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River Analysis System Model for Proposed Weirs at Downstream of Large Dam, Thailand

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***Abstract*—**This research was conducted in the Lower Ping River Basin downstream of the Bhumibol Dam and the Lower Wang River Basin in Tak Province, Thailand. Most of the tributary streams of the Ping can be considered as ungauged catchments. There are 10-pumping station installation at both river banks of the Ping in Tak Province. Recently, most of them could not fully operate due to the water amount in the river below the level that would be pumping, even though included water from the natural river and released flow from the Bhumibol Dam. The aim of this research was to increase the performance of those pumping stations using weir projects in the Ping. Therefore, the river analysis system model (HEC-RAS) was applied to study the hydraulic behavior of water surface profiles in the Ping River with both cases of existing conditions and proposed weirs during the violent flood in 2011 and severe drought in 2013. Moreover, the hydrologic modeling system (HMS) was applied to simulate lateral streamflow hydrograph from ungauged catchments of the Ping. The results of HEC-RAS model calibration with existing conditions in 2011 showed best trial roughness coefficient for the main channel of 0.026. The simulated water surface levels fitted to observation data with R^2 of 0.8175. The model was applied to 3 proposed cascade weirs with 2.35 m in height and found surcharge water level only 0.27 m higher than the existing condition in 2011. Moreover, those weirs could maintain river water levels and increase of those pumping performances during less river flow in 2013.

***Keywords*—**HEC-RAS, HMS, pumping stations, cascade weirs.

I. INTRODUCTION

THE Ping River, one of the largest tributaries of the Chao Phraya River Basin. A huge dam, Bhumibol Dam where was the 7th world largest concrete arch dam. The dam was constructed since 1964 and situates on the Ping River in Sam Ngao district of Tak Province, Thailand at 17°14′33″N 98°58′20″E. It was built for the multi-purpose of the water use project. The dam catchment is 26,400 square kilometers (km^2) while its reservoir capacity is $13,462 \times 10^6$ m^3 (13,462 MCM). The Lower Mae Ping Dam as a barrage dam is located at coordinate 17°14′31″N and 99°00′58″E. Additional, 5 km of downstream of the Bhumibol dam has created a lower reservoir with a storage capacity of 5 MCM and for the one pumped-storage, turbine back to the reservoir during off-peak hours of electricity consumed [1]. The Ping river flow at downstream of the dam is fully operated by the large Bhumibol dam and the Lower Mae Ping Dam under the Electric Generating Authority of Thailand (EGAT) in cooperating with the Royal Irrigation Department (RID). The Wang River is the largest tributary of the Ping and concern with a gauged catchment. Most of other tributary sub-basins of the Ping at downstream of the dam are ungauged catchments. This research was studied in the Ping River with a stream length of 81 km downstream of the dam in Sam Ngao, Ban Tak, Muang, and Wang Chao districts of Tak Province, respectively. The existing 10-pumping stations for irrigation purpose were installed at both riverbanks of the Ping and were built by the Royal Irrigation Department (RID). The first 2-stations at unit 9 and 10 in Sam Ngao were initially installed to supply water for the mitigated people's farmlands whom moved from the proposed reservoir during the construction of the Bhumibol dam. The remaining pumps were installed after the completion of the dam shown in Fig. 1.

