Analysis of Observed Data for Stage-Discharge Rating Curve

Stream - Bago River

Station - Bago Road Bridge

Catchment Area : 2681 Sq Km

Discharge observation data from IWUMD

Sr.No	Date	Mean Water Level , (h) cm	Observed Discharge, m^3/sec	Mean Water Level , (h-203) cm	Computed Discharge (m^3/sec) $Q = 0.0082*(h-203)^{1.7424}$
1	6.7.2012	626.00	268.18	423.00	308.99
2	27.7.2012	862.00	697.12	659.00	669.02
3	27.7.2012	868.00	680.78	665.00	679.67
4	28.7.2012	846.00	622.83	643.00	640.97
5	7.8.2012	870.00	647.84	667.00	683.24
6	7.8.2012	864.00	671.97	661.00	672.56
7	7.8.2012	866.00	684.86	663.00	676.11
8	11.9.2012	818.00	604.17	615.00	593.13
9	11.9.2012	813.00	603.08	610.00	584.75
10	21.9.2012	506.00	153.24	303.00	172.77
11	21.9.2012	492.00	158.13	289.00	159.10
12	5.10.2012	454.00	151.15	251.00	124.45
13	23.9.2013	706.00	414.99	503.00	417.86
14	23.9.2013	704.00	398.39	501.00	414.96
15	23.9.2013	682.00	382.77	479.00	383.73
16	23.9.2013	690.00	386.25	487.00	394.97
17	23.9.2013	700.00	397.05	497.00	409.21
18	26.9.2013	498.00	172.88	295.00	164.90
19	26.9.2013	502.00	166.80	299.00	168.82
20	26.9.2013	508.00	174.42	305.00	174.77
21	27.9.2013	498.00	181.80	295.00	164.90
22	2.10.2013	570.00	291.39	367.00	241.26
23	2.10.2013	580.00	310.73	377.00	252.83
24	2.10.2013	594.00	274.29	391.00	269.42

HEC-RAS Hydraulic Modeling

Observed Stage-Discharge Data Available at BRB

Table TR1-12: Analysis of Observed Data for Stage-Discharge Rating Curve

Stream - Bago River

Station - Bago Road Bridge

Catchment Area : 2681 Sq Km

Discharge observation data from IWUMD

Sr.No	Date	Mean Water Level , (h) cm	Observed Discharge, m^3/sec	Mean Water Level , (h-203) cm	Computed Discharge (m^3/sec) $Q = 0.0082*(h-203)^{1.7424}$
25	2.10.2013	606.00	319.73	403.00	283.99
26	2.10.2013	614.00	334.71	411.00	293.88
27	2.10.2013	618.00	247.01	415.00	298.88
28	3.10.2013	572.00	255.53	369.00	243.56
29	3.10.2013	562.00	235.37	359.00	232.17
30	3.10.2013	550.00	236.36	347.00	218.82
31	3.10.2013	540.00	229.12	337.00	207.95
32	3.10.2013	534.00	218.37	331.00	201.54
33	30.10.2013	810.00	609.14	607.00	579.75
34	30.10.2013	804.00	583.06	601.00	569.80
35	4.2.2014	274.00	12.73	71.00	13.79
36	**4.2.2014**	**262.00**	**10.36**	**59.00**	9.98
37	3.8.2014	875.00	765.94	672.00	692.18
38	3.8.2014	870.00	752.46	667.00	683.24
39	4.8.2014	860.00	609.74	657.00	665.49
40	4.8.2014	857.00	702.02	654.00	660.20
41	4.8.2014	855.00	689.77	652.00	656.69
42	6.8.2014	908.00	830.85	705.00	752.49
43	6.8.2014	910.00	844.77	707.00	756.21
44	6.8.2014	915.00	888.00	712.00	765.55
45	6.8.2014	918.00	911.00	715.00	771.18
46	7.8.2014	931.00	990.00	728.00	795.78
47	7.8.2014	938.00	1014.00	735.00	809.16
48	**7.8.2014**	**942.00**	**1053.00**	**739.00**	816.85
49	8.8.2014	935.00	945.00	732.00	803.41

HEC-RAS Hydraulic Modeling

Observed Stage-Discharge Data Available at BRB

Stream - Bago River

Station - Bago Road Bridge

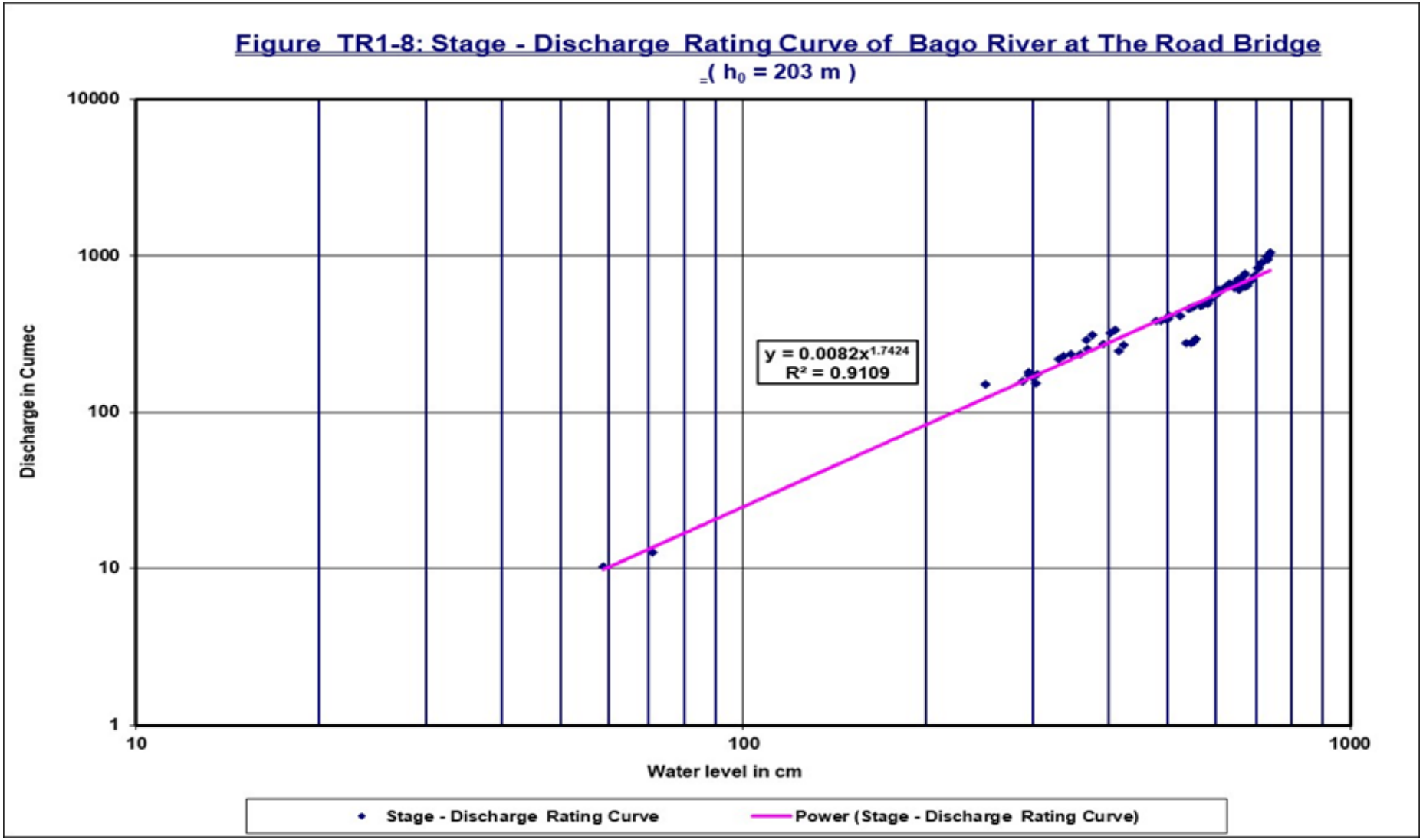
Catchment Area : 2681 Sq Km

Discharge observation data from IWUMD

Sr.No	Date	Mean Water Level , (h) cm	Observed Discharge, m^3/sec	Mean Water Level , (h-203) cm	Computed Discharge (m^3/sec) $Q = 0.0082*(h-203)^{1.7424}$
50	9.8.2014	899.00	749.00	696.00	735.83
51	9.8.2014	890.00	692.00	687.00	719.33
52	9.8.2014	880.00	646.00	677.00	701.18
53	9.8.2014	875.00	636.00	672.00	692.18
54	14.8.2014	792.00	525.00	589.00	550.13
55	14.8.2014	804.00	562.00	601.00	569.80
56	15.8.2014	828.00	635.00	625.00	610.04
57	15.8.2014	835.00	669.00	632.00	621.99
58	15.8.2014	840.00	652.00	637.00	630.59
59	18.8.2014	785.00	496.48	582.00	538.79
60	18.8.2014	784.00	501.63	581.00	537.17
61	18.8.2014	780.00	501.18	577.00	530.75
62	18.8.2014	775.00	490.70	572.00	522.76
63	18.8.2014	770.00	477.64	567.00	514.82
64	18.8.2014	760.00	295.66	557.00	499.11
65	18.8.2014	755.00	280.35	552.00	491.32
66	18.8.2014	750.00	277.32	547.00	483.60
67	19.8.2014	740.00	275.71	537.00	468.30
68	19.8.2014	728.00	415.34	525.00	450.21
69	19.8.2014	744.00	459.07	541.00	474.39
70	19.8.2014	750.00	463.94	547.00	483.60
71	20.8.2014	755.00	469.79	552.00	491.32

HEC-RAS Hydraulic Modeling

Stage-Discharge Rating Curve Available at BRB



HEC-RAS Hydraulic Modeling

Abstract of Tidal Water Levels Recorded at Tawa

YEAR	2014		2013		2012	
TIME	06:00	18:00	06:00	18:00	06:00	18:00
Mean August WL (ft)	18.43	18.37	18.43	18.45	19.32	19.32
Mean August WL (ft)	18.40		18.44		19.32	
Mean August WL (m)	5.61		5.62		5.89	
Annual Maximum (ft)	22.6	22.4	21.3	21.5	21.2	21.2
Mean Annual Maximum (ft)	22.50		21.40		21.20	
Mean Annual Maximum (m)	6.86		6.52		6.46	