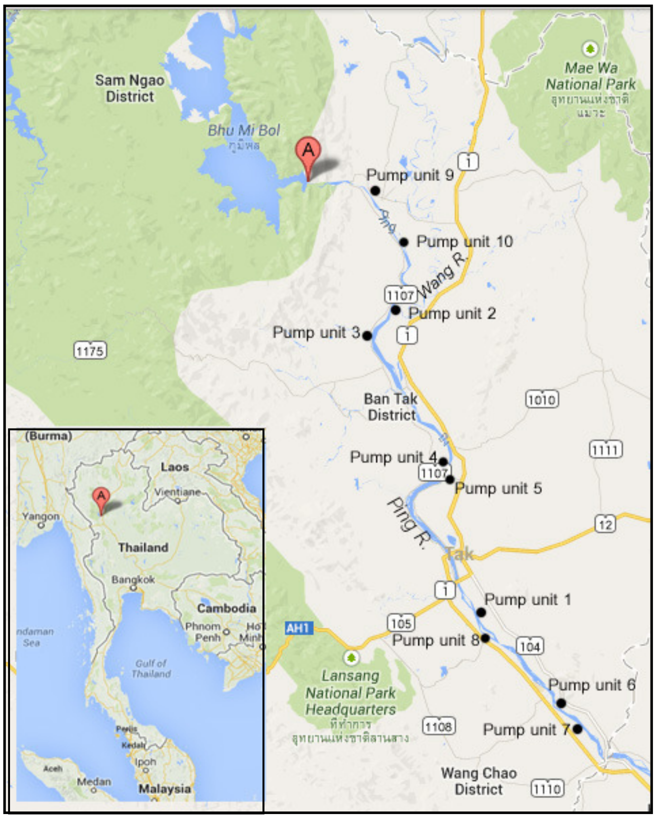

Fig. 1 Map of the Ping River and location of existing 10-pumping stations downstream of the Bhumibol Dam in Tak province

All pump stations were fixed-based with electric vertical axial flow pump type. The pump's diameters were between 20 to 24 inches by 1-4 units of pump engine systems depended on those serviced areas. The general information of each pumping unit, including location, construction period, pump diameter,

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length of irrigation canal, and irrigated area were shown in Table I.

TABLE I
GENERAL INFORMATION OF 10-PUMPING UNITS FOR IRRIGATION ALONG THE PING RIVER IN TAK PROVINCE

Unit no.	District name	Year of Constr.	Diameter (in.)-no.	Irr. Canal length (km)	Irr. Area, (ha)
9	Sam Ngao	1962	24"-1	14.51	800
10	Sam Ngao	1962	20"-1	4.09	320
2	Ban Tak	1970	24"-4	18.87	1,200
3	Ban Tak	1970	24"-3	33.33	1,360
4	Muang	1972	24"-1	21.08	880
5	Muang	1972	24"-1	14.82	432
1	Muang	1970	20"-2	26.18	1,200
8	Muang	1971	24"-1	10.50	288
6	Muang	1972	24"-1	9.99	352
7	Wang Chao	1971	24"-1	11.85	368

Note all pump stations ranging from upstream to downstream of Ping R. respectively.

The river flow during the dry season is mainly released through the dam's outlet which operated by the EGAT incorporate with the RID on the basis of weekly allocation scheduling. However, all tributary rivers included Wang River and other lateral stream name Huai Maesalid, Huai Tak, Huai Mae Thor, and Klong Pradang where meets the Ping River at the downstream of pump no. 9 and 10 in Ban Tak, Muang, and Wang Chao districts with less amount of streamflow than releasing flow from the dam. The fluctuation of river water levels at downstream of the dam during drought period affected by less amount of rainfall during late wet season and little amount of intermittent released outflow through the outlet of the dam. The released flow from the dam is usually approximate 5-6 hours per day as same as on-peak electricity demand during 3.00-9.00 PM. The declining of annual mean river flow downstream of the dam results to the mean river water level trend lower than riverbank was reported [2]. It caused farmers never met inundated water to their farmlands directly. Most of pump units could not be fully operated during drought period due to less amount of streamflow including released flow from the dam. It causes to lower water level than the propeller and sump levels of each pump station particular 2 pump units in Sam Ngao and Ban Tak districts that could not be operated. Many measures were studied with the aims of increasing the efficiency of pumping systems [2]. The study included all reviews of water demand include crop water requirements [3], pump system performance, and feasible alternative projects, respectively. More effective measures to increase efficiency in pump performance were proposed by cascade weir projects to maintain water level the Ping in front of involved pump stations. Even though it had fewer amounts of lateral flows and less released outflow from the dam. Therefore, this paper described the hydraulic behavior of water surface profiles in both cases with existing conditions and within proposed cascade weirs in the Ping at both periods of violent flood such in 2011 and severely drought such in 2013.