HEC-RAS Hydraulic Modeling

Calibration of the HEC-RAS Model for the Bago River

Generated Hydraulic Elements of the Flood at the BRB

File Type Options Help

River: Bago River Profile: 2014 Event

Reach Bago River RS: 29.5 Plan: 2014

Plan: 2014 Bago River Bago River RS: 29.5 Profile: 2014 Event

		Element	Inside BR US	Inside BR DS
E.G. US. (m)	9.38	E.G. Elev (m)	9.32	9.30
W.S. US. (m)	9.34	W.S. Elev (m)	9.17	9.20
Q Total (m3/s)	821.70	Crit W.S. (m)	4.33	3.48
Q Bridge (m3/s)	821.70	Max Chl Dpth (m)	10.45	10.40
Q Weir (m3/s)		Vel Total (m/s)	1.70	1.40
Weir Sta Lft (m)		Flow Area (m2)	482.19	585.16
Weir Sta Rgt (m)		Froude # Chl	0.17	0.14
Weir Submerg		Specif Force (m3)	1958.53	2309.83
Weir Max Depth (m)		Hydr Depth (m)		
Min El Weir Flow (m)	11.40	W.P. Total (m)	196.01	269.35
Min El Prs (m)	9.12	Conv. Total (m3/s)	26628.4	29783.8
Delta EG (m)	0.09	Top Width (m)		
Delta WS (m)	0.12	Frctn Loss (m)	0.01	0.00
BR Open Area (m2)	482.19	C & E Loss (m)	0.01	0.01
BR Open Vel (m/s)	1.70	Shear Total (N/m2)	22.97	16.22
BR Sluice Coef		Power Total (N/m s)	39.15	22.77
BR Sel Method	Energy only			

HEC-RAS Hydraulic Modeling

Calibration of the HEC-RAS Model for the Bago River

- ***Adopted Hydraulic Characters of the Bago River***

1. **River channel roughness, n_c … 0.033**
2. **River overbank roughness, n_b … 0.045**

HEC-RAS Hydraulic Modeling

Generation of Flood Profiles of the Bago River

Input Data into the Calibrated HEC-RAS Model

I. **Hydraulic parameters such as Manning's roughness, n, calibrated for the Bago River**

II. **Design flood peaks at the key locations**

III. **Cross sections (XS) at every 100 meters for the River**

IV. **Detail configuration of cross drainage structures such as bridges, culverts and afflux bunds along the River**

V. **Tidal data at D/S boundary of the hydraulic model at Tawa**

VI. **Flows or WL data at the Upstream (U/S) and D/S boundaries of the model**

VII. **Stage-discharge rating curve at the key location(s)**

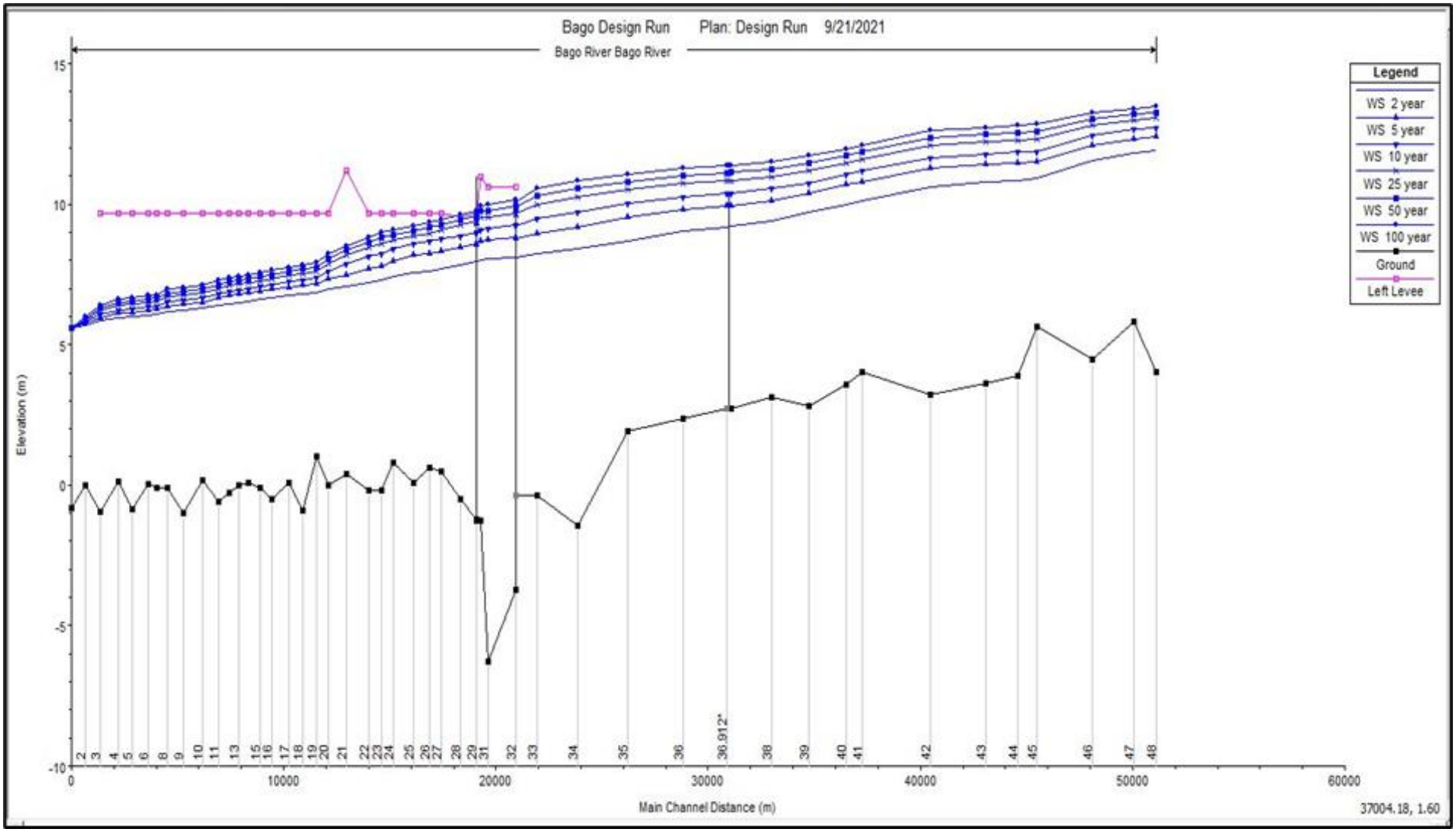
HEC-GeoHMS Hydrology Model

Design Flood Discharges Along the Bago River

Return Periods (year)	Design Flood Peaks (m^3/sec)				
	ZaungTu Dam	ZaungTu Weir	Letpangon village	BRB	Tawa
2	172.9	409.7	409.7	495.3	510.8
5	212.3	526.6	526.6	637.7	657.7
10	241.4	614.6	614.6	747.3	770.7
25	372.1	730.8	730.8	891.8	919.8
50	524.4	818.3	818.3	1000.8	1032.2
100	682.2	924.3	924.3	1126.0	1161.3

HEC-RAS Hydraulic Modeling

Generated Flood Profiles of Bago River for Different Return Periods



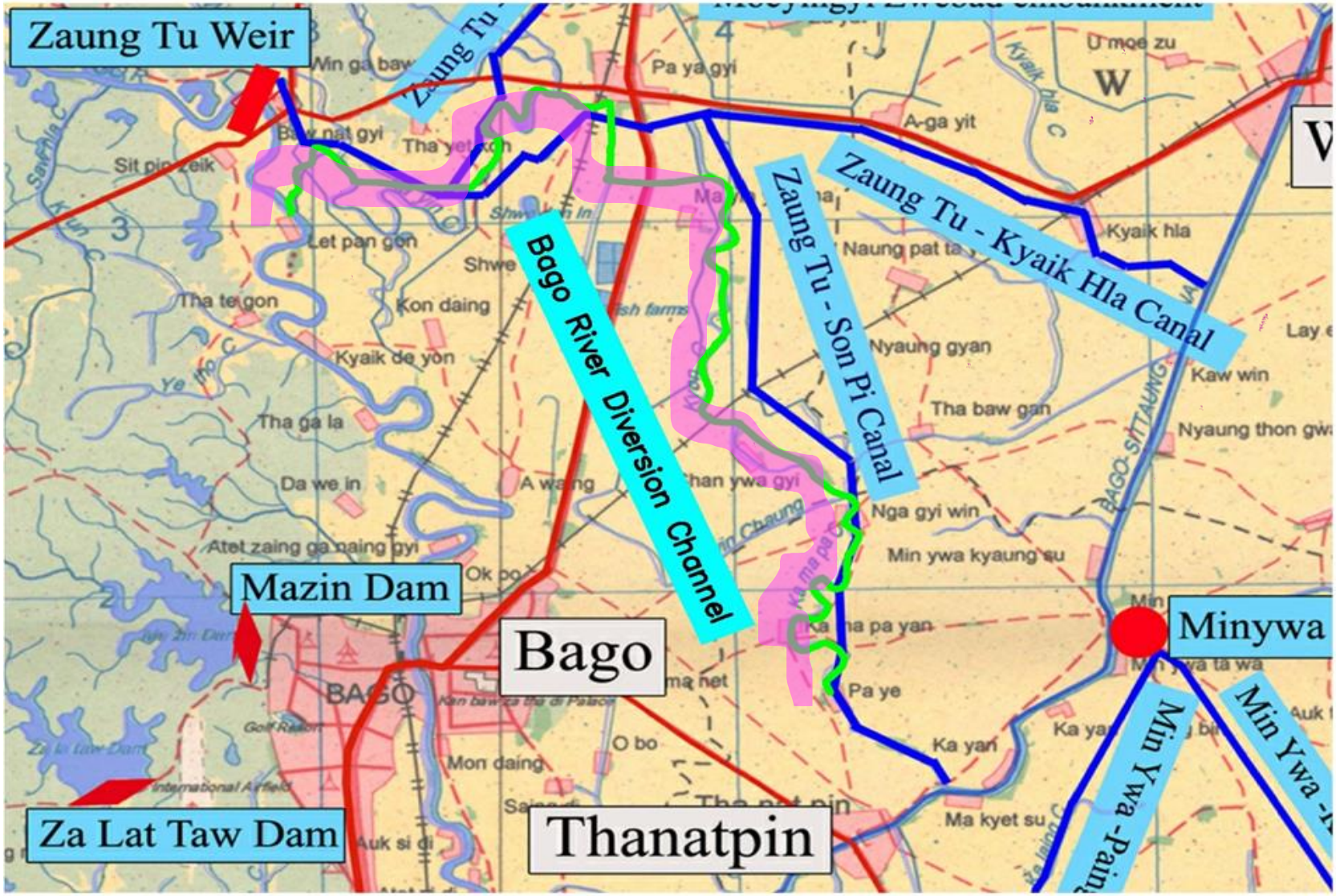
HEC-RAS Hydraulic Modeling

Peak Flood Levels Generated by the HEC-RAS Model

Return Periods (year)	Design Peak Flood Levels (cm)			
	ZaungTu Weir	Letpangon village	BRB	Tawa
2	1193	1091	800	570
5	1242	1151	867	575
10	1273	1188	911	580
25	1307	1229	953	587
50	1327	1257	975	593
100	1349	1283	995	600

HEC-GeoHMS Hydrology Model

Proposed Bago River Diversion Channel



HEC-RAS Hydraulic Modeling

Optimization of Diversion Channel Using HEC-RAS Hydraulic Model

1) **Width and bed level (IL) of proposed DC headwork is optimized to achieve the most cost-effective solution.**