II. MATERIALS AND METHODS

All relevant data, including location of pumping stations, irrigation system layouts, cross-section profiles of the Ping, meteorological and rainfall recorded, and hydrological observation data were collected and analyzed. The report [2] showed that most crisis problems attached to pump unit no. 9, 10, 2, and 3, respectively. Therefore, those pumps should be first priority to have proper measures such using 3-proposed cascade weirs in order maintain water level in the Ping for better pump performances during drought period. To ensure surcharge levels should not much affect to the existing farmland after developing those 3-proposed weirs. Therefore, the study of the hydraulic behavior of water surface profiles along the river should be modelled by both cases of existing conditions with a temporal weir at pump unit no. 3 and the case of proposed 3-weirs at unit no. 9, 10, and 3 in Sam Ngao and Ban Tak districts, respectively. The river analysis system model using HEC-RAS [4] was applied in this study. It was a mathematical to simulate 1-dimensional unsteady flow profiles along the river using St.Venant equations, both continuity and momentum shown in (1) and (2), respectively.

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}-q_l=0 \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial QV}{\partial x}+gA\left(\frac{\partial z}{\partial x}+S_f\right)=0 \tag{2}$$

where A is the flow area in each section, Q is total discharge, q_l is lateral inflow per length of the channel, t is considered time, x is the distance along the channel, V is flow velocity, z is water surface elevation, and S_f is friction slope, respectively.

All 25 cross sectional profiles were surveyed and applied as geometric model and automatically interpolated river sections with smaller step length (Δx) of 500 m. The upstream of a river reach was started from the RID's hydrological observation station: P12C at sta. 80+915 km or RS 80915 m in the model with the location at downstream of the Lower Mae Ping dam in Sam Ngao. The downstream end was located at the border of Tak and Kampaengphet provinces in Wang Chao district at RS 0 in the model shown in Table II and Fig. 2.

TABLE II
RIVER STATION, RIVERBANK, RIVERBED, AND PUMP'S SUMP LEVELS OF EACH PUMP UNITS ALONG THE PING RIVER REACH

Unit no.	RS, m	bank level	bed level	sump level
P12C	80915	134.21	130.17	-
9*	76580	135.85	125.41	128.68
10*	72330	133.20	123.19	127.35
2	63190	128.00	121.01	123.25
3*	59130	126.76	120.64	121.23
4	41680	117.48	112.50	112.60
5	41140	116.88	112.25	112.23
P2A	25500	108.59	100.94	-
1	21900	107.00	100.18	102.04
8	19470	106.42	98.98	100.69
6	8820	100.24	94.21	96.13
7	6340	99.72	93.20	95.12
End	0	96.51	90.17	-

Note *Location of proposed weirs, unit of all levels were in m above mean sea level, and P12C & P2A were RID's hydrological observation stations.