2) **To meet the target level which guarantee no flooding in the Bago City under the floods of 25-year return period.**

3) **Such water management system will not affect the Bago river regime adversely.**

4) **To ensure no flooding along the DC under 25-year flood.**

5) **To guarantee such diverted flow of 25-year return period will not increase the pond level of TFP more than six (6) inches.**

HEC-RAS Hydraulic Modeling

Input Data for Optimization of Diversion Channel (DC)

- **DC starting from Letpangon village just below the Zaungtu weir is 38 Km long**
- **DC finally flows into Flooded Pond (TFP) near Thanatpin Town.**
- **Every 100m cross sections of the DC are input with proposed levee sufficient to protect against the 50-year design flood.**
- **During monsoon mean WL of the TFP of 6.10-meter AMSL will be used**
- **Variable sizes and IL of the Diversion Spillway will be used to run the model to produce an optimized DC.**

Table 1: Eight (8) Scenarios of the Proposed Diversion Channel

Sr.No	Diversion Channel Structure	
	Bed Width (m)	Bed Level (RL, m)
1	100	
2	90	9.5
3	80	9
4	70	

HEC-RAS Hydraulic Modeling

Optimization of Diversion Channel Using HEC-RAS Hydraulic Model

Sr. No	Diversion Channel		Return Period, Year	Design Discharge at Stream Diversion			Design Discharge at Bago Bridge		Estimated Earthwork Volume, m^3
	Width meter	Bed Level meter		Bago River U/S m^3/sec	Bago River D/S m^3/sec	Diversion Channel m^3/sec	Discharge m^3/sec	Water Level m	
1	100	9.5	10	614.60	353.61	264.39	486.31	7.95	10,430,078
			25	730.80	397.17	339.57	558.17	8.30	
			50	818.30	427.13	387.84	609.63	8.53	
			100	924.30	471.88	456.96	673.58	8.82	
2	100	9.0	10	614.60	307.30	311.19	440.00	7.68	12,670,873
			25	730.80	341.02	384.37	502.02	8.03	
			50	818.30	370.18	440.77	552.68	8.28	
			100	924.30	406.61	510.45	608.31	8.52	
3	90	9.5	10	614.60	361.65	249.74	494.35	7.99	9,217,483
			25	730.80	407.27	320.07	568.27	8.35	
			50	818.30	443.81	372.15	626.31	8.61	
			100	924.30	492.08	440.87	693.78	8.89	
4	90	9.0	10	614.60	314.72	294.46	447.42	7.73	11,245,544
			25	730.80	354.72	369.11	515.72	8.10	
			50	818.30	391.90	434.91	574.40	8.38	
			100	924.30	431.70	499.01	633.40	8.65	
5	80	9.5	**10**	**614.60**	**377.13**	**241.84**	**509.83**	**8.07**	**8,025,415**
			25	**730.80**	**426.24**	**308.14**	**587.24**	**8.43**	
			50	**818.30**	**461.49**	**352.76**	**643.99**	**8.71**	
			100	**924.30**	**508.96**	**411.79**	**710.66**	**8.96**	
6	80	9.0	10	614.60	329.62	286.73	462.32	7.82	9,840,493
			25	730.80	376.10	359.66	537.10	8.21	
			50	818.30	409.15	411.15	591.65	8.45	
			100	924.30	450.80	469.87	652.50	8.74	
7	70	9.5	10	614.60	389.55	225.56	522.25	8.13	6,855,482
			25	730.80	442.96	287.51	603.96	8.50	
			50	818.30	483.92	332.01	666.42	8.80	
			100	924.30	539.40	391.17	741.10	9.08	
8	70	9.0	10	614.60	343.25	269.98	475.95	7.89	8,457,714
			25	730.80	395.67	339.46	556.67	8.30	
			50	818.30	428.77	383.60	611.27	8.53	
			100	924.30	477.29	441.63	678.99	8.84	

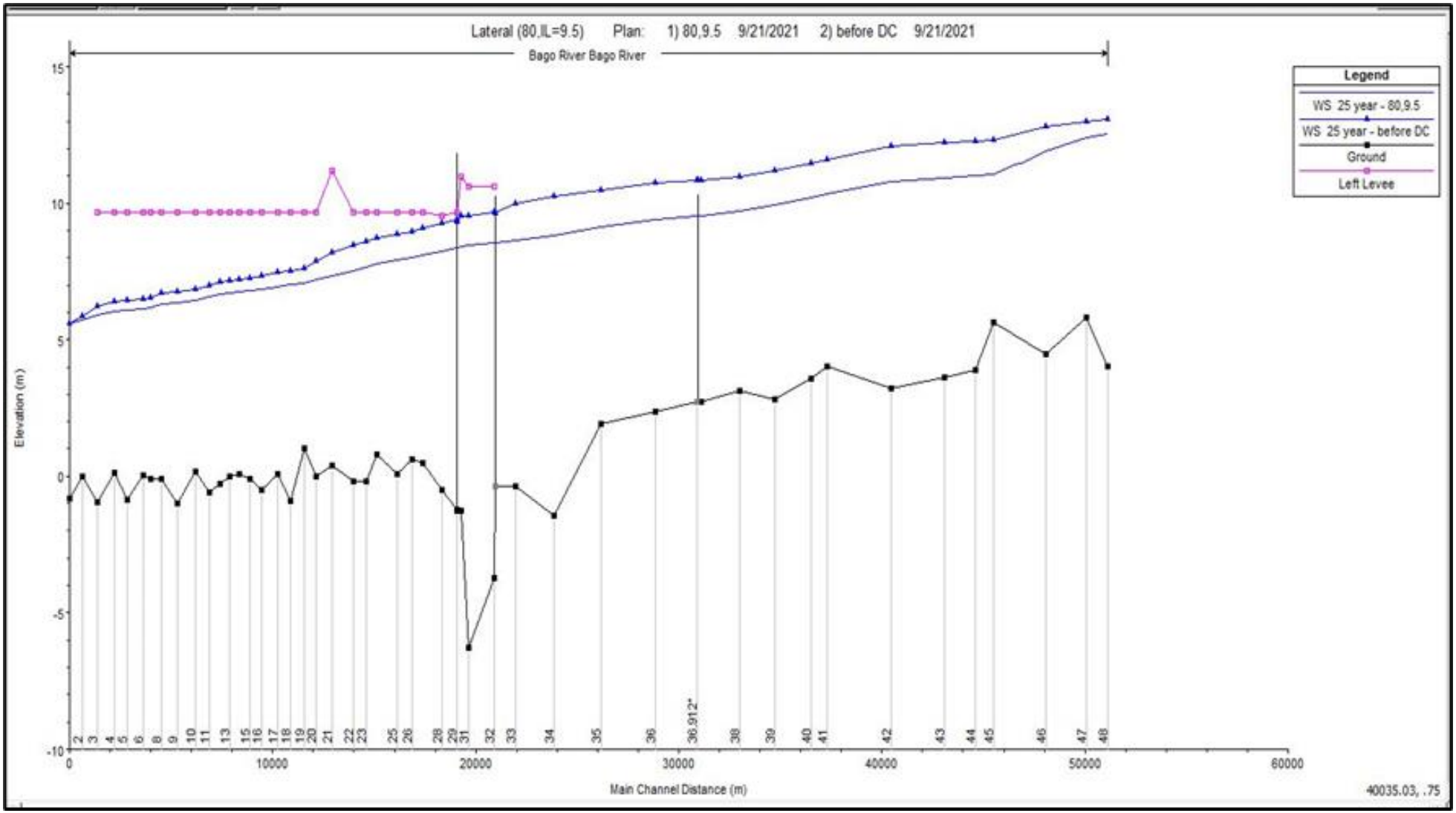
HEC-RAS Hydraulic Modeling

Recommended / Optimized Diversion Channel for Implementation

- **Total Length of Proposed Diversion Channel… 38.00 Km**
- **Base width of the headwork and DC … 80.00 meters**
- **Bed level (IL) of the headwork and DC … 9.50 meters**
- **Bed level (IL) of the DC at the tail … 3.00 meters**