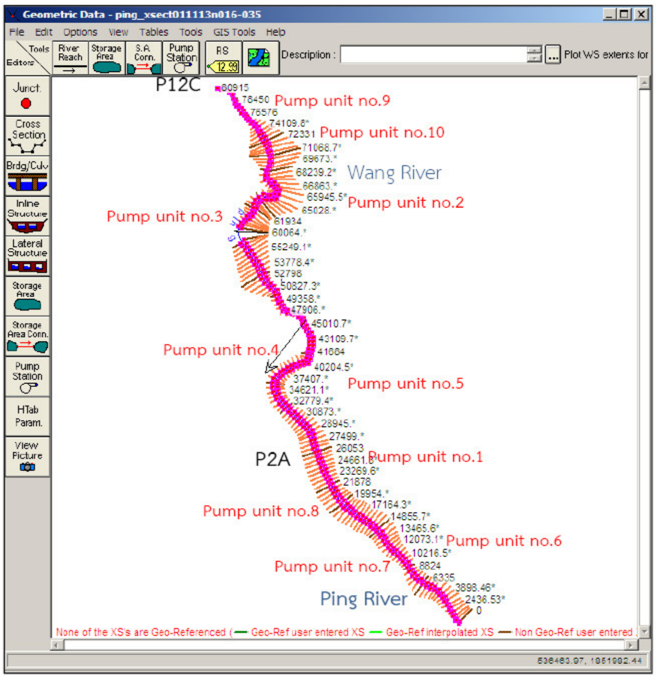

Fig. 2 Geometric data of plan, layout and location of cross-sectional profiles of the Ping River (reach) for each RS in HEC-RAS model

All of the original cross-sectional data from field surveyed, including ground surface elevation versus distance from the left to the right banks were used in the model. Moreover, each cross section in the model contained with Manning's roughness coefficient (n-value) at both floodplain on the riverbanks and in the main channel as well. The optional data, such as levee data at both riverbanks including bridges and inline structures, i.e. weirs in a river reach were also considered. The simulation of water profiles preferable in this study was unsteady flow based on a daily basis as time increment (Δt). The upstream boundary condition in the model at RS 80915 applied river flow hydrograph that released from the dam through an outlet structure which observed by the RID's hydrological station at P12C. The downstream boundary condition at RS 0 applied normal depth based on the average friction slope of water surface levels over a river reach. The 4-uniformed lateral inflow to the river reach at RS 67780, 52798, 26053, and 8824 with the Wang River, Huai Maesalid, Huai Tak, Huai Mae Thor, and Klong Pradang streams respectively, were initially estimated using HEC-HMS model [5] except the Wang with a gaged flow shown in Fig. 3.

The recorded data of daily rainfall from major existing rain gauges in Tak province name Bhumibol dam, Tak, and Doi Musor Highland Agricultural stations respectively were used in those ungauged catchments shown in Fig. 3. The HEC-HMS model was applied as for initial study as lateral inflow hydrograph from most tributary streams of the Ping River shown in Fig. 3. The recorded data from daily hydrograph observation stations from P12C and P2A at RS 80915 and 25500 respectively, were used for the calibration and verification of both HEC-HMS and HEC-RAS models. Moreover, digital elevation model (DEM) based on existing satellite image retrieved from the Geo-Informatics and Space Technology Development Agency (GISTDA) [6] as well as aerial photo maps from the Land Development Department (LDD) [7] were used to specify grounds surface elevations at floodplain of both river banks at same RS with each surveyed cross section of the Ping River.

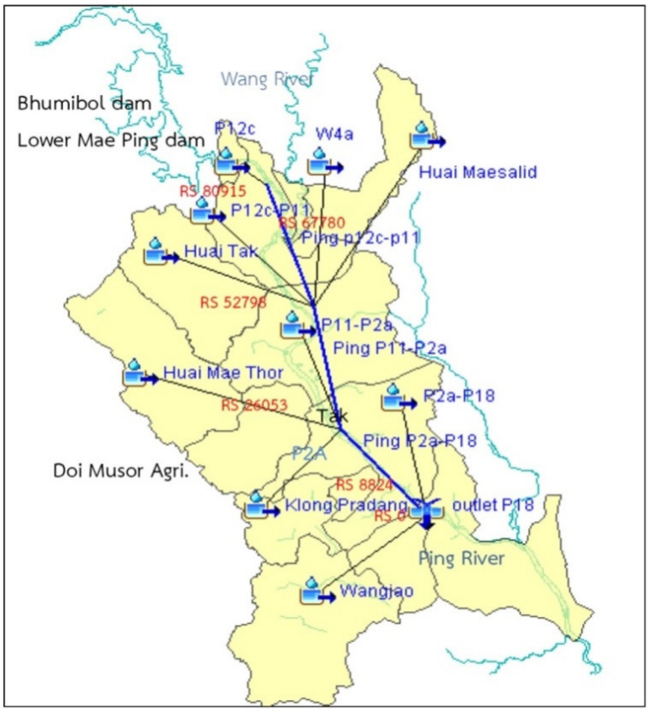

Fig. 3 Schematic map and location of lateral inflow from all catchments of the Ping River used in the HEC-HMS model

The transposing unit hygrograph's parameters for the Ping River Basins in Thailand [8] with (3) were initially applied in HEC-HMS based on the Snyder's transformed model formulation [9]. Therefore, the basin parameters involved in the model such as peak coefficients (C_p), peak lags (t_p), and loss rates shown in (4) were optimized using trial mode from the basin hydrographs. Finally, the hydrological parameter results from the optimized model were presented and fitted with observed data with gauged catchments.

$$t_p = C_t[LL_c/S^{0.5}]^b \tag{3}$$

$$t_p = 0.75C_t(LL_c)^{0.3}\text{, and } Q_P = 2.78C_pA/t_{lR} \tag{4}$$

where L, L_c are channel length, midstream lengths in km, S is the channel slope, A is the catchment area in km^2, t_p, t_{lR} are basin lag, adjust the duration in hours, Q_p is a peak discharge in m^3/s, C_t and b are basin coefficient and exponent values referred to RID report [6] and [7], and C_p is peak coefficient, respectively.

The upstream (u/s) discharge hydrographs from P12C result of observation and lateral inflow produced from HEC-HMS applied as u/s boundary condition of a reach in HEC-RAS.

The major parameter in HEC-RAS was trialed n-value of each cross section in a river reach. It was initially applied in HEC-RAS and computed water surface levels (WS) in the river reach at each RS. The products of WS from the model used to compare and try to fit with the hydrological observation data at P2A within the same period of simulation as the model calibration and verification. The relationship between simulated and observed hydrographs was fitted by using the correlation (R^2) which should be closed to 1.0. Therefore, calibrated *n*-value was used for the next simulation in HEC-RAS with the 3-proposed weirs. In this calibration of *n*-value, the recorded data of daily hydrograph at P12C and P2A during violence flood from Jul to Nov 2011 were used to simulate WS for all RS in a river reach. The model also applied this *n*-value to simulate WS during severely drought in 2013 with both cases of existing conditions with a wooden weir height of 2.1 m at RS 59084 downstream of pump no. 3 and with proposed 3-cascade weirs with a height of 2.35, 2.2, 2.5 m at RS 59084, 70500, 75400, respectively.

III. RESULTS AND DISCUSSION

The optimization of gauged hydrological parameters: t_p, C_p in HEC-HMS were applied as a calibration model with observed rainfall data in 2011 and summarized in Table III. The result from the simulated daily streamflow hydrographs were compared to observed data from their own stage gauges at sub-basins Huai Tak, and Klong Pradang were found that fit good relationship as shown in Figs. 4, and 5, respectively. Those productions of daily streamflow hydrographs were used as uniform lateral inflows in the HEC-RAS model.

TABLE III
HYDROLOGICAL PARAMETERS FOR SOME SUB-BASINS IN HEC-HMS

Sub-basin	Area, km^2	L, km	L_c, km	S	t_p, hr	C_p	Infiltration, mm/hr
Huai Tak*	354	36.8	18	0.0343	16	0.66	0.50
Mae Thor	642	85.6	43	0.0221	22	0.66	0.60
Pradang*	165	20.1	10	0.0454	12	0.66	0.50
Maesalid	247	50.6	25	0.0130	20	0.66	0.50

Note *RID's gauged basins at P52 and P51 hydrological observation stations, respectively.