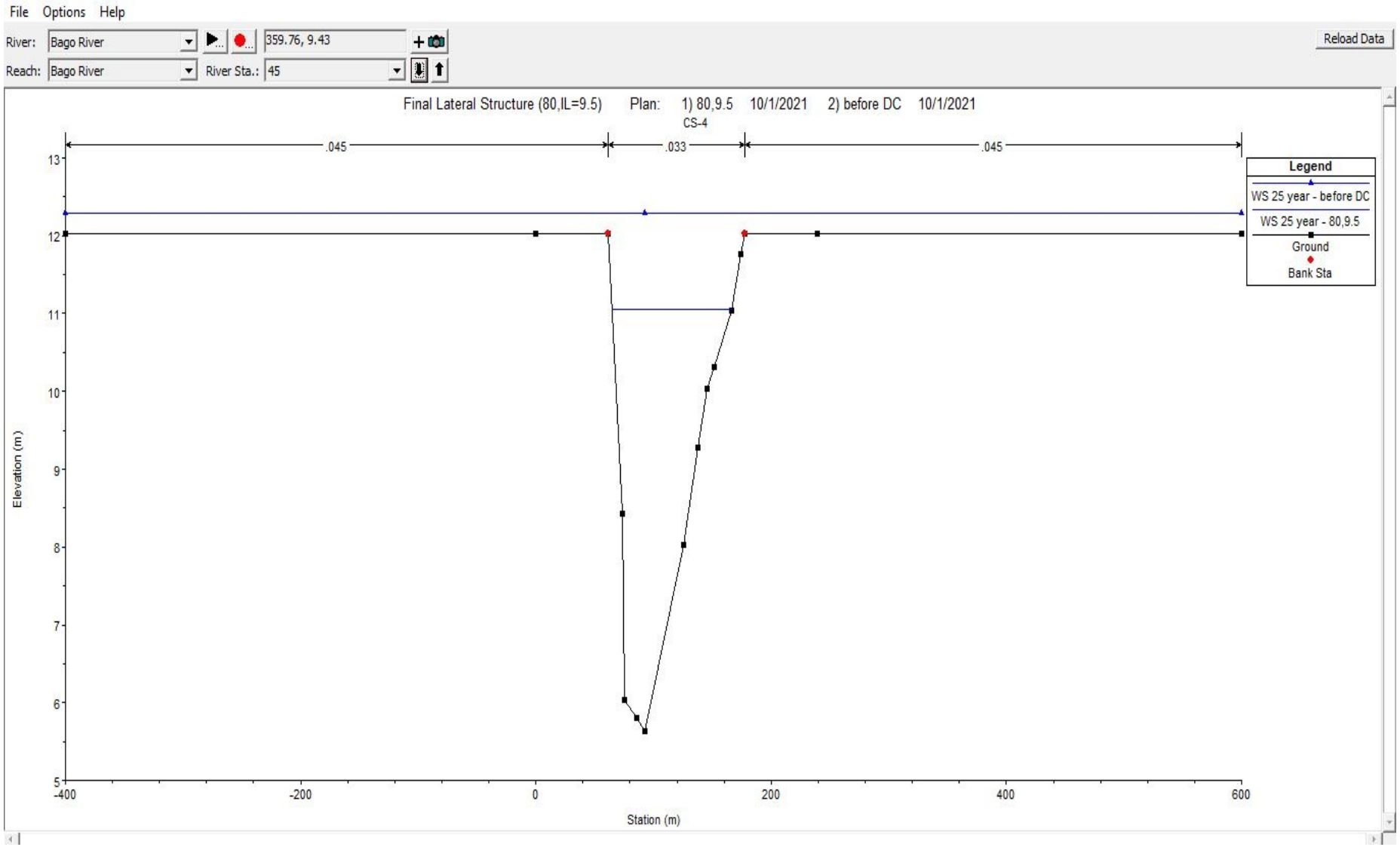
HEC-RAS Hydraulic Modeling

Comparing Flood Profiles of 25-year return period of Bago River with & without DC



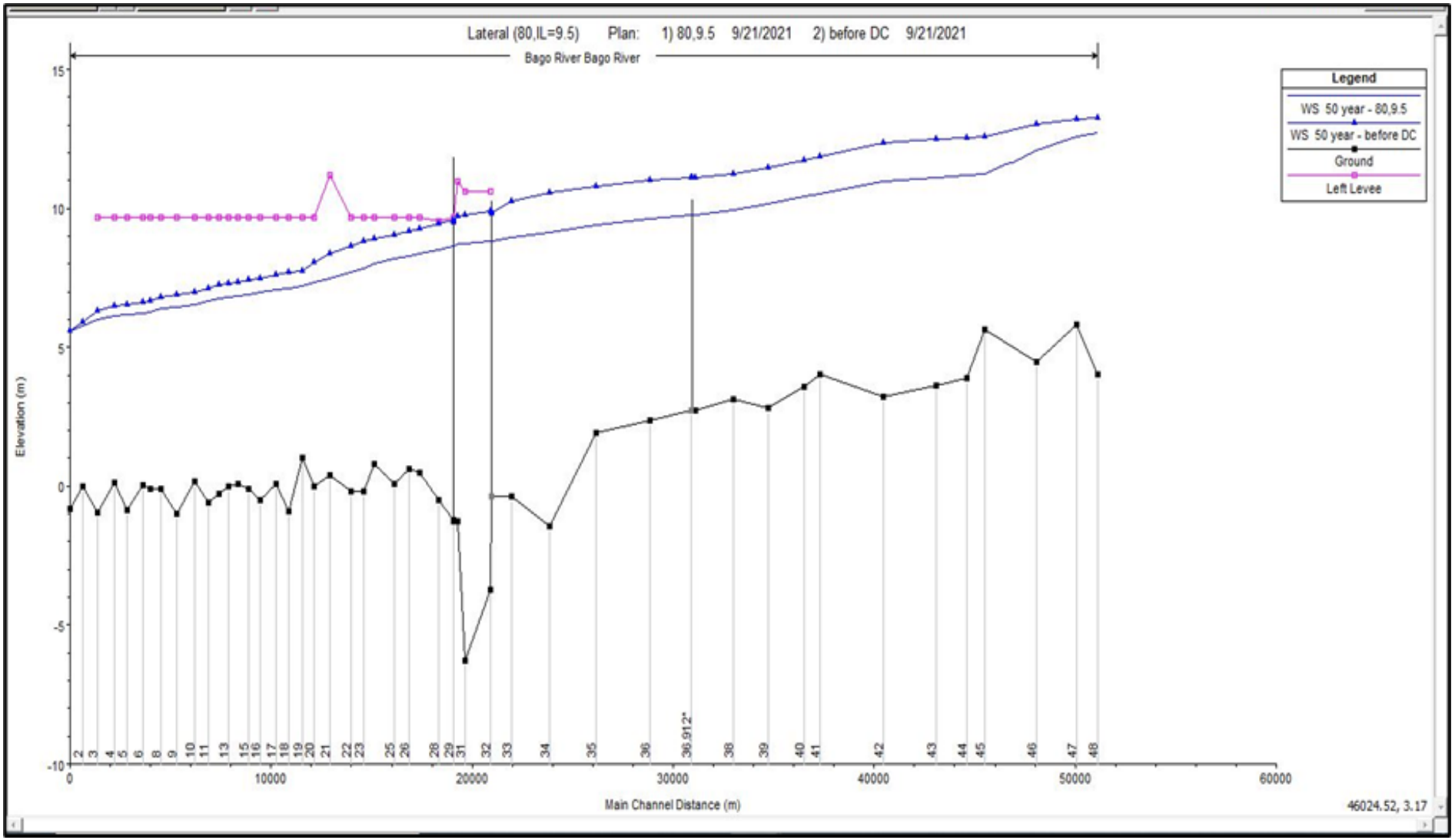
HEC-RAS Hydraulic Modeling

Cross Section at Downstream of the Diversion Channel (25-Year ARI)



HEC-RAS Hydraulic Modeling

Comparing Flood Profiles of 50-year return period of Bago River with & without DC