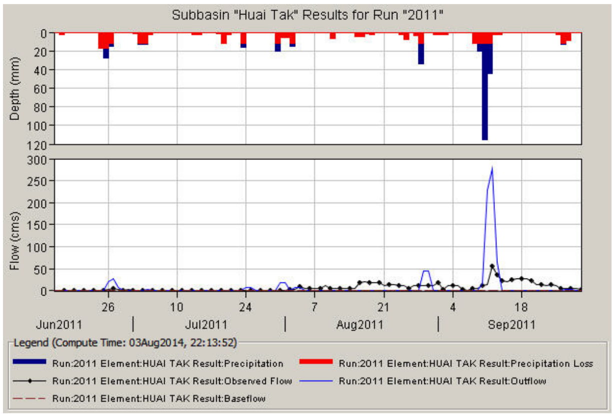

Fig. 4 Comparison of simulated & observed daily flow at Huai Tak

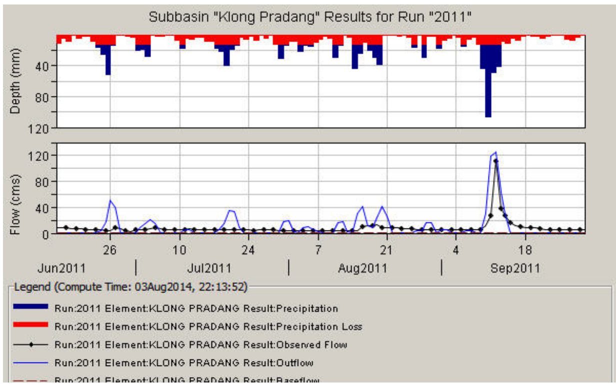

Fig. 5 Comparison of simulated &observed daily flow at Pradang

The 25-cross sections of the Ping from Wangjao to P12C at RS 0 to 80915 with a total length of 80.915 km were applied as for the geometric data module in HEC-RAS. Some of them were shown in Fig. 6. The mean *n*-value of 0.026 was product of trial variety values of 0.016, 0.025, and 0.035 which applied at RS 71490-80915, 59129-71490, and 0-59129 as upstream, midstream, and downstream, respectively. The water surface levels (WS) at each RS produced from the model based on upstream boundary conditions with daily unsteady flow hydrograph that released from the dam. The daily hydrographs from the Wang River, Huai Tak, Klong Pradang, Huai Maesalid, and Huai Mae Thor were used as uniform lateral inflow per length as a flow boundary condition in the model. Those boundary conditions applied to HEC-RAS in 2011 and 2013 with the violent flood and severely drought shown in Figs. 7 and 8, respectively. Moreover, the normal depth with mean friction slope of 0.00051 was produced from the average values of WS per length from upstream to downstream of a river reach.

For the model calibration, the simulated results of WS at each RS during the violent flood from 4 October 2011 to 23 November 2011 were compared with recorded data at the RID's hydrological observation stations at P12C and P2A. Those relationships of both WS from simulated and observed were fitted with the correlation (R^2) of 0.8175 in Fig. 9.

The simulated results of WS at each RS in wet season 2011 for each cross section profile and max WS profile along the river reach were shown on Figs. 6 and 10, respectively.

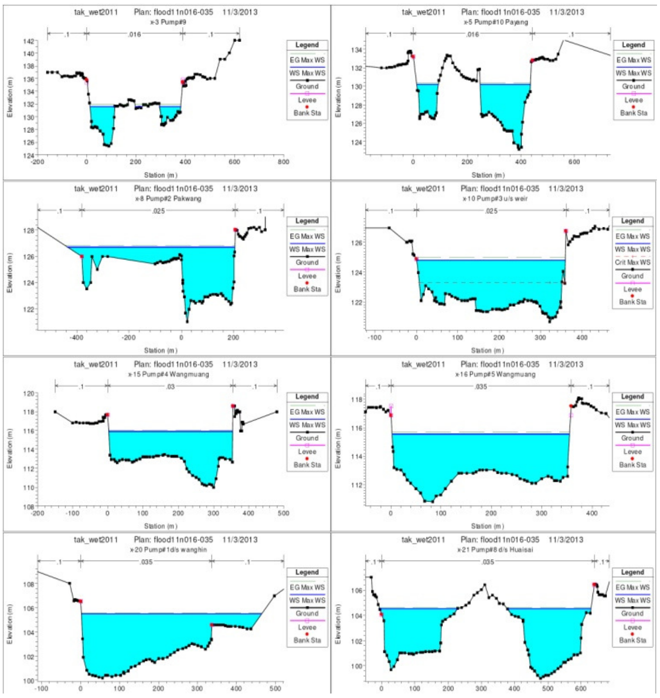

Fig. 6 Some cross-sectional profiles of the Ping R. and HEC-RAS's results of WS of all pumping stations at RS 76576, 72331, 63193, 59129, 41684, 41137, 21878, 19473, 8824, and 6335, respectively

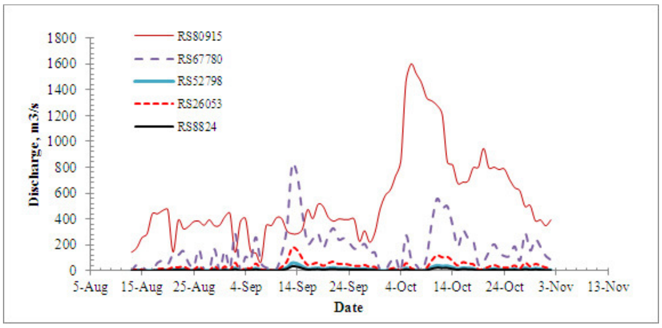

Fig. 7 Flow boundary conditions at each RS in the wet season 2011

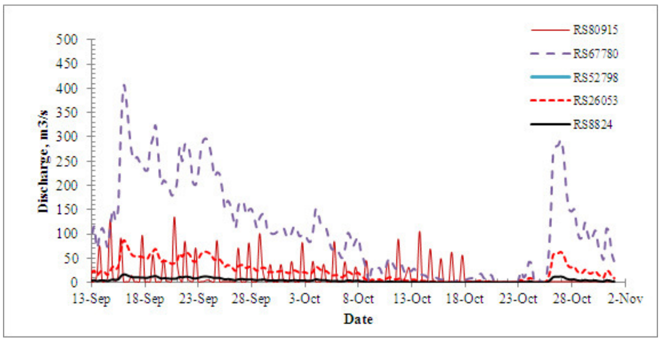

Fig. 8 Flow boundary conditions at each RS in the wet season 2013

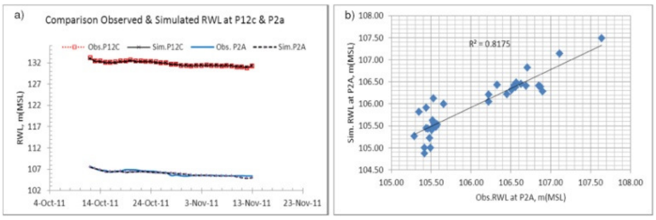

Fig. 9 Calibration results of HEC-RAS model from 4 Oct to 23 Nov 2011 with mean *n* of 0.026 whereas a) comparison of simulated and observed WS at P12C & P2A, and b) showed WS fitted relationship.

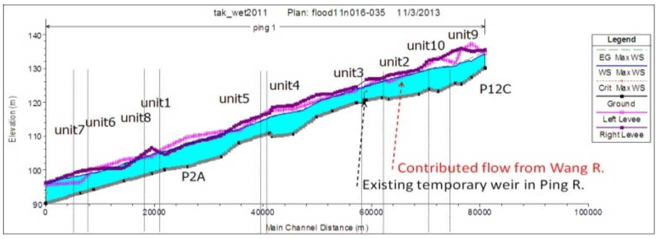

Fig. 10 Longitudinal profiles of max WS produced by HEC-RAS during 1 Jul – 30 Nov 2011 with the existing condition of a weir