HEC-RAS Hydraulic Modeling

Verification of Increased Flood Levels in the TFP During the Design Floods

- **Diverted flow through DC of 25-year ARI must not increase the pond level of TFP more than six (6) inches**
- **During monsoon, average area of TFP is approximately estimated as 20 sq ml or 12,800 acres**
- **All three outfall sluices (Minywa, Pagan Nyaungbin & Kyaikpadaing) of PS Canal are operational with 50% efficiency**
- **Initial water level of the TFP is assumed as 6.10 meter**

HEC-RAS Hydraulic Modeling

Observed Mean & Maximum Water Levels of PS Canal at Thanatpin

July /August	2018	2019	2020	Remark
Mean	19.74	20.01	17.19	All AMSL in feet
Maximum	20.75	20.95	18.70	
NOTE:	Adopted WL for the routing analysis:			
	Mean = 20.01 feet (6.10 meters)			
	Maximun = 20.95 feet (6.39 meters)			

HEC-RAS Hydraulic Modeling

Summary Results of Flood Routing Through Thanatpin Flood Pool (TFP)

Sr. No.	Retum Period of the Design Flood	Maximum Inflow m^3/sec	Maximum Outflow m^3/sec	Maximum Storage Acre-feet	Rise Above Mean WL Feet	Estimated Maximum WL During Floods Feet
1	10-year	241.84	265.00	0	0.00	20.01
2	25-year	308.14	265.00	6,230	0.49	20.50
3	50-year	352.76	265.00	19,872	1.55	21.56

NOTE: All Water Levels (WL) are above the Mean Sea Level (MSL)

HEC-RAS Hydraulic Modeling

Routing of Diverted Bago Flood Through the Thanatpin Flood Pool (TFP)

No	Time	Inflow	Outflow Through Minywa Sluice, O1	Outflow Through Pagan Nyaungbin Sluice, O2	Outflow Through Kyaikpadaing Sluice, O3	O1+ O2+ O3 Capacity	Mean Inflow	Mean Outflow	Change in Storage	Total Cumulative Storage in DP	Estimated Rise in Water Level of the DP	Remark
	Day	m^3/sec	m^3/sec	m^3/sec	m^3/sec	m^3/sec	m^3/sec	m^3/sec	Acre-feet	Acre-feet	Feet	
1	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0	0.00	
2	1	138.47	113.11	68.81	83.98	265.89	69.23	132.94	-4461.4	0	0.00	
3	2	129.28	113.11	68.81	83.98	265.89	133.87	265.89	-9244.6	0	0.00	
4	3	115.87	113.11	68.81	83.98	265.89	122.57	265.89	-10035.9	0	0.00	
5	4	157.11	113.11	68.81	83.98	265.89	136.49	265.89	-9061.5	0	0.00	
6	5	226.76	113.11	68.81	83.98	265.89	191.93	265.89	-5178.7	0	0.00	
7	6	237.18	113.11	68.81	83.98	265.89	231.97	265.89	-2375.1	0	0.00	
8	7	240.51	113.11	68.81	83.98	265.89	238.84	265.89	-1893.9	0	0.00	
9	8	275.76	113.11	68.81	83.98	265.89	258.13	265.89	-543.0	0	0.00	
10	9	**308.14**	113.11	68.81	83.98	265.89	291.95	265.89	1825.1	1,825	0.14	
11	10	306.75	113.11	68.81	83.98	265.89	307.44	265.89	2910.2	4,735	0.37	
12	11	267.70	113.11	68.81	83.98	265.89	287.23	265.89	1494.4	6,230	0.49	Maximum
13	12	204.29	113.11	68.81	83.98	265.89	236.00	265.89	-2093.2	4,136	0.32	
14	13	191.68	113.11	68.81	83.98	265.89	197.98	265.89	-4755.0	0	0.00	
15	14	190.08	113.11	68.81	83.98	265.89	190.88	265.89	-5252.5	0	0.00	
16	15	185.06	113.11	68.81	83.98	265.89	187.57	265.89	-5484.3	0	0.00	
17	16	174.60	113.11	68.81	83.98	265.89	179.83	265.89	-6026.2	0	0.00	
18	17	160.44	113.11	68.81	83.98	265.89	167.52	265.89	-6888.3	0	0.00	
19	18	144.58	113.11	68.81	83.98	265.89	152.51	265.89	-7939.5	0	0.00	

HEC-RAS Hydraulic Modeling

Achievement of the Proposed Scheme on Flood Mitigation at Bago

Return Periods (year)	Design Peak Flood Levels							
	Before the Project				*After the Project*			
	Zaungtu Weir	Letpangon Village	BRB	Tawa	Zaungtu Weir	Letpangon Village	BRB	Tawa
10	1273	1188	911	580	1281	1075	807	570
25	1307	1229	953	587	1321	1105	843	573
50	1327	1257	975	593	1347	1124	871	576
100	1349	1283	995	600	1377	1147	896	579

HEC-RAS Hydraulic Modeling

Conclusion of the Proposed Scheme on Flood Mitigation at Bago

- **On data analysis and processing, well known and world recognized statistical, hydrological and hydraulic software are applied to produce most reliable results of various scenarios for reasonable and easier judgement of the decision makers.**
- **Main objective of the study is to secure a most cost-effective flood mitigation scheme to alleviate the ongoing flooding problem at Bago City and Bago River downstream areas.**
- **It is observed that there is no significant environmental effect due to the above proposed flood mitigation scheme.**
- **Flood discharge at Bago (BRB) will be reduced about 30 percent from the pre-project condition.**
- **For 25-year return period, water level at BRB of 980 cm will be lowered to 871 cm curtailing approximately by 3.65 feet.**

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Exp Infrastructure Engineering Consultants Co.,Ltd