Therefore, the model applied those *n*-values with the case of 3-proposed cascade weirs in the Ping River during both the violent flood in wet season 2011 and severe drought of shortage river flow in wet season 2013. The simulated results from the model with 3 proposed cascade weirs during the peak time of flood period from 4 to 15 October 2011 show in Fig. 11. The results of simulates maximum WS at each RS in the year 2011 and 2013 were shown in Figs. 11 and 12, respectively. The simulated result in Fig. 11 showed that the surcharge level during the violence flood after apply 3-weirs were raised to 0.27 m above the previous maximum flood level at RS 59084 with same as position as existing 1-weir. Since a proposed weir height at the downstream of RS 59084 was 2.35 m above the riverbed and higher than the existing weir of 0.25 m. The remaining 2 proposed weirs with average weir height of 2.5 m above the riverbed. The comparisons on simulated daily WS hydrographs during flood in 2011 at RS 59084 to apply both cases of 1-weir and 3-weirs were shown in Fig. 13.

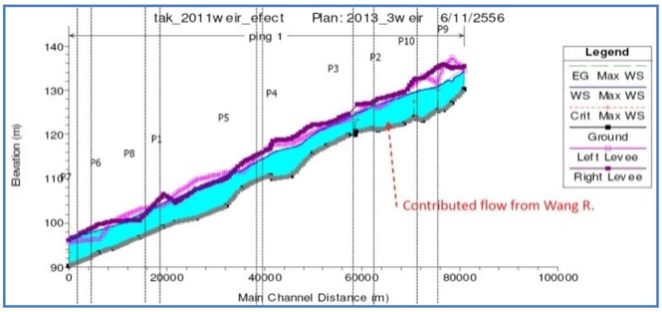

Fig. 11 Longitudinal profiles of max WS from the model during the violence flood in 2011 while applied 3-proposed cascade weirs

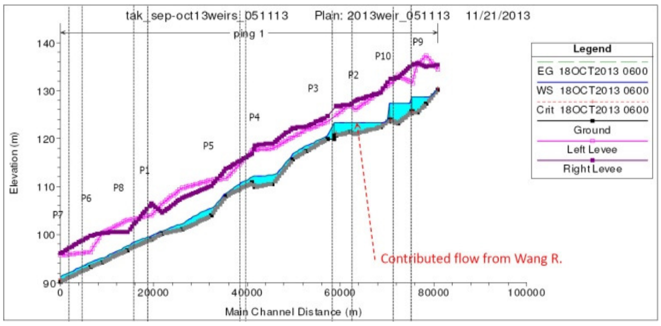

Fig. 12 Longitudinal profiles of min WS from the model during severely drought in 2013 while applied 3-cascade weirs

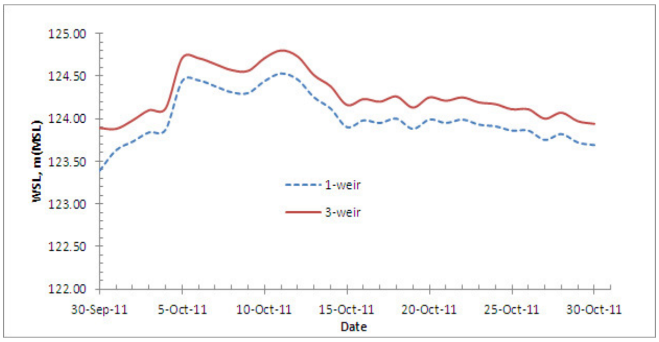

Fig. 13 Comparison of simulated WS at RS 59084 during violence floods in 2011 both cases with existing 1-weir and proposed 3-weirs

IV. CONCLUSION

These results showed that there were good relationships among simulated and observed WS while compared with the existing conditions. Therefore, both HEC-HMS and HEC-RAS models can be further applied to analyzing the hydraulic behaviors in the river reach. Either an existing condition or apply the proposed cascade weir projects in a river reach with many ungauged lateral inflows or outflows can be modelled. It is recommended to use the models, both of without and within cascade weir projects during the planning stage. They can explain the river hydraulics phenomenon whilst full fill and maintain WS in the river either for pumping stations or inundating irrigation schemes after applying proposed weirs during severe drought period. Therefore, overall irrigation systems efficiency particular at head works will be increased.

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